Cardno LawsonTreloar
Shaping the Future

BRISBANE WATER ESTUARY PROCESSES STUDY

Report Prepared for

Gosford City Council and Department of Environment and Climate Change

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FOREWORD

The management of different aspects of the Brisbane Water Estuary is undertaken by a host of organisations, principally Gosford City Council (GCC), the Department of Lands (DoL), the Department of Environment and Climate Change (DECC), the Department of Primary Industries (DPI) and NSW Maritime.

Related organisations/agencies and their broad management responsibilities with respect to estuary management include:

- Council (local planning policies, regulation of development, management of parks and reserves, management of land above the mean high water mark except for National Parks and Crown Land not under the trust of Council)
- DoL (management of Crown land not under trust and land below the mean high water mark)
- DECC – Natural Resources Branch (some aspects of vegetation management, specialist advice on estuary management)
- DECC – National Parks and Wildlife Service (National Park management, flora and fauna conservation, Aboriginal heritage matters)
- DECC - Environment Protection Authority (environmental protection through compliance enforcement and application of licensing legislation)
- DPI - NSW Fisheries (recreational and commercial fishing matters)
- NSW Maritime (navigation and boating matters, both recreational and commercial)
- NSW Department of Planning (state and regional planning policies)
- NSW Heritage Office (within the Department of Planning)
- Hunter-Central Rivers Catchment Management Authority (CMA) (catchment management planning including vegetation management).

The approach to the management of Brisbane Water falls under the umbrella of the Estuary Management Policy for New South Wales, which is defined in the Estuary Management Manual (NSW Government, 1992). The policy outlines a structured management process leading to the implementation of an Estuary Management Plan. In developing the plan, all values and uses of the estuary are considered. Each plan aims to be a balanced long-term management framework for the ecologically sustainable use of each estuary and its catchment.

The Estuary Management Manual recommends an eight step process in order to implement an Estuary Management Plan, as follows:

1. Form an Estuary Management Committee;
2. Assemble existing data (data compilation study);
3. **Undertake an Estuary Processes Study;**
4. Undertake an Estuary Management Study;
5. Prepare a draft Estuary Management Plan;
6. Review Estuary Management Plan;
7. Adopt and implement the Estuary Management Plan; and
8. Monitor and review the management process as necessary.

In line with this policy, GCC has formed an Estuary Management Committee through their Coastal and Estuary Management Committee (CEMC) and the Brisbane Water Data Compilation Study was completed in 2002.

Council commissioned Cardno Lawson Treloar, in association with Bio Analysis Pty Ltd, Sainty and Associates, Kellogg Brown and Root, GHD Geo-technics (previously GHD LongMac), HLA Envirosciences and Canonical Solutions Pty Ltd, to undertake this third stage of the process.

Due to unforeseen circumstances, the canonical analyses of process interactions were undertaken by Dr W Gladstone of Newcastle University rather than Canonical Solutions Pty Ltd. Additionally, studies undertaken concurrently with this processes study included a seabed sediment chemical analysis, undertaken by Dr Gavin Birch of Sydney University. Dr Iain Suthers of the University of New South Wales provided input on marine larval processes.

Dr Peter Freewater of GCC provided technical guidance to the overall project and specific technical input to marine ecological analyses, such as canonical analyses and larval transport modelling, and including participation in field work exercises.

This study was funded equally by Gosford City Council and the Department of Environment and Climate Change.

The structure of this report is as follows. The introduction provides the study context, objectives and methodology. The main report presents an overview and summation of the Estuary Process Study components listed below:

- Community consultation
- Catchment processes
- Hydraulic processes
- Estuary morphology and siltation
- Water quality processes
- Ecological processes
- Cultural heritage
- Recreational processes.

This information is synthesised in Section 10 to describe any interactions among these processes. The overall direction of the study and analyses has been to investigate how and to what extent the underlying catchment runoff and estuarine hydrodynamic processes influence the ecological processes and health of the estuary. Based on the consideration of these processes and any identified interactions, recommendations for management are made in Section 11.

The full technical reports for each estuary process considered for Brisbane Water form appendices to this main report.

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EXECUTIVE SUMMARY

Background

The Brisbane Water Estuary Processes Study was commissioned by Gosford City Council in partnership with the Department of Environment and Climate Change. Cardno Lawson Treloar was commissioned to undertake this study in association with Kellogg Brown and Root, GHD Geo-technics, HLA Envirosciences, Bio-analysis Pty Ltd and Sainty and Associates. Following the commissioning of the project, a number of supporting investigations were conducted under the supervision of GCC (Dr Peter Freewater, who also assisted with the report preparation). These investigations were undertaken by the University of Newcastle (Dr William Gladstone and Dr Margaret Platell), the University of New South Wales (Dr Iain Suthers), and Sydney University (Dr Gavin Birch). This report summarises all investigations and provides a comprehensive basis for the development of the Brisbane Water Estuary Management Study and Management Plan.

The study area encompasses the entire estuary and its drainage catchment with linkages to Broken Bay and the Tasman Sea. It comprises the tidal waterway, foreshore and adjacent land of Brisbane Water, including the entrance area and tidal tributaries covering the whole region of Brisbane Water from the channel connecting to Broken Bay at the eastern end of Ocean Beach in the south to Gosford in the north, and associated tributaries and catchments.

Objectives and Scope

The main objectives of this study were:

a) To identify and document the physical, ecological and biogeochemical processes of the estuary (i.e. hydrodynamic and sedimentary processes, including tidal behaviour, freshwater inputs, water balance, mixing, exchange with the Hawkesbury River and Broken Bay, catchment geology and geomorphic characteristics, sediment movement, sedimentation rates, and sediment types) and interactions among and between these processes (e.g. establishment of the water quality parameters of importance to the health of the estuary, mixing and flushing of pollutants, nutrient budget and establishing an appropriate model) through investigation and data collection and comprehensive analysis.
b) To identify and document the ecological processes of the Estuary and related processes covering flora and fauna, species composition and distribution; habitat composition and distribution; the productivity and health of the ecosystems; the range and sensitivity of habitats to environmental disturbance; and rare and endangered species.
c) To define a baseline condition of the Estuary (water quality, habitats, species, etc.) and interactions on which management decisions can be made.
d) To review the existing and future land use activities that may potentially impact upon the Estuary.
e) To undertake any further data collection to aid the subsequent stages of an estuary management study and formulating a management plan for the estuary.

In doing so, the study had to take into account the varying time scales on which estuarine processes operate, including:

- daily tidal fluctuations
- seasonal meteorological patterns
- variations in breeding cycles and migratory patterns

- nutrient behaviour
- long term flood or drought conditions
- greenhouse induced sea level rise
- event based processes (e.g. storms)
- El-Nino patterns.

In order to link the physical, chemical and biological estuarine processes and possible management strategies for the ecological sustainability of the estuary, the study followed a three-stage integrated modelling approach (Hydro-ecology) (Freewater, *in prep*):

1. The first stage focused on the characterisation of the study area, the catchment and foreshores. It included geological and geographical analyses, including analyses of land use patterns and the modelling of rainfall runoff and associated pollutant inputs to waterways.
2. The second stage focused on hydrological processes such as hydraulics and hydrodynamics and their influence on morpho-dynamics, transport processes and water quality.
3. The third stage focused on the biological processes and linking catchment and hydrological processes with ecological phenomena.

Relevant Findings

The findings from the above analyses were divided among eight major chapters (3-10) and a concluding chapter containing recommendations for management. A brief summary of these findings is presented below.

Catchment Processes

Chapter 3 describes various components of the study area including the land use, vegetation, geology, soils, climate, catchment modelling and implications of climate change. The key findings include:

- Catchment-derived runoff and associated pollutants are currently having a negative impact on the Estuary, leading to siltation and declining water and sediment quality.
- Narara and Erina Creeks are the greatest sources of catchment derived sediments and nutrients, followed by Kincumber Creek.
- Sewer overflows also affect water quality in Brisbane Water Estuary during high intensity rainfall events.
- Climate change is likely to have a significant impact on rainfall, resulting in expected lower average annual rainfall (up to 30%) with consequent effects on environmental flows. Conversely, the intensity of flood type rainfall events is expected to increase resulting in a potential increased risk of foreshore flooding, but not to a noticeable extent along the foreshores of Brisbane Water Estuary itself.

Hydraulic Processes

Chapter 4 summarises the outcomes of investigations into hydraulic processes (such as tidal behaviour and flushing times), which form an important driver to the overall water quality, sediment distribution and ecological condition of the waterway. Wave processes are included in these investigations, and like the currents, vary spatially and temporally. Details of these investigations are found in Appendix C. The key findings include:

- Tides contribute significantly to estuarine flushing and day to day water levels. The Rip is a control on tidal range, with flushing times generally being longer for areas upstream of The Rip Bridge. The attenuation of tidal flows influences the ecology of the estuary. This relates not only to the salinity range within the Estuary, but also the dispersion of larvae. Modelling suggests that advection and dispersion is sufficient to transport larvae throughout the estuary, although some areas may have more limited connectivity than others.

- Flushing of the estuary is generally complex, being of relatively short duration at locations strongly influenced by tides (such as The Rip and Ettalong), and longer in areas further upstream and in embayments. Flushing is the primary control of water quality through the dispersion and dilution of pollutants and promotion of mixing. The Gosford Broadwater has a flushing time of up to 30 days.
- There is little difference in wave heights between the 5-years ARI and 100-years ARI storm events due to limited water depths and fetches. In terms of the estuarine ecology, more frequently occurring wave events will have a more significant influence on the community structure and biodiversity of the estuary. Due to limits on wave heights during extreme events, storm disturbance is likely to be relatively infrequent resulting in a generally stable community structure. For this reason, human induced ecological disturbance has the potential to play an important role in estuarine ecology and biodiversity.
- Wave events also play an important part in the process of shoreline recession. In general, the smaller wave heights in the upper estuary lead to lower levels of erosion from storm 'bite'. However, recovery from storm bite is inhibited by the lack of swell, resulting in permanent shoreline recession. This process may be exacerbated by uncontrolled shoreline development.

Estuary Morphology and Siltation

Chapter 5 discusses various facets of the morphological characteristics and siltation processes of Brisbane Water. It summarises the more detailed information provided in Appendices D, F and G. It includes information on sediment characteristics, acid sulfate soils, bank erosion and shoreline dynamics (with particular reference to hot spots such as St Hubert's Island, Hardy's Bay, Ettalong foreshore and Correa Bay). The key findings include:

- Human activities can have a significant impact on estuarine sedimentary characteristics. The present rate at which sediments are delivered to the estuary from the catchment was determined to be 5.7 million kg/year.
- Human activities also impact on the quality of sediments via the introduction of a range of pollutants, including heavy metals. Lead, copper and zinc were found to be present in the highest concentrations in samples collected. These metals are associated with discharges from some industries and runoff from roads. The most significant locations where heavy metal contaminants were identified are Narara Creek, followed by Erina Creek.
- An assessment of the likely effects of heavy metal contaminants on the estuarine ecology has determined that low-level negative impacts on the biota can be expected. This is an important consideration given the conservation value of the estuarine ecology and the commercial value of some species, oysters in particular (these filter feeders generally bio-accumulate these pollutants).
- Human activities are also affecting estuarine morphology and coastal processes through the construction of foreshore structures, such as jetties, seawalls and boat ramps, much of which has been unregulated. Foreshore structures can directly impact on patterns of sediment transport by forming a physical barrier, and indirectly by altering coastal processes (e.g. waves, currents) which govern sediment transport. This can lead to accretion in some areas and erosion in others.
- Modelling indicates that a number of reaches of natural shoreline are subject to a general trend of recession, with severe-storm bite expected to result in around 1 to 2m of horizontal recession. In general, there is a high potential for long term

shoreline recession within Brisbane Water Estuary because beach recovery is limited. This issue provides further motivation for control of foreshore development. Any future planning for foreshore areas should also take into account the impacts of global climate change on water levels, wave climate and foreshore inundation.

Water Quality Processes

Chapter 6 discusses the water quality of Brisbane Water and provides a comparison with water quality trigger levels reported in ANZECC (2000). These ANZECC 'guidelines' consider a number of waterway usage objectives in terms of constituent concentrations, ranging from aquatic ecosystem health, to primary and secondary contact recreation (e.g. swimming). The key findings include:

- The water quality data collected to date represents a 'snap-shot' in time and it is understood that there is limited consistency with respect to location and tidal phase of sampling sites. Therefore, it is difficult to identify overall trends in water quality from field data.
- The extent of oceanic influence partially governs water quality processes within the estuary, whereby flushing times are much longer in the upper-estuary due to the attenuation of tidal flow. For these reasons the upper-estuary generally exhibits poorer water quality and longer recovery times after a rainfall event.
- It appears that there may have been a general trend towards water quality improvement in more recent years, which could be related to a reduction in catchment runoff associated with drought conditions.
- A comparison between simulations of catchment runoff in wet and dry years suggests that any increases in the frequency and/or intensity of rainfall events (such as that expected to be associated with climate change), may lead to a more extreme short term decline in water quality due to increased nutrient and sediment loads. Should this occur, this process will be exacerbated by the projected population increase for the Gosford region and future planning should carefully consider patterns of land use and catchment based controls on water quality.

Ecological Processes

Chapter 7 summarises the ecological studies undertaken, which are reported in detail in Appendices H, I, J, K and L. The key findings include:

- Only 8km (9%) of the estuary foreshore remains unmodified from a natural state and more than half is considered to be highly disturbed. The main causes of loss of intertidal habitats are the construction of seawalls, jetties and piers. While these structures enhance amenity for individual residential properties, they often have the effect of precluding public access to the foreshore, have poor habitat value and also impact on sediment dynamics. Loss and degradation of foreshore vegetated habitats results in loss of the ecological function that such foreshore habitats (e.g. saltmarsh and mangrove ecosystems) provide. For example, these habitats afford the benefits of shoreline protection, nutrient cycling, buffering water quality and sediment trapping. Controls on foreshore development need to be reassessed and regulations implemented.
- Mangroves are thriving and the extent of their habitat appears to be increasing at the expense of saltmarsh habitat. Whilst there were no apparent trends in the density of mangroves or their canopy cover, there were fewer burrowing crabs found among mangroves located at the mouths of Erina and Narara Creeks. These locations are now known to have higher levels of sediment-bound heavy metals.
- Burrowing crabs living among saltmarsh-mangrove habitats are exporting large amounts of larvae into the estuary (average of 2,000 per cubic metre of water). The

larvae are a critical component of the estuarine food web. It is almost the only food for glass fish, which are themselves food for larger fish, such as bream, flathead, jewfish and others. Saltmarsh has recently been listed as an endangered ecological community because the habitat has been decimated along the NSW coast. The conservation and rehabilitation of these habitats needs to become a higher priority for management.

- It is thought that the spatial extent of the seagrass, *Posidonia australis* (strap weed) has decreased by nearly 50% over the last 20 years, whilst *Zostera capricorni* (eel grass) has increased by approximately 8% (Jelbart and Ross, 2006). Seagrass meadows are the habitat for most commercially and recreationally important juvenile fish species, prawns and crabs. Seagrasses in Brisbane Water are also the home for a surprisingly diverse and abundant number of sygnathid fishes (such as seahorses and pipe fish).
- Particular seagrass locations are used preferentially to recruit different species of juvenile fishes. For example, juvenile Blue Groupers were only found among seagrass meadows near Ettalong wharf.
- Fish and invertebrate assemblages in the estuary are variable and best described as a mosaic. However, particular areas were found to have higher diversity of species than others. These areas tended to be areas of relatively high variation in salinity, such as the entrance to the estuary around Ettalong and the mouths of creeks. Biodiversity indices were generated and will have significant implications for future management.
- Wetlands associated with Brisbane Water have been recognised as being of national significance. The estuarine bird assemblages consist of at least twelve functional groups that included a suite of wetland birds (waterfowl, piscivores, large and medium wading birds, waders and omnivore-scavengers), together with species usually associated with terrestrial habitats (carnivores including diurnal raptors, insectivores, aerial insectivores, insectivore-nectarivores and seedeaters). A total of 110 species were identified in Brisbane Water estuarine habitats. There are 11 documented threatened species that use Brisbane Water habitats including two endemic threatened species whose populations are supported by the array of saltmarshes, mangroves and mudflats. Brisbane Water estuary is on the route of the East Asian-Australasian Flyway that is used by 21 trans-equatorial migratory waders.

Cultural Heritage

Chapter 8 includes a review of both indigenous and non-indigenous (European) heritage. The detailed report is located in Appendix M. The key findings include:

- The natural resources found in the estuary and catchment made the Brisbane Water Estuary an attractive place for Aboriginal groups to camp and there are a large number of Indigenous places and artefacts associated with the area. The areas of Pretty Beach and Daley's Point have the highest concentration of known sites, and Kariong, Woy Woy and Cockle Broadwater also have concentrations of known sites. There are concerns over as yet unidentified sites, for which there is significant potential, given the history of known Aboriginal occupation of the area.
- There are 11 items of European heritage significance located on the estuary foreshores.
- There are a number of shipwrecks in the Estuary; however, the exact location of these wrecks is unknown. At least half of these wrecks are thought to be located on the bar near the entrance.
- The implications of global climate change and sea level rise should be considered in the ongoing management and conservation of historic sites and artefacts, both Indigenous and European.

Recreational Processes

Chapter 9 summarises recreational processes that were investigated to provide an overview of recreational activities and foreshore land use for the estuary. Human use of the estuary has resulted in conflicts between users in relation to land use and the recreational use and enjoyment of the foreshore and waterways, as well as degradation of the natural environment. High population growth and tourism continues to exacerbate these conflicts. The full report can be found in Appendix N. The key findings include:

- Public safety is a significant concern, particularly with respect to boating activities. Hazards to navigation include mobile sand shoals, erosion and sedimentation and strong tidal currents. The diverse range and size of watercraft and the intensity of boating activity also indicate the potential for safety hazards and conflict between recreational users.
- Recreational fishing and boating activities have the potential to cause environmental impacts, such as habitat loss and degradation (both terrestrial and aquatic), declining water and sediment quality, shoreline erosion, sedimentation and siltation and detrimental impacts on the aquaculture industry.
- In order to manage the risk of conflict between users, as well as negative environmental impacts, it may be prudent to consider partitioning of activities. This may include the explicit use of zoning of different parts of the estuary for different user groups and should incorporate consideration of some form of protection for environmentally sensitive areas.
- At present 35% of the foreshore of Brisbane Water Estuary is held in public reserves, National Parks and Nature Reserves. The remaining 65% is privately owned / managed. Regulation of foreshore development has been a challenge and many un-regulated activities have occurred, with associated impacts on the environment. These developments also impact on recreational activities in that they prohibit foreshore access in many locations.

Chapter 10 provides a synthesis of the preceding chapters and includes conceptual models to illustrate interactions between processes. It concludes with an overview of the ecological health of the estuary.

Chapter 11 provides an overview of recommendations for the future management of Brisbane Water.

GLOSSARY AND ABBREVIATIONS

Allelopathic	A plant that produces chemicals that kill off surrounding plants as a defence mechanism.
Ambient	Refers to the immediate surrounds. In the case of water quality (Section 6) this refers to chronic or 'push' conditions.
Amenity	Those features of an area that foster its use for various purposes.
Animal	Any animal, whether vertebrate or invertebrate, and at whatever stage of development.
Anthropogenic	Related to human activities.
Anoxic	Without oxygen / zero oxygen.
ARI	Average Recurrence Interval
ASS	Acid Sulfate Soil(s)
Beach Berm	The area of shoreline lying between the swash zone and the dune system.
Beach Nourishment	The supply of sediment by mechanical means to supplement sand on an existing beach or to build up an eroded beach.
Benthic / Benthos	Benthic refers to the bottom, i.e. the estuarine floor. Benthic animals live on the estuarine floor or seabed. Collectively they are known as the benthos.
Biota	Living organisms.
Bird	Any bird that is native to, or is of a species that periodically or occasionally migrates to Australia, and includes the eggs and the young thereof and the skin, feathers or any other part.
BoM	Bureau of Meteorology
Canonical Analysis	A statistical method of investigating the relationship between two sets of variables, e.g. environmental variables (bed shear stress, salinity, chlorophyll *a*, etc.) and ecological attributes (species diversity, species abundance, community structure).
Catchment	The area draining to a site. This always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
CEMC	Coastal and Estuary Management Committee
Chlorophyll	The pigment used by plants in the process of photosynthesis.
CLAM	Coastal Lake Assessment and Management
CMA	Catchment Management Authority
Coriolis Force	The Coriolis Force is the result of the Earth's rotation. It acts to the left of wave or wind flow in the southern hemisphere and to the right of the flow in the northern hemisphere. The Coriolis Force is zero at the equator and strongest at the poles. It leads to the deflection of currents and winds such that storm systems spin in a clockwise direction in the Southern Hemisphere and in an anti-clockwise direction in the Northern Hemisphere.
COSS	Coastal Open Space System
Coastal Hazards	Detrimental impacts of coastal processes on the use, capability and amenity of the coastline.
CP Act	*Coastal Protection Act, 1979*
Crustacean	A class of arthropods that are mainly aquatic and possess two pairs of antennae and a hard carapace; including barnacles, crabs, copepods, lobsters and prawns.
DCP	Development Control Plan
DEC	Department of Environment and Conservation (incorporating EPA, NPWS).
DECC	Department of Environment and Climate Change. This recently created department incorporates DEC, DNR and some functions of NSW Fisheries.
Demersal	Dwelling at or near the bottom of a water body, e.g. a demersal fish.
Depuration	The process by which shellfish metabolise and/or flush chemicals from their organs.
Desiccation	The process of drying out, e.g. intertidal flora and fauna exposed to the air on the low tide.
Design Wave Height	The wave height adopted for the purposes of designing coastal structures such as breakwaters and seawalls. It is chosen to ensure that the structures are not at undue risk of wave damage.

Detritivore	Any organism that consumes detritus (decaying matter).
Diffraction	The "spreading" of waves into the lee of obstacles such as breakwaters by the transfer of wave energy along wave crests. Diffracted waves are lower in height than the incident of waves.
DIPNR	Department of Infrastructure, Planning and Natural Resources (became Department of Planning and Department of Natural Resources, now DECC).
DLWC	Department of Land and Water Conservation (Became DNR, now DECC).
DNR	Department of Natural Resources (Now DECC and DWE)
DoL	Department of Lands
DoP	Department of Planning (Previously DIPNR)
DPI	Department of Primary Industries
Drogue	An instrument that can be deployed from a boat that is used to track currents.
Ecosystem	A community of living organisms, together with the environment in which they live and with which they interact.
Endangered Fauna	Protected fauna of a species under Schedule 1 or 2 of the *Threatened Species Conservation Act*, 1995.
EPA	Environment Protection Authority
EP&A Act	*Environmental Planning and Assessment Act, 1979*
EPBC Act	*Environmental Protection and Biodiversity Conservation Act, 1999.*
Epiphytic	A plant that grows on another plant, but does not derive any nourishment from it.
Euphotic Zone	The upper portion of the water column that is penetrated by light, in which photosynthesis can take place.
Eutrophication	The over-enrichment of a water body with nutrients, leading to the excessive growth of plants and plankton and the depletion of oxygen.
Fauna	Any mammal, bird, reptile, amphibian or fish.
Fish	All or any of the varieties of marine, estuarine or freshwater fishes (whether indigenous or not) and their young, fry and spawn and unless contrary intention be expressly stated, or the context otherwise requires, includes crustacea, oysters and all marine, estuarine and freshwater animal life.
FM Act	*Fisheries Management Act 1994*
GCC	Gosford City Council
Habitat	The places in which an organism or community lives.
Halophytic	Halophytic organisms are highly tolerant of saline conditions.
Herbivore	An animal that consumes plants.
Invertebrate	Animal without a backbone or notochord.
IPCC	Intergovernmental Panel on Climate Change
IPO	Inter-decadal Pacific Oscillation
LALC	Local Aboriginal Land Council
LEP	Local Environment Plan
LG Act	*Local Government Act, 1993*
LGA	Local Government Area
Met-ocean	Synergy between meteorological and oceanographic conditions.
MHWS	Mean High Water Springs
MHWN	Mean High Water Neaps
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
Mollusc	An invertebrate that secrete a shell and has a muscular foot, including snails, mussels, oysters, octopus, squid and cuttlefish.
MSL	Mean Sea Level
Nekton	This term describes the animals than live in the mid-range of the water column.
NPWS	National Parks and Wildlife Services
NSW	New South Wales
PASS	Potential Acid Sulfate Soils
Pelagic	Pelagic animals live in the middle of the water column.
Photosynthesis	The process by which plants convert the energy in sunlight into chemical energy.
Piscivore	Fish eating animal.

Plankton	Plankton ("ocean wanderers") are the animals and plants that live in the surface layer of the water column. This term is often used to describe the microscopic component of this community (e.g. larvae and phytoplankton). However, in reality the term describes a lifestyle and many marine species, both micro and macroscopic, inhabit the plankton for at least part of their life cycle.
Pneumatophores	The peg like mangrove roots that grow up out of the mud to absorb oxygen for the mangrove tree. Only some mangrove species have peg roots, e.g. *Avicennia marina*.
PoEO Act	*Protection of Environment Operations Act, 1997*
Propagule	Any part of an organism capable of independent growth, e.g. a mangrove propagule is the fertilised seed.
RCBS	Regional Biodiversity Conservation Strategy
Reflected Waves	That part of an incident wave that is returned seaward when a wave impinges on a steep beach, barrier or other reflecting surface.
Refraction	The tendency of wave crests to become parallel to bottom contours as waves move into shallower waters. This effect is caused by the shoaling process which slows down waves in shallower waters.
Refugia	A place that acts as a refuge.
Reptile	A snake, lizard, crocodile, tortoise, turtle or other member of the class reptilian (whether native, introduced or imported), and includes the eggs and the young thereof and the skin or any other part thereof.
Riparian Vegetation	Vegetation growing along banks of rivers.
Runoff	That proportion of rainfall that drains off the lands surface.
Seawall	Wall built parallel to the shoreline to limit shoreline recession.
Sedimentation	The act or process of depositing sediment, especially by mechanical means of matter suspended in a liquid.
Semi-diurnal tides	Tides with a period, or time interval between two successive high or low waters, of about 12.5 hours.
SEPP	State Environmental Planning Policy
Sessile	Attached to the substratum.
Sewage	Refuse liquids or waste matter carried off by sewers.
Shoaling	The influence of the seabed on wave behaviour. Such effects only become significant in water depths of 60m or less. Manifested as a reduction in wave speed, a shortening in wavelength and an increase in wave height.
Shoreline Recession	A net long-term landward movement of the shoreline caused by a net loss in the sediment volume.
Storm Surge	The increase in coastal water level caused by the effects of storms. Storm surge consists of two components: the increase in water level caused by the reduction in barometric pressure (barometric setup) and the increase in water level caused by the action of wind blowing over the sea surface (wind setup).
Swell Waves	Waves that have travelled into the observation area having been generated by previous winds in other areas.
Sea Waves	Sea waves are generated locally and move in the same direction as the surface wind.
Taxa	A grouping of organisms given a common taxonomic name, e.g. species, genus, family, etc.
Tides	The regular rise and fall of the sea level in response to the gravitational attraction between the sun, moon and Earth.
Transient	Passing. In the case of water quality (Section 6), this refers to intermittent, acute events or press events.
TSC Act	*Threatened Species Conservation Act, 1995*
Vertebrate	Animal with a backbone or notochord.
Viviparous	Giving birth to live young.
Water Quality	The suitability of the water for various purposes, as measured by the concentration or level of a wide variety of contaminants.
Wave Height	The vertical distance between a wave trough and a wave crest.
Wave Period	The time taken for consecutive wave crests or wave troughs to pass a given point.

Wave Run-up	The vertical distance above mean water level reached by the uprush of water from waves across a beach or up a structure.
Wave Set-up	The increase in water level within a surf zone above mean still water level caused by the breaking action of waves.
Wind Set-up	The increase in mean sea level caused by the "piling up" of water on the coastline by the wind.
Wind Waves	The waves initially formed by the action of wind blowing over the sea surface. Wind waves are characterised by a range of heights, periods and wavelengths. As they leave the area of generation (fetch), wind waves develop a more ordered and uniform appearance and are referred to as swell or swell waves.

1. INTRODUCTION

This report has been prepared by Cardno Lawson Treloar (previously Lawson and Treloar), in association with Bio-analysis Pty Ltd, Sainty and Associates, Kellogg Brown and Root (KBR), GHD Geo-technics (previously GHD LongMac), HLA Envirosciences (HLA), the University of Newcastle, the University of New South Wales and Sydney University for Gosford City Council (GCC) and the Department of Environment and Climate Change (DECC; previously the Department of Natural Resources).

Following the commissioning of the project, a number of supporting investigations were conducted under the supervision of GCC. These associated reports have provided additional information for the preparation of this Estuary Processes Study, namely:

- Barnes, P.B. (2006) *Sessile Epibenthic Invertebrates of Brisbane Water Estuary: Patterns in Sponges and Ascidians.* Bio-analysis Pty Ltd. Prepared for Cardno Lawson Treloar.
- Boyland, T. (2006) *The Temporal and Spatial Variability of Zostera capricorni and their Influence on Fish Assemblages in the Brisbane Water Estuary, NSW, Australia.* Honours thesis, School of Science and Technology, University of Newcastle.
- Cardno Lawson Treloar (2007a) *Brisbane Water Estuary Processes Study Catchment Modelling – MUSIC. Appendix B.* Prepared for GCC and DNR.
- Cardno Lawson Treloar (2007b) *Brisbane Water Estuary Processes Study Hydraulic Modelling. Appendix C.* Prepared for GCC and DNR.
- Cardno Lawson Treloar (2007c) *Brisbane Water Estuary Processes Study Estuarine Morphology and Siltation. Appendix D.* Prepared for GCC and DNR.
- Cardno Lawson Treloar (2007d) *Brisbane Water Estuary Processes Study Water Quality Modelling. Appendix E.* Prepared for GCC and DECC.
- Ford, J., Fowler, A. and Suthers, I. (2006) *Brisbane Water Estuary Study: Larval Fish Settlement, Zooplankton and Phytoplankton, During Spring 2005.* School of Biological, Earth and Environmental Sciences, University of New South Wales. Prepared for GCC.
- Freewater, P., Platell, M., Gladstone, W., Taylor, D., Garber, S. and van Ormondt, M. (2007) *Export and Dispersal of Crab Zonae from Saltmarsh-Mangrove Complexes in Brisbane Water and Their Importance to Fish.* Prepared for GCC.
- GHD LongMac (2004) *Brisbane Water Estuary Processes Study Acid Sulfate Soils Investigation.* Prepared on behalf of Cardno Lawson Treloar for GCC and DNR.
- Gladstone, W. (2006) *Spatial and Temporal Variation in the Biodiversity of Macroinvertebrates in Brisbane Water Estuary and its Relationship to Environmental Variation.* School of Environmental and Life Sciences, University of Newcastle. Prepared for GCC.
- Gladstone, W. (2007) *Patterns of Spatial Variation in Assemblages of Estuarine Organisms in Brisbane Water Estuary and their Relationship to Environmental Variation.* School of Environmental and Life Sciences, University of Newcastle. Prepared for GCC.
- Gladstone, W. and Shokri, M.R. (2007) *Spatial and Habitat-related Patterns in the Biodiversity of Brisbane Water Estuary: A Tool for Sustainable Estuary Management.* Draft Final Report. School of Environmental and Life Sciences, University of Newcastle. Prepared for GCC.
- HLA-Envirosciences (2005) *Desktop Heritage Study of Brisbane Water, Gosford, NSW.* Prepared for Cardno Lawson Treloar.
- Jelbart, J.E. and Ross, P.M (2006) *Examination of the Loss of Seagrass and Associated Fauna in Gosford Local Government Area.* University of Western Sydney. Prepared for GCC.
- Kellogg Brown and Root (2005) *Brisbane Water Estuary Process Study Recreational Activities and Foreshore Land Uses.* Prepared for Cardno Lawson Treloar.

- Roberts, D.E. (2006) *Spatial Patterns in the Macrobenthic Fauna of Mangrove Forests in the Brisbane Water Estuary.* Bio-analysis Pty Ltd. Prepared for Cardno Lawson Treloar.
- Roberts, D.E. and Sainty, G.R. (2006) *Spatial Variation in Mangrove Forests Around the Brisbane Water Estuary.* Bio-analysis Pty Ltd and Sainty & Associates. Prepared for Cardno Lawson Treloar.
- Roberts, D.E. and Sainty, G.R. (2006) *Spatial Variability in the Saltmarshes around the Brisbane Water Estuary: Patterns Associated with the Tidal Regime and Anthropogenic Disturbance.* Bio-analysis Pty Ltd and Sainty & Associates. Prepared for Cardno Lawson Treloar.
- Robinson, M.V. (2006) *The Birds of the Brisbane Water Estuary*. Bioregen Ecological Assessment and Restoration. Prepared for Bio-analysis Pty Ltd.
- Sainty, G.R. and Roberts, D.E. (2007) *Ecological Assessment of the Shoreline around the Brisbane Water Estuary.* Bio-Analysis Pty Ltd and Sainty and Associates. Prepared for Cardno Lawson Treloar.
- USEGG (2007) *Heavy Metal Distribution and Sediment Quality in the Brisbane Water Estuary, NSW.* The University of Sydney Environmental Geology Group. Prepared for GCC.

These reports have been included as Appendices. In addition to undertaking a number of investigations, Cardno Lawson Treloar was also responsible for synthesis of the above information and the preparation of this report with input from Dr Peter Freewater of Gosford City Council.

The study was conducted as intended over an extended period between 2004 and 2007 due to the nature of the temporal scales of some of the processes being evaluated. It consisted of a wide range of quantitative and qualitative assessments, including field work, liaison with numerous stakeholders, desktop reviews of existing literature and numerical modelling of the catchment, hydrodynamics of the estuary, sediment transport processes and water quality modelling.

1.1 Study Context

The Estuary Management Process

The NSW Coastal Policy (1997) and Sydney Regional Coastal Management Strategy (1998) have as their central focus the ecologically sustainable development (ESD) of the coastal zone. ESD refers to development that uses, conserves and enhances the community's resources so that the ecological processes on which life depends are maintained and the total quality of life now and in the future can be increased. The four principles of ESD are:

- Conservation of biological diversity and ecological integrity
- Inter-generational equity
- Improved valuation, pricing and incentive mechanisms
- The precautionary principle.

One of the Coastal Policy's strategic directions is the preparation and implementation by local Councils of detailed management plans for estuaries in accordance with the Estuary Management Policy. The Estuary Management Policy is defined in the Estuary Management Manual (NSW Government, 1992). The policy outlines a structured management process leading to the implementation of an Estuary Management Plan. In developing the plan all values and uses of the estuary are considered. The plan aims to be a balanced long-term management framework for the ecologically sustainable use of the estuary and its catchment.

The Estuary Management Manual recommends an eight step process in order to implement an Estuary Management Plan, as follows:

1. form an Estuary Management Committee;
2. assemble existing data (data compilation study);
3. **undertake an Estuary Processes Study;**
4. undertake an Estuary Management Study;
5. prepare a draft Estuary Management Plan;
6. review Estuary Management Plan;
7. adopt and implement the Estuary Management Plan; and
8. monitor and review the management process as necessary.

In compliance with steps 1 and 2, GCC has formed an Estuary Management Committee through their Coastal and Estuary Management Committee (CEMC) and the Brisbane Water Data Compilation Study was completed in 2002. It should be noted that the data compilation study for Brisbane Water (SMEC and Umwelt Australia, 2002) is a comprehensive volume and should be read in conjunction with this report.

Study Area

The study area comprises the tidal waterway, foreshore and adjacent land of Brisbane Water, including the entrance area and tidal tributaries covering the whole region of Brisbane Water from the channel connecting to Broken Bay at the eastern end of Ocean Beach in the south to Gosford in the north, and associated tributaries and catchments.

A locality map of the study area is shown in Figure 1.1.

There are five major waterways that comprise the Brisbane Water Estuary as identified in the Brisbane Water Plan of Management (GCC, 1995), as well as a number of smaller waterways. They are:

- Entrance Reach between The Rip and Half Tide Rocks
- Woy Woy Reach, including Pelican Island, Riley's Island and St Hubert's Island
- Kincumber Broadwater
- Brisbane Water (upstream of Pelican Island)
- Woy Woy "Bay" And Woy Woy "Inlet", which are almost separated from Woy Woy "Reach" by a road and rail causeway.
- Ettalong Beach
- Booker Bay (south-east of The Rip Bridge)
- Blackwall Point
- Woy Woy Channel
- Woy Woy Inlet
- Woy Woy Bay
- Noonan Point
- The Broadwater (Point Clare and Fagan's Bay)
- Point Frederick
- Ironbark Point
- Rocky Point
- Green Point
- Cockle Channel
- Cockle Bay
- Fishermans Bay (northeast of The Rip Bridge)
- Rileys Bay
- Hardy's Bay
- Pretty Beach
- Wagstaffe Point.

Major tributary creeks of the system include the following as shown in Figure 1.2:

- Ettalong Creek
- Woy Woy Creek
- Coorumbine Creek
- Upper and Lower Narara Creek
- Upper and Lower Erina Creek
- Kincumber Creek.

Many other small creeks drain into the estuary, some of which are un-named.

Summary of Key Characteristics

As an overview, numeric values of key characteristics of the estuary are listed in Table 1.1 – drawn from the Data Compilation Study and other later information, for example, MHL (2004).

Table 1.1 Key Parameters for Brisbane Water Estuary

Estuarine Characteristics	
Classification	Wave dominated estuary
Condition	Extensively modified
Estuary length	17.72 km
Estuary width	3.74 km
Total entrance width	0.16 km
Catchment and Tributaries	
Catchment area	165 km^2
Catchment land use proportions	• Forest: 49.9% • Residential: 27.2% • Rural: 17.3% • Industrial: 2.7% • Commercial: 1.3% • Road: 0.5% • Other: 1.3%
Catchment soils	Predominantly Erina and Watagan, but ranging to Somersby and Norah Head. Soils are generally affected by erosion and water logging
Number of identified sewer overflow points in catchment	121 (based on the location of sewer pumping stations)
Number of major tributaries (not including stormwater inflows)	8 (Ettalong, Woy Woy, Coorumbine, Upper Narara, Lower Narara, Upper Erina, Lower Erina and Kincumber Creeks)
Water Body and Riparian Zone	
Water surface area	27.2 km^2
Perimeter	89.43 km
Approximate minimum bed level	-38mAHD
Approximate average bed level	-5mAHD (but in many places as shallow as -3m AHD)
Approximate mean low water spring ocean tide level	-0.4m AHD
Approximate mean high water spring ocean tide level	+0.4m AHD
Maximum ocean tidal level (MHHW)	+0.7m AHD
Water Quality	
Key pollutant constituents and typical timing of delivery	TN and TP – 3-6 hours from onset of rainfall in the catchment
Average Salinity range in main water body	20 to 33ppt, depending upon runoff history

Flora and Fauna	
Fisheries value	High
Number of recorded bird species	110
Number of threatened and/or protected species, populations and ecological communities.	- 60 Vulnerable and 14 Endangered animal species, and 16 Vulnerable and 8 Endangered plant species (TSC Act, 1995). Most of these are terrestrial species or marine mammals that may visit the area. - SEPP 14 Wetlands

It is important to note that the estuary is large and that all of these parameters show high spatial variability. For example, the tidal range is higher at Ettalong than at Gosford and water levels at both sites are affected by met-ocean conditions.

1.2 Study Objectives

The main objectives of the study are broad in their scope and are primarily to:

- Identify and document the physical, ecological and bio-chemical processes of the Estuary (i.e. hydrodynamic and sedimentary processes, including tidal behaviour, freshwater inputs, water balance, mixing, exchange with the Hawkesbury River and Broken Bay, catchment geology and geomorphic characteristics, sediment movement, sedimentation rates and sediment types) and interactions among and between these processes (e.g. establishment of water quality parameters (physical, chemical and biological) of importance to the health of the Estuary, mixing and flushing of pollutants, nutrient budget and establishment of an appropriate modelling system) through investigation, data collection and comprehensive analysis.

- To identify and document the ecological processes of the Estuary and related processes covering flora and fauna, species composition and distribution; habitat composition and distribution; the productivity and health of the ecosystems; the range and sensitivity of habitats to environmental disturbance; and rare and endangered species.

- To define a baseline condition of the Estuary (water quality, habitats, species, etc.) and describe interactions on which management decisions can be made.

- To review the existing and future land use activities that may potentially impact upon the Estuary.

- To undertake any further data collection to aid the subsequent stages of an estuary management study and formulation of a management plan for the Estuary.

1.3 Methodology Overview

An overview of the methodologies employed in undertaking the various components of the Brisbane Water Estuary Process Study is provided below:

- A review of existing literature, including studies and reports held by GCC.

- A search of a range of relevant databases (eg EPA Licensed Premises and Contaminated Lands Registers, AHIMS, State Heritage Inventory, Register of the National Estate, Maritime Archaeology, NPWS Wildlife Atlas, DPI – Fisheries Fish Notes).

- Modelling of water quality processes in the catchment using the MUSIC software (refer to Section 3 and Appendix B).

- Modelling of estuarine hydraulics (Section 4 and Appendix C), estuarine morphology and siltation (Section 5 and Appendix D) and estuarine water quality (Section 6 and Appendix E), all using the DELFT3D software.

- Sediment sampling at discrete locations (both cores and grab samples) for determination of the extent of Acid Sulfate Soils (ASS) and sedimentary contamination, as well as sediment grain size analysis.

- Field based ecological studies (both observational and manipulative), and associated laboratory and statistical analyses, utilising a range of techniques (Section 7).

- Synthesis of published information on recreational usage and presentation of the data relevant to this study (Section 8).

- Synthesis of published information on cultural heritage (indigenous and non-indigenous) and presentation of the data relevant to this study (Section 9).

- Compilation of the entire data set and integration of the data set on process interactions by the core team of environmental engineers and scientists for the project (Section 10).

Further details on the methods used in the preparation of this study are provided in the relevant report sections and appendices.

Several site visits were undertaken by the study team to investigate different facets of the Estuary Processes Study. This included a land-based site visit on 13 January 2004 and a water-based site visit on 20 January 2004. Subsequently, a number of informal site visits have been conducted by members of the study team over the course of the study period (2004 – 2007) for the purpose of inspecting specific areas.

Additionally, some investigations, for example the ecological components of the study, involved numerous field campaigns.

Mapping was prepared by the study team based on GIS data provided by Gosford City Council, DECC and DPI – Fisheries, as well as those GIS layers created based on investigations by the study team.

Stakeholder consultation formed an important part of the Brisbane Water Estuary Processes Study. This involved several elements including:

- Direct stakeholder engagement via correspondence
- A public information session at the outset of the project
- A series of five progress meetings
- CEMC representation
- Agency consultation.

Further details on the community consultation elements of the Brisbane Water Estuary Processes Study can be found in Section 2.

Consultation, including survey, was also used as part of the heritage and recreational aspects of the study (Sections 8 and 9 respectively).

A Coastal Lake Assessment and Management (CLAM) tool has also been initiated for the Brisbane Water Estuary and will provide a link between the Estuary Processes Study and the Estuary Management Study. The CLAM is not reported on herein, but will form part of the Management Study.

2. STAKEHOLDER CONSULTATION

2.1 Overview

The completion of an Estuary Processes Study is driven by the objective of gaining an appreciation of the physical processes occurring within the Estuary. Many of these processes are influenced by human behaviour and intervention. The subsequent phases of the Estuary Management process, the Estuary Management Study and Plan, will be more focused toward decision making for the future by the various responsible authorities and consequently have a much greater consultative element than this processes study.

Nonetheless, given the fundamental need for consultation through the life of the Estuary Management process, a consultation element has been incorporated into this study.

Key elements of the consultation included:

- Direct stakeholder engagement via correspondence
- A public information session
- Agency stakeholder consultation
- Periodic meetings with the Committee
- Periodic website updates to describe study progress.

The materials utilised for the consultation can be found in Appendix A.

2.2 Direct Stakeholder Engagement via Correspondence

At the outset of the project a letter was forwarded to the following stakeholders regarding the project:-

- Australian Plant Society
- Nature Conservation Council of NSW
- Australian Museum (Museum on the Road)
- Bob Turners Wildlife Adventures
- Central Coast Community Environment Network
- Darkinjung Local Aboriginal Land Council
- Department of Education & Training Central Coast District Office-Gosford
- Environmental Defenders Office
- Gosford City Council
- Gosford Council Bush Care Officer
- Gosford Local History Group
- Gosford Library
- Botanic Gardens Trust
- Central Coast Waste Board
- Department of Agriculture (now DPI)
- Department of Environment & Heritage
- Friends of the Earth
- Gould League NSW
- Greening Australia
- Keep Australia Beautiful Council
- Koolewong & Point Clare-Tascott Progress Association
- Land Care
- Land Care Resources (Newcastle/Lake Macquarie)
- National Parks & Wildlife Service
- National Parks Association
- Native Fish Society

- NSW Fisheries (under DPI)
- NSW Heritage Office
- Organic Matters
- Oyster Farmer's Association
- Planet Ark
- Professional Fishers
- Rumbalara Field Studies Centre.
- State Forests
- St Hubert's Island Residents Association
- Wambina Flying Fox Education & Research
- Wilderness Society of NSW
- World Wide Fund for Nature

The letter was an introduction to the study, advising of the objectives of the project and seeking inputs from the stakeholder to the study.

A copy of the letter can be found in Appendix A.

2.3 Public Information Session

A public information session was held on the 1st July 2004 at the Erina Room at the Erina Fair Shopping Centre, Erina from 7.30pm – 9.30pm. This session involved audio-visual presentations by speakers including:

- Louise Gee, Director Environmental Planning, GCC
- Dr Peter Freewater , Natural Resources Officer, GCC
- Louise Howells, Cardno Lawson Treloar
- Tom Holden, Kellogg Brown & Root
- Dr Danny Roberts, Bio-Analysis
- Geoff Sainty, Sainty & Associates
- Dr William Gladstone, Newcastle University
- Dr Anna Redden, Newcastle University
- Tenielle Boyland and Mandy Cox - Newcastle University.

The primary purpose for the meeting was to convey early scientific information on the processes within the estuary in a readily understandable form.

2.4 Agency Stakeholder Consultation

Agency stakeholder consultation was undertaken on an as-needed basis. The primary mechanism for agency consultation was through the initial letter consultation (Section 2.2) and follow up for additional information as required.

2.5 Periodic Meetings with the Committee

From the project inception in early 2004, through to the issue of the draft report in mid 2007, a sequence of five progress meetings was held with the Estuary Management Committee. This committee was formed by GCC through its CEMC.

These meetings involved keeping the Committee briefed on the progress of the study and providing updates on those components of the study that were available for discussion at the time.

2.6 Website Updates

Given the lengthy duration of the project, periodic updates for the community were provided via a dedicated link from GCC's website:

www.gosford.nsw.gov.au/environment/water/bw_estuary.html.

Updates were provided in February and July, 2004, and August and November, 2006. Copies of the update information can be found in Appendix A.

2.7 Coastal Lake Assessment and Management (CLAM)

CLAM is a decision-support tool to assist in the future management of coastal lagoons and estuaries. CLAM allows local councils to assess the impacts of different land use and management options on estuaries. It can assist in making integrated planning and management decisions from the perspective of sustainable estuarine management.

GCC is investigating the suitability of using a CLAM for Brisbane Water Estuary. The CLAM will be populated with data from the Estuary Processes Study and integrated within the Estuary Management Study.

3. CATCHMENT PROCESSES

3.1 Overview

Compared to the size of the waterway, the Brisbane Water estuary has a relatively small catchment of 165km^2, which has undergone a range of rural, residential and industrial development. However, natural forest still covers about 50% of the catchment and about 15% comprises Brisbane Water itself.

The principal aspects of the catchment that affect Brisbane Water are the variations, temporal and spatial, in runoff and material loads (e.g. nutrient/sediment) delivered to the waterway. Brisbane Water has sandy and silty shorelines, such as those found at Ettalong, Booker, and Fagan's Bay. The shorelines of Brisbane Water reflect the nature of the catchment. Some of the catchment areas are steep, such as Killcare, and others are flat, such as Davistown.

The climate, soil types, terrain and development condition all affect the volume and rate of runoff, as well as the uplifted sediment load and type and mass of contaminants delivered to the estuary. As outlined above, relative to the surface area and volume of the waterway, the catchment is quite small and catchment flows themselves have very little impact on water levels in most of the estuary, other than in enclosed areas such as Fagan's Bay and the mouth of Narara Creek (Cardno Lawson Treloar, 2007e). This means that nutrient levels will not be high in the estuary, other than in enclosed areas such as Fagan's Bay and near the entrances to creeks, such as Erina Creek.

3.2 Catchment Characteristics

Brisbane Water is a wave dominated barrier estuary and tidal tributary of the Lower Hawkesbury River system. It is located approximately 50km north of Sydney within the City of Gosford Local Government Area. In a regional context, the area is strategically located on the established railway and freeway network between Sydney and Newcastle.

Detailed mapping of the catchment was undertaken for this study, resulting in an estimated total catchment area of 165km^2, falling under the Hunter Central Rivers Catchment Management Authority (CMA). This value differs from that reported in the Data Compilation Study (SMEC and Umwelt Australia, 2002) and the Plan of Management (GCC, 1995), which report a catchment area of 185 km^2. No details of the manner in which the area was calculated previously are provided in either report. The value of 165km^2 is adopted throughout this study and is used in the catchment modelling described in this chapter.

The Brisbane Water catchment is bounded by Broken Bay in the south, the coastal catchment to the east and extends to include Gosford and Matcham in the north. Urban areas have developed around the Brisbane Water foreshores and there are also a number of reserves and National Parks located within the catchment boundaries.

The extent of the catchment and its sub-catchments is shown in Figure 1.2.

3.2.1 Land Use

Land use in the catchment is shown in Figure 3.1. Much of the western part of the catchment consists of Brisbane Water National Park, with Bouddi National Park covering part of the southwest corner of the catchment. There are also a number of other Reserves within the catchment. The catchment is partly urbanised with major concentrations of development centred on Gosford in the north and the region of Umina Beach, Ettalong Beach and Woy Woy in the southwest. Other smaller residential centres, including Green

Point, Kincumber, Saratoga, Davistown, St Hubert's Island, Killcare and Pretty Beach, are scattered along the eastern parts of the catchment. Increasing urbanisation in the catchment has been reported to be placing further pressure on the environment (GCC, 2003a).

Land use in the catchment has been categorised on the basis of aerial photography. These aerial photographs have been taken in 1954, 1986 and 2005. A large proportion of the catchment is comprised of forested or rural/open space. Dominant usage includes:

- Forest - 50%
- Rural - 20%
- Urban residential – 25%.

Specific types of land use considered for this study include:

- Urban residential areas
- Rural residential areas
- Public reserves
- National Parks
- Parks and sporting grounds
- Urban commercial/industrial areas
- Schools
- Major roads
- Marinas.

In general, land use has changed in many areas since European settlement from bushland to urban residential areas, particularly around Gosford and Ettalong/Woy Woy, with smaller residential areas located around the foreshores. Parts of the western and northern catchment have remained in a significantly more natural state and the National Park areas have been retained substantially in an undeveloped state.

3.2.2 Historical and Future Land Use

A series of aerial photographs provided by GCC from 1954, 1986 and 2005 were compared to investigate observable changes in the Brisbane Water Estuary catchment in the latter half of the 20th Century. Unfortunately, the 1954 and 1986 aerial photographs are not available in a format that may be presented herein. However, the 2005 aerial photograph has been used in Figure 1.1.

1954

Generally speaking, the level of development was of a lesser extent and of a lower density in 1954 than that for 1986. In 1954 land use in the Brisbane Water catchment primarily consisted of forested and rural land uses, although some low density residential development is apparent in many areas. In general, in 1954 the catchment and foreshore to the east of the estuary have much lower levels of development than that observed in 1986. The eastern catchment is rural in character with a few scattered buildings and a high proportion of forested land.

Locations at which what appear to be new residential developments are observable in photographs taken in 1954, including:

- Pearl Beach, Ettalong Beach, Umina Beach and Woy Woy in the south-west.
- Limited development at Fagan's Bay and Tascott.
- The beginnings of residential development in Yattalunga, Saratoga and Davistown.
- The beginnings of residential development in Killcare, Hardy's Bay, Pretty Beach and Wagstaffe.

In these locations there is typically low density residential development occurring in 1954, with numerous vacant blocks visible, and road construction beginning to extend out from the fringes of these areas. The Woy Woy area did not exhibit much development in 1954, even for the foreshore areas. The bridge between Woy Woy and Koolewong had been constructed by this time. Between Woy Woy and Point Clare (and further inland) there was very little development, consisting of occasional scattered rural holdings, but most of the catchment here was forested in 1954. To the north of Erina and east of Gosford there is a higher proportion of rural land uses and less forest in the 1954 aerial photographs. The Rip Bridge had not yet been constructed.

In 1954 the catchment had a relatively low level of development. The creeks appear to have had a reasonable amount of riparian vegetation and foreshore areas are generally reasonably accessible. In 1954, the riparian zone for Narara Creek was relatively wide and the creek catchment appears to have consisted largely of rural land uses with some scattered villages. The Erina Creek catchment was relatively undeveloped in 1954, with some rural land holdings and a high proportion of forest. There was very little development in the Kincumber Creek catchment in 1954, consisting primarily of what appear to be wetlands and forest, as well as a few scattered land holdings. Development to the east of Kincumber Broadwater has not yet begun.

In the Estuary itself, St Hubert's Island had not yet been constructed by 1954. The various shoals around the Estuary are easily observable.

1986

This aerial photograph was taken in the midst of a period of rapid growth in the Gosford LGA, during which Gosford had one of the highest growth rates in NSW. By 1986 there had been extensive residential development from Pearl Beach up to Woy Woy. As with much of the catchment, this development increased in extent and also in density. There were few green spaces visible. Further to the north, there had also been some further residential development of Fagan's Bay by 1986. Some additional residential development of the area between Koolewong and Point Clare had taken place by 1986. However, this part of the catchment had not undergone a great deal of change between 1954 and 1986. Similarly, the south-eastern corner of the Brisbane Water Estuary catchment did not undergo a great deal of change over this time period. However, the residential developments around Hardy's Bay, Pretty Beach and Wagstaffe had become established by 1986.

Much of the development that did occur between 1954 and 1986 centred around Gosford, including high density residential expansion and commercial / industrial land uses. To the north-west and north-east of Gosford, the catchment remained largely rural in character, albeit at a higher density more accurately described as semi-rural land use. Similarly, a great deal of development occurred over the period 1954-1986 in the Kincumber area. This consisted of what appears to be residential and commercial development. The development density for this area is much higher in 1986 than for 1954.

By 1986 St Hubert's Island had been constructed, as had The Rip Bridge. In addition, construction of the Sydney to Newcastle Freeway had commenced. In general, the foreshore areas are more densely developed in 1986, which can be assumed to have negatively impacted on foreshore access. The riparian zones for the major tributaries to the Estuary also appear to have decreased in extent / width.

2005

By 2005 additional residential developments can be observed in the Ettalong and Fagan's Bay areas. To the north of Gosford, increasing residential development of former rural lands can be observed, although this appears to represent a change in land use to higher density development rather than an increase in the spatial extent of development. This development has impacted on the Narara Creek catchment. However, the Erina Creek catchment appears largely as it did in 1986.

There had also been some further residential expansion near Erina to the north of Rocky Point and at Green Point. Some further development in the Kincumber Creek catchment is also observable in 2005, although it is unclear as to whether this is industrial or residential.

Moving Forward

For over 25 years Gosford has been a locality where new residential areas have met the demand as the wider Sydney Region expands. The availability of re-zoned land for urban development in the 1980s has been the primary reason for the population growth in Gosford, which increased more than 50% over the 17-years period between 1978 and 2001 (GCC, 2003a). The population growth rate peaked in 1989 at 11,000 people per annum, but after this time the growth rate declined to around 4,000 people per annum or less than 1.5% per year (NSW DoP, 2006). Associated with this population growth is further pressure for residential land release. However, it is understood that in the period since 1989, land release areas within the Gosford LGA have been exhausted (NSW DoP, 2006).

GCC recently developed a strategic vision for the Gosford LGA, known as '*Vision 2025'* (GCC, 2006), which identified several key issues relating to future land use in the Brisbane Water catchment:

- Despite projected population growth, retaining the mix of rural, urban and parkland/bushland areas was considered important. It is intended that urban sprawl will be restricted and agricultural land will be retained. In addition, small parks and community gardens will be promoted in residential areas, while small scale farms and market gardens will be promoted in rural areas.
- Planning is also important in terms of controlling development on ridgelines, near riparian zones and also for foreshore areas.
- Improved water and catchment management will include stormwater harvesting and effluent recycling, which should lead to improved water quality.
- Marine related industries such as tourism, sport, aquaculture and boat-building have been targeted for development.

GCC, with its *Vision 2025 Strategic Plan,* and the people of Gosford wish to retain the character of the area, while improving natural resource management and developing the economy.

The Department of Planning (DoP) recently released the *Draft Central Coast Regional Strategy* (2006), which places *Vision 2025* in the regional context. This strategy specifically targets future greenfield development and an increase in medium density development in coastal locations and around Gosford to accommodate a projected population increase of 64,250 people by 2031, for which an additional 36,000 dwellings will be required (NSW DoP, 2006). In addition to releasing new areas of land, development will also focus on providing more units and townhouses in key centres such as Gosford, with a view to providing a better housing mix. Associated with this population increase, the DoP (2006) highlight the need to supply 6,000 new jobs in Gosford, necessitating the requirement for sufficient employment land and commercial and retail floor space. Targets relating to population growth, housing and employment are situated within the context of:

- Planning for long term water supply
- Prevention of development in areas constrained by hazards relating to coastal hazards and flooding
- Protection of indigenous and non-indigenous heritage values and the visual character of the surrounding landscapes

- Protection of significant environmental assets and natural resources
- New development is to occur in a sustainable manner.

The *Draft Central Coast Regional Strategy* (NSW DoP, 2006) also targets improved water cycle management and improved protection of water quality and quantity in catchment areas. This is to be achieved through a range of measures, including:

- A requirement for GCC to implement policies defined within the Hunter-Central Rivers Catchment Management Authority Catchment Action Plan.
- Ensuring new development incorporates water sensitive urban design (WSUD), minimises water use and implements the provisions of BASIX.
- Investigate measures such as dual reticulation (grey water recycling, etc.) in new developments.
- Local catchment planning and stormwater initiatives.
- Establishment of Estuary Policy, Coastal Policy and Floodplain Development Policy, and ensuring that the revised LEP implements these policies.

It is understood that the DoP is currently reforming planning in NSW such that all local governments will be required to revise their LEPs. The Gosford City Centre Local Environment Plan 2006 has been drafted by GCC and it is anticipated that changes to land use zonings are proposed. However, at present there is no available mapping showing these new zones.

3.2.3 EPA Licensed Premises and Other Point Source Land Use Issues

Sources of pollutants affecting runoff water quality include:

- “Point” sources – discrete sources of water pollution in fixed locations, for example, industrial or commercial sites (eg those licensed under the PoEO Act, 1997), contaminated land, landfill sites, sewage treatment plants, or locations at which sewer overflows are known to occur regularly.

- “Non-point” sources – discharges from diffuse sources, for example, the build-up of pollutants on road surfaces or runoff from fertilised gardens, rural lands etc.

There are a number of point source land use issues in the Brisbane Water Estuary catchment. A search of the EPA Public Register of premises licensed under the *Protection of Environment Operations Act 1997* conducted on 31 July 2007 returned 46 records for the Gosford LGA. Based on mapping provided by GCC, 21 of these premises fall within the Brisbane Water catchment. The approximate location of these premises is indicated in Figure 3.2. Most are clustered around Gosford, Woy Woy and Kincumber.

The types of premises include, for example, Concrete Batching by Boral Resources, Brisbane Waters Private Hospital and Energy Australia. The type of pollutants expected to be discharged in runoff from these sites that may affect Brisbane Water includes; hazardous waste, industrial waste, or Group A pollutants (non-aqueous liquid waste or controlled aqueous liquid waste).

The EPA record of contaminated land notices was also searched on 31 July 2007. Two current notices were found relating to the remediation of contaminated sites within the catchment. The first one is located at Woy Woy Bogas Service Station. A notice of remediation site was issued on 01/08/2005. The second one is located at 1 Ashton Road Erina. A note of existence of voluntary remediation was issued on 23/08/2004.

Sewage overflows are a common point source of pollutants. Typically, sewage pumping stations are located where sewer overflows tend to occur. The locations of sewage pumping stations (provided by GCC) have also been indicated in Figure 3.2. It is understood that the use of septic tanks has historically represented a significant source of pollutants. However, most of these systems have been replaced by a reticulated sewer system.

3.2.4 Vegetation

A survey of vegetation in the Lower Hunter Central Coast region was conducted as part of the Regional Biodiversity Conservation Strategy (RBCS). This survey led to the identification of 55 vegetation communities with an estimated 65% of the original native vegetation remaining in the Lower Hunter Central Coast Region (GCC, 2000).

The catchment contains diverse vegetation communities, from woodlands, dry forest and hanging swamps to rainforest, moist forest, heath and coastal, riverine wetlands and saltmarsh. Figure 3.3 shows the vegetation types found in the Brisbane Water catchment.

The relatively high coastal rainfall and shale-enriched soils support moist tall forest and coastal warm temperate rainforest in protected gullies. These consist of a variety of rainforest species including *Acmena smithii* (Lillypilly), *Doryphora sassafras* (Sassafras) and *Ceratopetalum apetalum* (Coachwood*)*. Coastal Narrabeen Moist Forest is relatively widespread in the north eastern section and is dominated by *E. saligna* (Bluegum), *A. torulosa*, *S. glomulifera* and to a lesser extent *E acmenioides* (White Mahogany) and *E. pilularis* (Blackbutt).

On higher ridges with deeper shales Coastal Narrabeen Ironbark Forest occurs, dominated by *E. paniculata* subsp. *paniculata* (Grey Ironbark), *E. punctata* (Grey Gum), *S. glomulifera* subsp. *glomulifera* and *E. acemenioides*. Narrabeen Coastal Blackbutt Forest occurs on drier ridges dominated by Blackbutt, Turpentine and Forest Oak with a shrubby understorey. On Kincumba Mountain and Mount Elliot ridges, the Hawkesbury Sandstone geology supports Katandra Hawkesbury Woodland and further south on the Bouddi peninsular supports Killcare Hawkesbury Woodland.

Saltmarsh communities occur along the major creeks and are generally fringed by Estuarine Swamp Forest dominated by *C. glauca* (Swamp Oak) with an understorey of sedges and rushes. Further back, on areas with impeded drainage, Swamp Mahogany-Paperbark forests occur characterised by *E. robusta* (Swamp Mahogany) and a range of paperbark species such as *Melaleuca biconvexa, M. linariifolia* (Snow in Summer), *M. styphelioides* (Prickly-leaved Paperbark) and *M. quinquenervia* (Broad-leaved Paperbark).

Within the Brisbane Water Catchment a large amount of native vegetation is preserved in National Parks and reserves, as well as the Coastal Open Space System (COSS), shown in Figure 3.4. As stated in Section 3.2.1, approximately 50% of the catchment is forested (see also figure 3.1). This large percentage of native vegetation is directly linked with the health of the estuarine ecosystem and its conservation will be crucial to maintaining good water quality in the long-term.

3.2.5 Geology and Soils

Brisbane Water was formed as the result of the drowning of an ancient river valley in relatively recent geological time. The catchment topography rises to 300m above sea level on the high escarpment forming the western catchment boundary. The western to north-western parts of the catchment have generally higher elevations than elsewhere in the catchment. A high proportion of these elevated areas are forested.

The 1:100,000 scale Geological Series Sheet for Sydney (Chapman *et al.*, 1983) and the Soil Landscapes Map for Gosford (Murphy and Tille, 1993) indicate that the catchment is underlain by Hawkesbury Sandstone and the Narrabeen Group Terrigal Formation. Quaternary Alluvium is shown over most of the Woy Woy – Umina Peninsula and around the south-eastern foreshores of the investigation area.

A number of soil types can be found in the catchment ranging from Somersby to Norah Head. Chapman and Murphy (1989) and Murphy (1993) report the soil types for the area on two 1:100,000 sheet soil maps. These maps were overlain on the catchment mapping, as presented in Figure 3.5. The predominant soil types in the Brisbane Water catchment are Erina and Watagan, being classed as Erosional and Colluvial soil types respectively. Erina soils suffer from a very high soil erosion hazard, low wet-strength subsoil, localised run-on and seasonal waterlogging of foot-slopes. Watagan soils have mass movement hazard, steep slopes, severe soil erosion hazard and occasional rock outcrops.

3.2.6 Climate

Summers in the Hunter-Central Rivers region are relatively hot, with average maximum January temperatures of 29-32˚C, while winters are fairly mild, with average maximum July temperature of 17-18˚C (NSW Government and CSIRO, 2007). Peak precipitation occurs between January and March, and is highly variable from year to year.

The closest operating Bureau of Meteorology Automatic Weather Station (AWS) to Brisbane Water catchment is the Gosford Narara Research Station. Table 3.1 and Figure 3.6 provide a summary of a range of meteorological parameters.

Table 3.1 Summary Statistics for Gosford Narara Research Station AWS (source Bureau of Meteorology, 2007)

Summary Statistics	Annual
Mean Daily Maximum Temperature (°C)	23.0
Mean Daily Minimum Temperature (°C)	11.0
Mean Rainfall (mm)	1312
Mean 9am wind speed (km/h)	7.9
Mean 3pm wind speed (km/h)	10.4

Appendix B provides further information on climate, including rainfall and evaporation.

3.2.7 Catchment Modelling

Appendix B provides the full details of the Catchment Modelling undertaken for this study (Cardno Lawson Treloar, 2007a). That report includes climate information, water quality data and further information on catchment properties. This information was used to model runoff water quality for Brisbane Water using MUSIC software. This modelling formed critical input to the comprehensive estuary modelling reported in Section 6.

Pollutants considered as part of the catchment modelling were those that are key stressors for aquatic habitat values, namely Total Phosphorous (TP), Total Nitrogen (TN) and Total Suspended Solids (TSS). A summary of the annual average loads of these pollutants from the main catchment areas is provided in Tables 3.2-3.4.

Table 3.2 Annual Loads for Representative Average Rainfall Year (1995)

Location	Area (ha)	Annual Flow (ML/yr)	Runoff Coefficient	Annual Loads (kg/yr)		
				TSS	TP	TN
Upper Narara	2811	8920	0.20	831000	1810	15000
Lower Narara	4565	16800	0.23	1680000	3820	30600
Upper Erina	1926	4370	0.14	246000	541	5420
Lower Erina	3252	9310	0.18	774000	1860	15500
Kincumber Creek	484	2050	0.27	238000	604	4540
Woy Woy Creek	588	1760	0.19	167000	260	2470
Ettalong Lagoon, Umina	780	3350	0.27	348000	981	7080
Coorumbine Creek	361	1450	0.25	160000	329	2710
Total Catchment	**16,466**	**58,500**	**0.22**	**5,660,000**	**14,000**	**109,000**

Table 3.3 Annual Loads for Representative Wet Rainfall Year (1998)

Location	Area (ha)	Annual Flow (ML/yr)	Runoff Coefficient	Annual Loads (kg/yr)		
				TSS	TP	TN
Upper Narara	2811	23500	0.53	1710000	3870	33900
Lower Narara	4565	40500	0.56	3170000	7380	62300
Upper Erina	1926	14700	0.48	801000	1790	18000
Lower Erina	3252	26300	0.51	1810000	4330	38100
Kincumber Creek	484	4440	0.58	432000	1110	8620
Woy Woy Creek	588	4840	0.52	319000	559	5640
Ettalong Lagoon, Umina	780	7190	0.58	601000	1690	12700
Coorumbine Creek	361	3260	0.57	274000	585	5070
Total Catchment	**16466**	**142000**	**0.55**	**10800000**	**27100**	**222000**

Table 3.4 Annual Loads for Representative Dry Rainfall Year (2000)

Location	Area (ha)	Annual Flow (ML/yr)	Runoff Coefficient	Annual Loads (kg/yr)		
				TSS	TP	TN
Upper Narara	2811	4820	0.11	541000	1130	9140
Lower Narara	4565	9370	0.13	1100000	2420	19000
Upper Erina	1926	2100	0.07	157000	301	3010
Lower Erina	3252	4890	0.10	502000	1140	9300
Kincumber Creek	484	1190	0.16	155000	385	2860
Woy Woy Creek	588	938	0.10	108000	160	1450
Ettalong Lagoon, Umina	780	1930	0.16	230000	635	4510
Coorumbine Creek	361	828	0.15	104000	209	1690
Total Catchment	**16466**	**32500**	**0.12**	**3700000**	**8910**	**67600**

Key outcomes of the comprehensive catchment modelling are:

- Narara Creek was shown to deliver a large proportion of the pollutant load entering the Estuary. This is a function of the larger size of its catchment and also the development within its catchment.
- By comparison, Erina Creek is well developed in the lower reaches of the catchment, while the upper catchment is largely rural and forested. As a result, Erina Creek produces approximately half the pollutant loads of Narara Creek.
- The smaller sub-catchments of the Brisbane Water Estuary represent approximately 40% of the total pollutant load that enters the estuary. A number of these sub-catchments comprise highly developed, water-front land. This situation results in a higher proportion of impervious area, and hence a greater runoff and associated pollutant loads.

- In terms of pollutant intensity, Kincumber Creek produces a greater pollutant load per hectare than the other major tributaries of Brisbane Water. Kincumber Creek has a mixture of industrial and residential areas, all of which have high proportions of impervious area. Similarly, Ettalong Creek, with runoff sourced from some of the highly developed Woy Woy area, has high pollutant intensity.
- The pollutant loads from Woy Woy Creek and Upper Erina Creek are low when compared with the rest of the sub-catchments. Both of these catchments have a low proportion of impervious areas, and as a result, a reduction in runoff. Furthermore, Woy Woy Creek has a high proportion of forested area, which naturally has lower stormwater pollutant concentrations.

3.2.8 Relationship with Contemporary Estuary Conditions

Catchment derived freshwater inflows have the potential to affect the Brisbane Water Estuary. Runoff carries eroded sediments, nutrients and pollutants that can result in issues such as:

- Increased siltation
- Eutrophication
- Algal blooms
- Declining water quality
- Sediment quality impacts.

These issues can affect the ecology, human health and amenity of the Brisbane Water Estuary and are discussed in subsequent sections.

The erodible nature of the catchment soils and increasing development pressure within the catchment put the estuary at risk of siltation. As discussed in Section 5, there is some evidence of long-term sedimentation due to catchment derived sediments (for example, Mud Flat Creek, Hardy's Bay). Maintenance of vegetation (particularly riparian) and controls on development are important in controlling sediment loads in urban and rural runoff.

The results of a range of water quality simulations undertaken using seasonally and weather based variations in catchment loads have been conducted and details can be found in Appendix E. The data are presented graphically and demonstrate clearly that:

- Narara and Erina Creeks, followed by Kincumber Creek, provide the greatest nutrient loads and, being located in the most upstream regions of the estuary, these are the areas flushed most slowly.
- Those areas in the upstream reaches of the estuary show less tidal variation in nutrient concentration than those areas close to Broken Bay.

The outcomes of nutrient modelling, supported by results of the water quality monitoring data, indicate that there is potential for ecological impacts, such as algal blooms in Brisbane Water. In addition, other pollutants (for example, faecal coliforms and heavy metals) can have a significant impact on water and sediment quality, resulting in the potential for effects on ecological and human health. Regulation of both point and non-point catchment based sources of pollutants is important in mitigating these problems. This may include management of licensed premises, sewer overflows and runoff.

3.2.9 Implications of Climate Change

In the future, climate change may affect catchment processes with flow-on effects for the Brisbane Water Estuary.

It is understood that the Commonwealth Scientific and Industrial Research Organisation (CSIRO) are currently undertaking modelling of the rainfall climate of eastern Australia incorporating climate change aspects. Preliminary results indicate that more intense rainfall events will occur more frequently for the east coast of Australia (CSIRO, 2007).

Hennessy *et al.* (2004), in their review of extreme weather events under climate change scenarios, indicate the following:

- While both increases and decreases in drought conditions are possible, the tendency is towards increases.
- Marked increases in the intensity and frequency of extreme daily rainfall events.

The changes in catchment processes resulting from the effects of climate change are likely to be significant and should be considered in policy development, planning and natural resource management. The Intergovernmental Panel on Climate Change (IPCC) has released the fourth assessment report on climate change. Change in average annual flows in the order of 30% are projected (IPCC, 2007). There are also predicted effects on coastal erosion from climate change. This includes changes in coastal sediment supply and storm intensity and frequency. On the northern NSW coast, linkages between the Inter-decadal Pacific Oscillation (IPO) and El Niño-Southern Oscillation, and changes in coastal geomorphology, have been demonstrated (IPCC 2007).

The report states that eutrophication is a major water quality problem for Australia and is projected to rise due to the effects of climate change (IPCC, 2007). In addition, toxic algal blooms are to become more prevalent and frequent due to climate change (IPCC, 2007).

The effects of climate change have also been considered specifically for the Hunter-Central Rivers catchment in a report prepared by the NSW Government and the CSIRO (2007). It is thought that average temperatures will be warmer, but projected changes in average rainfall are not clear. However, given projected increases in evaporation, it is anticipated that the catchment will be drier. These conditions are likely to lead to increases in the incidence of heat waves, extreme winds and fire risk (NSW Government and CSIRO, 2007). However, despite the trend towards drier conditions, extreme seasonal rainfall events may potentially increase in frequency and intensity. The NSW Government and CSIRO (2007) also stress that flows in creeks and rivers in the Hunter-Central Rivers catchment are likely to decrease and, in combination with increased temperatures, this may lead to declining water quality. In addition, groundwater quality may be impacted by rising sea levels and seawater infiltration.

Patterns in climate change such as those described for the Hunter-Central Rivers catchment (NSW Government and CSIRO, 2007) will drive changes in the distribution of animal and plant species which, when combined with other extraneous impacts, may lead to declines or extinctions on the local or regional scale.

These implications need to be considered for future management of the Brisbane Water Estuary.

3.3 Summary of Key Findings

The key findings relating to catchment processes are that:

- **Catchment Planning:** The population of Gosford has grown significantly in recent years and this trend is expected to continue in the future. Planning will become increasingly important as the pressure on catchment processes increases, with associated impacts for the Brisbane Water Estuary.
- **Catchment Pollutant Loads:** Catchment-derived runoff and associated pollutants in excess of loads under pre-developed conditions are currently having a negative impact

on some portions of the Estuary, leading to siltation and declining water and sediment quality. Siltation is currently affecting access and amenity in some portions of the Estuary (Section 5.6). Catchment soils are predominately erosional in character and there is a substantial risk for exposed surfaces to contribute to sediment loads. Nutrient inputs can affect ecological processes and may result in eutrophication and/or algal blooms, which can alter community dynamics in the short or long term.

- **Sub-Catchment Prioritisation:** Narara and Erina Creeks are the greatest sources of catchment derived sediments and nutrients, followed by Kincumber Creek. Any catchment based source controls should target these sub-catchments as a priority.
- **Catchment Controls:** Catchment based controls for both point and non-point pollution sources should form an important part of planning and development control. Catchment-based pollution control measures can play an important role in the maintenance of the ecological health of the Estuary, and in providing a safe, high amenity resource for both commercial and recreational use.
- **Sewer Overflows:** Sewer overflows also affect water quality in Brisbane Water Estuary during high intensity rainfall events.
- **Estuary Water Quality:** Water quality is discussed further in Section 6, while Section 4 considers the impact of hydraulic processes on flushing times, which affect the dispersion and dilution of pollutants. The relationship between the estuarine ecology and water quality are discussed further in Section 7.
- **Estuary Sediment Quality:** Sediment quality is also affected by catchment derived pollutant inputs. Similarly, contaminants such as heavy metals are also associated primarily with Narara and Erina Creeks (Section 5.2.1) and have been significantly enriched since European settlement. Contaminants associated with sediments can have impacts on the ecology of the estuary.
- **Climate Change**: Climate change is likely to have a significant impact on rainfall patterns (and therefore catchment inputs) to Brisbane Water, resulting in expected lower average annual rainfall (up to 30%) with consequent effects on environmental flows. Conversely, the intensity of flood type rainfall events is expected to increase resulting in a potential increased risk of creek flooding, but not the Brisbane Water shoreline itself.

4. HYDRAULIC PROCESSES

4.1 Overview

This section presents a summary of the report *Brisbane Water Estuary Processes Study Hydraulic Processes Appendix C* (Cardno Lawson Treloar, 2006b), as provided in full in Appendix C.

4.2 Tidal Behaviour

Tides are caused by the relative motions of the Earth, Moon and Sun and their gravitational attractions. While vertical tidal fluctuations are generated as a result of these forces, the distribution of landmasses, bathymetric variation and the Coriolis Force determine the local tidal characteristics.

The astronomical tide is generally the dominant water level forcing phenomenon in the Estuary. However, the extent to which water level forcing can be attributed to tides depends on local conditions for different sites around the Estuary. For example, tides at Ettalong are attenuated in the order of 15% from the ocean range due to the presence of the sandbar and the estuarine form at this location. Tidal planes for Broken Bay at the entrance to Brisbane Water area are similar to those for Sydney Harbour, but are attenuated further into Brisbane Water.

Tides in Broken Bay are semi-diurnal, that is, there are two high and two low tides each day (Table 4.1). Tables 4.2-4.4 show the tidal planes determined for various sites within the estuary based on information from Manly Hydraulics Laboratory (2004). The locations of the sites listed in these tables are indicated in Figure 4.1.

Table 4.1 Tidal Planes for Broken Bay

Tidal Plane	Water Level	
	m LAT	m AHD
Mean High Water Springs (MHWS)	1.58	0.65
Mean High Water (MHW)	1.45	0.52
Mean High Water Neaps (MHWN)	1.32	0.39
Mean Sea Level (MSL)	0.95	0.02
Mean Low Water Neaps (MLWN)	0.57	-0.36
Mean Low Water Springs (MLWS)	0.32	-0.61

Table 4.2 Comparison of Tidal Planes - Woy Woy Inlet

Tidal Planes	Ocean Site 0 (m AHD)	Brisbane Water				Woy Woy Inlet
		Site 2 (m AHD)	Site 4 (m AHD)	Site 6 (m AHD)	Site 9 (m AHD)	Site 16 (m AHD)
HHW (SS)	0.980	0.796	0.736	0.610	0.623	0.614
MHWS	0.646	0.519	0.471	0.369	0.384	0.376
MHW	0.518	0.435	0.400	0.318	0.331	0.322
MHWN	0.389	0.350	0.329	0.267	0.278	0.269
MSL	0.016	0.077	0.089	0.071	0.076	0.068
MLWN	-0.357	-0.196	-0.150	-0.124	-0.126	-0.133
MLW	-0.485	-0.280	-0.221	-0.175	-0.179	-0.186
MLWS	-0.614	-0.364	-0.292	-0.227	-0.232	-0.240
ISLW	-0.852	-0.562	-0.482	-0.398	-0.403	-0.410

Table 4.3 Comparison of Tidal Planes - Narara Creek

Tidal Planes	Ocean Site 0 (m AHD)	Brisbane Water				Narara Creek	
		Site 2 (m AHD)	Site 4 (m AHD)	Site 6 (m AHD)	Site 9 (m AHD)	Site 20 (m AHD)	Site 22 (m AHD)
HHW (SS)	0.980	0.796	0.736	0.610	0.623	0.621	0.727
MHWS	0.646	0.519	0.471	0.369	0.384	0.385	0.362
MHW	0.518	0.435	0.400	0.318	0.331	0.333	0.325
MHWN	0.389	0.350	0.329	0.267	0.278	0.280	0.288
MSL	0.016	0.077	0.089	0.071	0.076	0.089	0.077
MLWN	-0.357	-0.196	-0.150	-0.124	-0.126	-0.102	-0.133
MLW	-0.485	-0.280	-0.221	-0.175	-0.179	-0.155	-0.171
MLWS	-0.614	-0.364	-0.292	-0.227	-0.232	-0.207	-0.208
ISLW	-0.852	-0.562	-0.482	-0.398	-0.403	-0.375	-0.469

Table 4.4 Comparison of Tidal Planes - Erina Creek

Tidal Planes	Ocean Site 0 (m AHD)	Brisbane Water				Erina Creek	
		Site 2 (m AHD)	Site 4 (m AHD)	Site 6 (m AHD)	Site 9 (m AHD)	Site 10 (m AHD)	Site 18 (m AHD)
HHW (SS)	0.980	0.796	0.736	0.610	0.623	0.628	0.644
MHWS	0.646	0.519	0.471	0.369	0.384	0.391	0.398
MHW	0.518	0.435	0.400	0.318	0.331	0.338	0.343
MHWN	0.389	0.350	0.329	0.267	0.278	0.285	0.288
MSL	0.016	0.077	0.089	0.071	0.076	0.081	0.082
MLWN	-0.357	-0.196	-0.150	-0.124	-0.126	-0.123	-0.125
MLW	-0.485	-0.280	-0.221	-0.175	-0.179	-0.176	-0.180
MLWS	-0.614	-0.364	-0.292	-0.227	-0.232	-0.229	-0.235
ISLW	-0.852	-0.562	-0.482	-0.398	-0.403	-0.398	-0.410

The typical spring tide range reduces from 1.3m in the open sea to about 0.6m near Gosford, with a phase lag of about 2 hours.

The regular rise and fall of the tide level in the sea causes a periodic inflow (flood tide) and outflow (ebb tide) of oceanic water into the Estuary and mixed oceanic and freshwater from the Estuary to the sea, respectively. A consequence of this process is the generation of tidal currents. The volume of sea water that enters the Estuary or leaves the Estuary on flood and ebb tides, respectively, is termed the tidal prism. This parameter varies due to the inequality between tidal ranges and spring/neap tide ranges. The tidal prism is affected by changes in inter-tidal areas, such as areas of reclamation, but not by dredged areas below low tide. The volume of the tidal prism is one parameter in the estuarine flushing process (discussed further in Section 4.3).

Associate Professor Iain Suthers (UNSW) was engaged by GCC to investigate the spatial and temporal distribution of larval and juvenile fish among seagrass beds in Brisbane Water (further details provided in Section 7.3.5). Following discussions between Assoc. Prof. Suthers, Dr Peter Freewater and Cardno Lawson Treloar, tidal volumes that pass eight seagrass sites of interest were determined for ecological and mean shear index (MSI) analyses (Figure 4.2). Comparisons were to be made between the abundances of larval (<20 mm) and juvenile (20-100 mm) fish to investigate the migration of individuals into the estuary with development. It was found that during periods of spring tides, water levels within the estuary are pumped up, slightly, and drain during periods of neap tides. This is a common estuarine characteristic.

The Rip is a major control on tidal range in the upper estuary and the volume of water exchange between Brisbane Water and Broken Bay. This feature is located between Ettalong and Woy Woy. There is a significant reduction in the tidal range upstream of The Rip and a phase change of approximately 1-hour in the tidal signal. Tidal flows over The

Rip sill show rapid spatial acceleration and large eddy structures upstream and downstream of The Rip with a head loss of about 0.15m on spring tides. Mean water level in Brisbane Water is about 0.1m AHD.

Maximum tidal currents through The Rip are in the order of 1.5m/s. This current speed has the potential to present a navigational hazard in this area. Section 9.1 describes boating activity for the Estuary.

Tides and their associated currents are significant drivers for estuarine ecology. For example, numerical model drogue tracking undertaken for this study (Appendix K) indicates that the tidal currents alone are sufficient to transport larvae throughout the Estuary and are the primary determinant of the dispersion of invertebrate larvae. Further discussion of this process can be found in Section 7.3.5.

4.3 Flushing Times

The concept of estuarine flushing refers to the rate of water exchange due to tidal and catchment flows. Quantitative investigations into flushing could be used to describe the likely character of water quality responses of an estuarine system. For example, flushing rates can be used to assess the time it takes for a particular pollutant to disperse in various sections of an estuary. Then, considering flushing times and nutrient loads, biological response rates for a particular estuary can be investigated.

The flushing of Brisbane Water Estuary is a complex process due to the geometry and scale of the water body. A wide range of valid approaches can be adopted to investigate flushing, depending on the focus of a particular investigation. For this study a general description of estuarine flushing throughout Brisbane Water was developed using the concept of 'e-folding' time (that is, the time it takes for an initial concentration of a patch of 'tracer' within the estuary to go from 100 to 37).

Due to the scale and complexity of the system, flushing was investigated using numerical modelling for a number of regions (referred to here as 'bio-regions') of Brisbane Water. Key flushing times are:

- *Gosford – Broadwater:* Ranges from 30 days in the south, up to 42 days near Erina Creek.
- *St Hubert's Island – Paddy's Channel:* The flushing gradient upstream of The Rip is steep, with flushing times at The Rip of approximately 5 days, rising to 25 days in the Paddy's Channel area.
- *Ettalong:* From The Rip towards Ettalong flushing times vary between 2 and 3 days. There is a significant variation between the flushing times in the middle of the channel compared to nearby embayments, such as Hardy's Bay; in the order of 2.75-3 days.
- *Kincumber:* Flushing varies between 2 days in the western area of the main channel to up to 28 days near Kincumber Creek.
- *Fagan's Bay*: Flushing times vary between 2 to 3 days.
- *Woy Woy Bay*: Flushing times are significantly longer compared to Fagan's Bay, varying between 10 and 15 days.

A map showing these bio-regions can be found in Figure 4.3.

Note the apparent inconsistency between the 2 and 3 days flushing time for Fagan's Bay, to the approximate 30 days in the Gosford Broadwater. The outcome is related to the method of definition. If Fagan's Bay and the Gosford Broadwater were considered as one region in terms of flushing time, then Fagan's Bay would have a flushing time greater than 30 days. Hence, the flushing rates are highly dependent on the area of consideration. The bio-region areas have been selected on the basis of providing a general description of the estuarine flushing throughout Brisbane Water.

4.4 Wave Processes

Waves that affect the study area transport energy. This energy can occur in two distinct frequency bands (termed ‘swell’ and ‘sea’, defined commonly by the wavelength and wave period). These are principally related to the generation and propagation of ocean swell (up to Ettalong) and local sea (in waterway areas beyond Ettalong, but may also occur at Ettalong). Large waves generated by an ocean storm are generally categorised as “sea” because wind energy is still being transferred to the ocean, but propagate to Ettalong as swell.

Ocean waves have a dominant direction of wave propagation and directional spread about that direction. Directional spread is reduced by refraction as waves propagate into the shallow, nearshore regions and the wave crests become more parallel with each other and with the seabed contours. Directional spreading causes the sea surface to have a more short-crested (glittery) wave structure in deep water. Waves propagating into shallow water may undergo changes caused by refraction, shoaling, bed friction, wave breaking and, to some extent, diffraction.

Both sea and swell are important in different regions of Brisbane Water Estuary. Local sea affects a greater proportion of the estuary and occurs throughout the estuary, being most important in the wide expanse of the Gosford Broadwater. On a minor-scale, local sea is important in the region north-east of St Hubert’s Island to the Cockle Channel.

Swell wave conditions typically affect coastal areas and locations near Ettalong, seaward of about Schnapper Road (Figure 4.4). Swell energy does not propagate past The Rip. Severe ocean-storm swell is important at Ettalong, especially at high tide when larger waves can propagate over the Ettalong Point shoal.

Wave Modelling

Wave modelling for this study was based on the SWAN wave model, which is integrated into the Delft3D modelling system. SWAN was developed at the Delft Technical University and includes wind input, (local sea cases), combined sea and swell, offshore wave parameters (swell cases), refraction, shoaling, non-linear wave-wave interaction, a full directional spectral description of wave propagation, bed friction, white capping, currents and wave breaking. Full details of the modelling can be found in Appendix C.

Wave modelling using the SWAN model was undertaken by setting the estuary water levels at 1m and 1.6m AHD, these being typical, high storm-tide water levels within the Brisbane Water Estuary (compared with average water level in the estuary reported in Section 4.2 to be approximately 0.1m AHD).

For both the sea and swell cases, extremal wave conditions for selected average recurrence intervals (ARI) were estimated. Figure 4.5 shows the SWAN wave model grid extents adopted for these analyses.

For the 5-years ARI near-shore local sea wave conditions, the largest waves occur in the Broadwater areas that are exposed to the south-easterly to south-westerly fetches. For the 100-years ARI conditions, wave heights generally increased, particularly at exposed Broadwater locations. There are some protected areas where there is little difference between the 5-years ARI and 100-years ARI conditions because wave generation is fetch limited, for example, at Hardy’s Bay (Figures 4.6 and 4.7).

For the 5-years ARI swell wave conditions in the lower portion of Brisbane Water (south of St Hubert’s Island), swell wave heights of up to 1m (H_s) can be expected (for example, near Ettalong). Under 100-years ARI conditions wave heights are generally similar. As outlined above, swell propagation to Ettalong is limited by water depth on the Ettalong Point shoal and, therefore, is dependent on water levels in Broken Bay.

Seabed Shear Forces

In addition to an influence on shoreline circulation within an estuary (wave breaking processes generate a longshore current), waves have impacts on the estuary bed. Shear forces on the bed induced by waves have the ability to mobilise sediment and can have an effect on ecological function, for example, by disturbing benthic organisms and estuarine flora (e.g. seagrass).

Brisbane Water Estuary is comprised of sandy bed regions, as well as areas that are principally formed from silts or muds. The manner in which bed forces induced by waves are normally described depends on the bed material. For example, sandy regions typically have bed forces described by the near-bed current speed, while for muddy areas they are described by the bed shear stress. In both cases the point is to describe the parameter threshold value above which bed movement is initiated.

The numerical wave model was used to create spatial maps to identify regions where bed forces may be significant (Figure 4.8). Key areas are described below:

- Comparing the 1-year and 5-years ARI results for the Broadwater area, significantly larger areas are subject to re-suspension forces for the 5-years ARI case. However, from a biological perspective, common conditions, such as an event which occurs every year, are likely to have a more significant influence on the ecology than conditions which occur less frequently.
- For The Rip region, the 1-year ARI results indicate that the deeper water depths and smaller fetch lengths act to produce lower bed shear forces compared to the Broadwater area. However, shear stresses caused by the tidal flow will be much greater here and have acted to erode the bed to bedrock (or equilibrium) levels.
- In the eastern St Hubert's Island area, high bed forces are concentrated in the intertidal areas and near oyster leases, causing suspension of bed sediments at these locations.
- The 1-year ARI bed forces in the Cockle Channel area were investigated and it was found that, although the fetch lengths in the region are not as large as those in the Broadwater region, the shallow depths contribute to relatively high bed forces during relatively low wave conditions. Therefore, the Cockle Channel area will be susceptible to re-suspension of bed sediments with ecological consequences.
- The Woy Woy Bay area represents a relatively deep branch that is also somewhat protected from high wave conditions and the area exposed to high near-bed forces is much less than in other areas of Brisbane Water. As a result, relatively small areas of Woy Woy Bay are subject to re-suspension of bed sediments.

The re-suspension of bed material can re-introduce nutrients and bacteria into the water, which can affect ecological processes, such as algal dynamics/blooms (see Section 7.2.4). In addition, oysters, which are cultivated throughout the estuary, feed on bacteria and nutrients from the water column (see Section 7.3.4). However, with respect to oysters, it is understood that higher concentrations of nutrients in the water column may lead to stress, thereby resulting in reduced melanin production, which subsequently leaves the oysters vulnerable to disease, specifically QX attack (N. Kelleher, pers. comm., 29/10/07).

Storm Bite

Storm 'bite' represents the loss of sand from the beach face through offshore sediment transport processes caused by the waves and high water levels typically associated with storm conditions. The morphological response of the shoreline due to storm wave conditions and occurs over relatively short periods (hours). This response primarily involves the erosion of the normal sub-aerial (above water level) beach face through offshore transport and deposition near the storm wave break point to form an offshore bar – small in the case of local sea in Brisbane Water Estuary. On open sea coasts the beach face slowly rebuilds as sand in the bar is transported shoreward under swell wave conditions with lower steepness.

Modelling of six sites located around Brisbane Water Estuary was undertaken to investigate likely shoreline recession due to storm bite. These locations are located near Green Point, Koolewong, and Point Clare, with a further three sites located in the vicinity of Booker Bay, (Figure 4.9). These sites are representative of many reaches of shoreline of Brisbane Water and the results are therefore considered transferable in terms of indication of response. Significantly, the sites selected are not exposed to swell waves. This lack of exposure to swell inhibits the beach rebuilding process, likely resulting in permanent shoreline recession.

The results for the storm bite analysis indicate that, for a water level of 1.6m AHD and peak 100-years ARI storm wave, there would typically be 1 to 2m of horizontal shoreline recession at beach berm levels between 1.5 and 2m AHD.

Similar erosion would occur at a lower level should these wave conditions occur at a lower water level. In that case, the overall smaller water depths would lead to lower wave heights and less shoreline recession. However, as previously discussed, these beach areas would recover very slowly (or not at all) because of the lack of swell waves at those sites. Therefore, the potential for long term shoreline recession in Brisbane Water Estuary is significant at some locations and has been one of the drivers of management actions such as seawall construction in Brisbane Water.

4.5 Elevated Water Levels

The dominant water level forcing phenomenon is the astronomical tide (Section 4.2) which peaks during ‘spring’ tides. However, the highest water levels ever recorded in the estuary occurred during the severe ocean storm of May 1974. Water levels may also be higher from time to time in certain locations, such as at creek confluence points, particularly in relatively enclosed bay areas, due to a severe creek flood. Design flood assessments associated with catchment runoff into the estuary are the subject of a separate and on-going study (Cardno Lawson Treloar, 2007e). Local wind set-up may also cause higher water levels. Water levels associated with oceanic and estuarine processes are the focus of this study.

Water level investigations were undertaken for storm and normal conditions, and included:

- Hindcast investigations of the May 1974 storm event,
- Simulation of events with selected return periods (i.e. 10 and 20-years ARI events), and
- Analyses of recorded water level data.

The above investigations highlighted differences between the water levels experienced in enclosed water bodies and the open coast. Simulation of the May 1974 event and actual water level data available for the May 1974 storm in Brisbane Water have demonstrated that water levels at Ettalong and further upstream in the Brisbane Water Estuary may exceed the water level observed at Fort Denison (Sydney Harbour) during the same very severe event. Nevertheless, more commonly, water levels in Brisbane Water are lower than those in Broken Bay and at Fort Denison.

Recorded water level data from a number of sites within Brisbane Water Estuary indicate that the normal tidal range is lower than in other similar enclosed water bodies (such as Sydney Harbour at Middle Harbour and Fort Denison). This causes an apparent discontinuity between the normal and extreme water levels distributions within Brisbane Water. Continued water level data collection at the Koolewong site (which has water level records up to 10 years old) would allow further refinement of the design water level distribution using measured data in the future (for example, in 10 or 20 years time). Inside Brisbane Water Estuary the return periods for water levels associated with the May 1974 storm are probably much longer than those in Sydney Harbour because the combined influences of storm duration, wave setup and wind set-up on water level are more significant at Brisbane Water.

Table 4.5 provides indicative, rare water level information for Brisbane Water.

Table 4.5 Indicative Peak Water Levels Based on DELFT3D Storm Simulations (after Cardno Lawson Treloar, 2007b)

	Ettalong	Woy Woy	Koolewong	Gosford
10-years ARI	1.41	1.37	1.43	1.47
20-years ARI	1.47	1.43	1.51	1.55
May 1974	1.62	1.64	1.75	1.80

4.6 Impacts of Flood Mitigation Works

It is understood that there are no major flood mitigation works located in the Brisbane Water Estuary catchment. Generally there are only minor flood mitigation works along the shoreline of the estuary, such as the one-way flood gate at Shelly Beach Road, Empire Bay. They have little or no effect on the overall water levels in the estuary, but do reduce local flooding. However, it is anticipated that some mitigation works will be proposed as part of a series of flood management plans and studies that are currently being undertaken for a number of estuary tributaries.

Foreshore flooding is currently being assessed for Brisbane Water by Cardno Lawson Treloar (on behalf of GCC) for extreme ocean water levels and extreme runoff inputs from the catchment. A number of flood studies are also currently being conducted for individual tributaries. These include flood studies for Turo Creek and Mud Flat Creek (by Cardno Lawson Treloar).

The key ecological issue is the potential for flood mitigation works to impede fish passage. These issues are discussed further in Section 7.3.3.

4.7 Summary of Key Findings

Key findings of the detailed hydraulic processes assessment (Cardno Lawson Treloar, 2007b) include:

- **Tidal Character:** Tides contribute significantly to estuarine flushing and day to day water levels. However, attenuation of tide range occurs up-estuary, with 15% of tidal range attenuated at Ettalong. Therefore, wave parameters such as wave set-up are more important controls on peak water levels in the region of Ettalong. Similarly, The Rip is a control on tidal range, with flushing times generally being longer for areas upstream of The Rip. For these reasons, freshwater inputs associated with very intense rainfall in the catchment can be a significant influence on water level in the upper estuary (e.g. at Fagan's Bay). Flood mitigation works have the potential to impact on the hydraulics and hydrology of Brisbane Water Estuary, but on a very localised basis.
- **Tidal Character and Ecology:** The attenuation of tidal flows influences the ecology of the Brisbane Water Estuary. This relates not only to the salinity range within the Estuary, but also the dispersion of larvae. Modelling suggests that advection and

dispersion is sufficient to transport larvae throughout the estuary, although some areas may have more limited connectivity than others. This has important implications for ecological management and conservation. Other studies (discussed in Section 7) suggest that larval dispersal may occur in a staged process, whereby a series of locations are important for connectivity between the ocean and the upper estuary.

- **Tidal Character and Navigation:** Being subject to high velocity tidal flows, The Rip area is generally well flushed/well mixed. Ocean swell, tidal currents, eddy formation and mobile sand shoals represent a significant hazard to boating activities and navigation in the region of The Rip and Ettalong. Ocean waves can cause dangerous conditions at Ettalong, particularly over the Ettalong Shoals.
- **Flushing:** Flushing of the estuary is generally complex, being of relatively short duration at locations strongly influenced by tides (such as The Rip and Ettalong), and longer in areas further upstream and in embayments. Flushing is the primary control of water quality through the dispersion and dilution of pollutants and promotion of mixing. The Gosford Broadwater has a flushing time of up to 30 days. As outlined in Section 3.2.7, Narara Creek, which is a tributary of the Broadwater, is a major source of nutrients and suspended solids. Therefore, water quality may be compromised in this location due to the coincidence of elevated catchment loads and relatively long flushing times. Water quality is discussed further in Section 6.
- **Wave Character:** There is little difference in wave heights between the 5-years ARI and 100-years ARI storm events due to limited water depths over the Ettalong Shoals. Further up the Estuary from The Rip, ocean swell is attenuated and local sea is the dominant wave force. This is evident in the larger expanses of open water, such as the Gosford Broadwater. Similarly, a comparison of 5-years and 100-years ARI wave conditions shows that there is not a large increase in local sea wave heights, although in this case this is due to limited fetch.
- **Wave Character and Ecology:** Wave events can influence ecological processes. In terms of the estuarine ecology, more frequently occurring wave events will have a more significant influence on the community structure and biodiversity of the estuary. Due to limits on wave heights during extreme events, storm disturbance is likely to be relatively infrequent resulting in a generally stable community structure. For this reason, human induced ecological disturbance has the potential to play an important role in the community structure and biodiversity of the estuarine ecology. These processes are described in Section 10.2.1.
- **Wave Character and Shoreline Processes:** Wave events also play an important part in the process of shoreline recession. In general, the smaller wave heights in the upper estuary lead to lower levels of erosion from storm 'bite'. However, recovery from storm bite is inhibited by the lack of swell, resulting in permanent shoreline recession. This process may be exacerbated by uncontrolled shoreline development, as discussed in Section 5.5. Shoreline recession, particularly under climate change scenarios, should form an important consideration in future planning for the Brisbane Water Estuary.
- **Wave Character and Bed Shear:** Bed-shear forces associated with waves passing over the bed can lead to the re-suspension of bed sediments. Under certain conditions this process results in the re-suspension of sediments over large areas of The Broadwater and Cockle Channel. In more sheltered areas such as Woy Woy Bay, only small areas of the bed are prone to re-suspension forces. Around St Hubert's Island, the high levels of sediment re-suspension in intertidal areas and around oyster leases has implications for the management of aquaculture operations (Section 7.3.4), including the potential for increased vulnerability to disease. Sediment re-suspension may result in either positive or negative impacts on oyster growth. Where this process leads to increased nutrient levels in the water column, algal blooms may occur. These algal blooms have the potential to impact on the safety of oysters for human consumption. However, it is understood that shellfish poisoning has not been an issue for the Brisbane Water Estuary. The plankton dynamics of the estuary are discussed further in Section 7.2.4.
- **Climate Change:** It is generally accepted amongst the scientific community that global warming of the Earth's atmosphere will lead to a rise in mean sea level due to the

Greenhouse effect. However, predictions of the extent of sea level rise vary considerably. The IPCC 2007 predictions for sea level rise are between 18 and 59cm by 2100. This will have associated effects on day to day tidal levels and ranges of up to 0.59m.

5. ESTUARY MORPHOLOGY AND SILTATION

5.1 Overview

This section of the report provides a discussion of various facets of the morphological characteristics and siltation processes typifying Brisbane Water Estuary. Much of the information presented in this Section is a summary of a report prepared by Cardno Lawson Treloar (2007c), which is provided in full in Appendix D. Section 5.3 presents a summary of University of Sydney Environmental Geology Group (2007), which is provided in full in Appendix F, and Section 5.4 presents a summary of GHD LongMac (2004) presented in Appendix G.

5.2 Bed Sediment Characteristics

Estuaries typically have a range of sedimentary environments that have different characteristics. The sedimentary environment is inextricably linked with the physical, chemical and ecological features of an estuary: for example, stands of mangrove forest that are capable of thriving in areas affected by inundation and variable salinity where fine sediments tend to deposit (e.g. creek mouths). However, whilst mangroves are opportunistic, the sediment loads and other conditions must be appropriate to support the establishment of mangrove forests (Section 7.2.2). These environments occur in the intertidal zone and are typically associated with creek drainage networks. Mangroves accumulate sediments due to trapping and baffling by vegetation. These sediments are generally silts and clays high in adsorbed organic material. Mangroves provide shoreline protection, and support diverse and productive communities of flora and fauna. The sedimentary environment plays an important role in nutrient cycling, with several species that feed off organic matter within the sediments. It is unclear as to whether mangroves will establish where sediments are already accumulating, or if the accumulation of fine sediments is due to the presence of mangroves. It is likely to be a combination of both factors.

Central basins, such as The Broadwater, are quite different sedimentary environments. These deeper, lower energy environments typically comprise organic rich, sub-tidal mud and sandy mud. The shallower margins of the central basin will often feature coarser sand material, which is the result of action from wind waves and tidal flux. In contrast, channels are more high energy environments in terms of either tidal movement (e.g. The Rip) or fluvial flow. Salinity, water quality and sediment types are variable in these areas. However, coarser grained materials are common on the channel floor. These are typically non-depositional environments and are sometimes erosional. For example, The Rip is known to be subject to scouring due to the constriction of tidal flows at this location. Channels are important environments for a wide range of marine and estuarine organisms and provide shelter and access for larger predators. The dynamic nature of bed sediments within channels will have a significant impact on the benthic ecology.

There are a number of models that define the different types of sediments found in estuaries, but they effectively fall into two categories: fluvial sediments and marine sediments. Fluvial sediments are derived from the catchment and are delivered to the estuary via freshwater inflows from tributary creeks or rivers. Marine sediments are generally coarser, sandy sediments that may be introduced to the estuary via tidal inflows or waves, and may have been deposited in an earlier geological period. Both fluvial and marine sediments have different characteristics and will play a role in shaping an estuary's characteristics.

5.2.1 Fluvial Sediments

The movement and re-suspension of sediment particles effectively depends upon the particle size and the force exerted on that particle by moving water. The speed of creek flows slows down as they flow into the estuary. As this process occurs, the sediment transport capacity decreases and sediments will begin to fall out of suspension. Larger particles, such as organic matter (e.g. leaves or twigs), pebbles, rocks or even boulders, may also be washed down tributaries to the estuary as bed load. Due to their size, larger particles will tend to fall out of suspension and settle faster than finer sedimentary material and will tend to settle on the bed very close to the tributary mouth.

In the case of fine silts that may settle near the mouths of creek entrances, cohesive forces are also important. Where freshwater inflows carrying sediment particles are mixed with more saline estuarine water, fine mud-sized particles (<63µm) will tend to fall out of suspension and settle due to electrolytic flocculation or organic flocculation (Woodroffe, 2002), whereby fine particles are attracted to each and bind together to form larger sediment particles.

Once settled, fine sedimentary or mud particles will remain in a stable state on the estuary bed until they are disturbed by forces that exceed those needed to initiate sediment motion. These forces are caused by tidal and wind driven currents, as well as by wave action. The extent to which these forces occur will vary under different conditions and for different locations within the Brisbane Water Estuary. Even quite small wind waves that break at the shoreline can cause sediment re-suspension (Section 5.3). Once re-suspended, and depending on flow patterns, fine particles may be transported throughout the estuary. These re-suspended particles will tend to settle in more sheltered, deeper parts of the estuary, typically the central basin (e.g. the Broadwater). These central basin areas are the main sink for fluvial sediments as, once settled, it is likely that wave action and mixing at these locations will be insufficient to re-suspend fine particles in deeper water.

Sediment Sampling

Ray *et al.* (1977) undertook a geological survey of parts of Brisbane Water Estuary. They found that, upstream of The Rip, fluvial sediments were more prevalent. Samples collected immediately upstream of The Rip contained mud with a high organic content (Ray *et al*., 1977). Sand-sized sediments of terrestrial origin have not been found in Brisbane Water.

Sediment cores collected from the Woy Woy foreshore were classified as sand, but had a high proportion of fine fluvial material or mud (<63µm) in the range of ~9-18% (Cardno Lawson Treloar, 2007c), that provided significant cohesive character. Sediments were also found to contain shells and plant and wood fragments. The proportion of fine material found at other foreshore locations (GHD LongMac, 2004), including Hardy's Bay and Pretty Beach (~9-17% silt), is consistent with these results. The two foreshore sediment samples collected in Hardy's Bay by GHD LongMac (2004) indicate that there is a slightly higher proportion of fine material in sediments located near Mudflat Creek (17% silt), compared to another sample collected in another Hardy's Bay foreshore location (9% silt). However, these results should be interpreted with caution as the sediment analysis is based on a single sample from each site and sediment characteristics may vary on small spatial scales. In any case, the proportion of fine, silty sediments recorded from Hardy's Bay appears to be consistent with other foreshore locations within Brisbane Water.

Lawson and Treloar (1996) also report on sediment samples from Brisbane Water centre-channel shoals near Ettalong. There was virtually no silt in these samples (<2%).

In addition to the sample at Hardy's Bay, GHD LongMac (2004) collected further samples at five other 'foreshore' sites in Brisbane Water Estuary:

- Woy Woy Inlet,

- To the south of Noonan Point,
- Near the mouth of Erina Creek,
- Off Yattalunga, and
- St Hubert's Island.

These samples were not subjected to grain size analysis (their prime purpose was the investigation of acid sulfate soil potential, described in Section 5.4). However, the descriptions provided indicate that foreshore samples were generally sandy with some amount of finer silts and organic matter (root fibres). A foreshore sample collected from the north-eastern side of St Hubert's Island consisted of coarser sand than other foreshore sediment samples. Note that this is not a naturally formed beach.

GHD LongMac (2004) also took a further nine sediment samples from sites located in deeper water (<2m depth):

- Woy Woy Inlet,
- Noonan Point,
- Point Clare,
- Off Yattalunga,
- St Hubert's Island,
- Hardy's Bay,
- Booker Bay, and
- Blackwall.

Similarly, these sediments were not subject to grain size analyses. However, descriptions are provided. These samples were generally described as being predominantly comprised of fine material such as clay or silt, with some sandy material (GHD LongMac, 2004). The samples collected off Noonan Point and Point Clare were described as having higher proportions of sand.

These results support the earlier statement that finer particles tend to be re-suspended and transported to deeper, calmer waters, except in sheltered areas such as the entrance to Mudflat Creek. Further sediment cores and analyses would need to be collected to pinpoint locations at which siltation is occurring and whether the rates of siltation are higher than prior to European settlement. The selection of these locations would be best informed by the results of the detailed assessments reported in Appendix G.

Environmental Effects Associated with Sedimentation

Reliable estimates of the average annual influx of catchment sediments to Brisbane Water Estuary under pre-European settlement catchment conditions are not available. However, it can reasonably be assumed that sediment influx was substantially lower for the majority of the catchment prior to European settlement in the area. European settlement of the area does not appear to have taken off until the 1830's (Section 8.2) and residential development in particular did not appear to increase until the latter half of the 20th Century (Section 3.2.2).

While sedimentation is a natural process, following European settlement, catchment clearance and disturbance has most likely increased sediment loads in creeks discharging into estuaries, considerably increasing the rate at which they are infilling (Brooke, 2002). A literature review by Brooke (2002) shows that contemporary rates of sedimentation can be at least double the rate observed in the late Holocene, prior to European settlement.

The deposition of relatively large volumes of catchment-derived sediment may lead to a range of long-term impacts, including:

- Increases in turbidity (frequency and concentration) as fine sediments deposited in shallow areas are continually remobilised by wave action.
- Formation of mud flats where there may have formerly been relatively clean sand.
- Increases in the amount of sediment-bound nutrients (e.g. TN, TP) and trace elements (e.g. Fe, Zn, Pb) entering estuaries from the catchment.

These impacts can result in a range of ecological characteristics, such as mangrove propagation, seagrass die-back, eutrophication and algal blooms. However, it should be emphasised that estuaries are dynamic environments and that the physical, chemical and ecological properties of a particular estuary will change over time. The key management issue is that the rate and direction of change is likely to have been altered or exacerbated by human activities.

5.2.2 Marine Sediments and Rock

Historically, during periods of sea level rise, large deposits of marine sand have been mobilised and transported landward across the inner continental shelf (Roy *et al.,* 1980; Roy, 1984). These deposits of marine sand are apparent today as two distinct barriers, the outer and inner barriers, and have been influential in the formation of extensive estuarine channels between the barriers. Therefore, marine sands have historically exerted an influence on the evolution of estuaries in NSW.

Marine sediments can enter coastal estuaries and embayments due to hydrological processes such as tidal currents or wave action. The movement of marine sand can impact on:

- Navigation,
- Coastal protection, through the dissipation of wave energy, and
- Recreational amenity, through the loss or growth of beaches.

Beach and tidal delta sands have been identified in Brisbane Water Estuary as far up-estuary as Pelican Island. The deltaic formation to the north of Pelican Island is thought to represent the limit of infilling of Brisbane Water by marine sand (Ray *et al.,* 1977). This sediment deposition is the result of infilling with marine sand during the Holocene Transgression.

It is understood that strong tidal currents in the region of The Rip have scoured out the sediment down to the bedrock (refer to Section 4.4). The Rip represents a rock barrier (sill) of approximately 4m depth and constricted channel width. Scour holes up to 35m deep have formed on either side of the rock outcrop (Ray *et al.,* 1977). These geological features create strong tidal flows through The Rip, with the effect of moving sand away from The Rip towards Ettalong on ebb tide and away from The Rip towards Pelican Island on the flood tide. However, it is thought that there is no movement of sand-sized materials across The Rip (Ray *et al.,* 1977).

Modelling conducted as part of the current study (Appendix D) suggests that there is a slight net sand export from Brisbane Water Estuary in low wave conditions. Tidal currents promote the export of sand from the Ettalong Shoals out to Broken Bay. However, this process is counteracted to some extent by the wave climate at the entrance to Brisbane Water Estuary. Catchment flows also affect net sediment movement near Ettalong. Propagation of the Ettalong Shoals has led to recent constriction of the navigation channel on the eastern side of the entrance. Water depths over the Ettalong Shoals are currently as shallow as 1-2m at low tide.

Apart from the interpretation of recent aerial photography, no detailed information is available on the extent of rock and marine sediments within Brisbane Water Estuary. Data collected as part of the National Land and Water Resources Audit (2001;

http://www.nlwra.gov.au/) indicates that Brisbane Water Estuary has 0.01km^2 of rocky reef habitat and no bedrock.

5.2.3 Morphological Modelling

A catchment model (Section 3.2.7, Appendix B) was used to determine annual sediment loads for inclusion in the calibrated hydrodynamic model of Brisbane Water Estuary (Appendix C). These simulations were used to describe the estimated present-day siltation rates at a number of selected sites such as Mudflat Creek and Fagan's Bay (Narara Creek).

To establish the model, the Brisbane Water catchment was divided into a number of sub-catchments according to topography and land-use. These details were used to create the model which is a 'node-link' style arrangement where pollutants are generated in each node (catchment) and translated down each link (representing a creek or river) to flow to Brisbane Water (the receiving water). The steep slope characteristics of some catchments were incorporated in the model in order to develop realistic catchment loads that were consistent with deposition volumes estimated by consideration of historical aerial photographs. The model was also checked against field monitoring data to ensure the results are representative of the catchment behaviour.

Model simulations were undertaken on a continuous basis for dry, average and wet rainfall years. Based on an average year of rainfall (described in Section 3.2.7), the total annual influx of suspended solids is approximately 5.7 million kg.

These catchment loads are then re-distributed throughout the estuary by ambient currents (tide, wave and freshwater flow currents).

Historically, the main creeks that flow to Brisbane Water have carried silt and mud, as well as some larger sand particles and organic matter, to the waterway mainly during periods of high rainfall. Examples of other types of pollutants and debris similar to sediment size include excess road-base and glass. The geological characteristics of the catchment are discussed in Section 3.2.5 and the catchment soil landscape is shown in Figure 3.5. Where a creek (or perhaps now a drain in some cases where the creek has been modified) discharges to a relatively 'energetic' area of the estuary, such as near Beach Street at Ettalong, the higher waves or current speeds 'winnow-out' the finer particles, which are then transported to more tranquil areas of the estuary leaving the shoreline in a more sandy state. A series of sediment cores collected near Ettalong Beach, Wagstaffe Point, Rocky Point and Booker Bay were all classed as sand with little or no fine material (Cardno Lawson Treloar, 2007c). At other sites such as Blackwall Road, Woy Woy, wave conditions are of much lower energy and fine silts accumulate in the region.

Morphological modelling was undertaken using the calibrated overall Delft3D modelling system of Brisbane Water (Section 4.3) and applying the integrated sediment transport and morphological modules. Where necessary, wave action was also included. Both mud/silt (cohesive) and sand (non-cohesive) sediments were addressed, as appropriate for each selected site. In the absence of comprehensive, successive comparative bathymetric surveys, it is not possible to calibrate the morphological processes (it is important to note that key driving processes such as hydrodynamics and dispersion processes were calibrated, see Appendix D). Nevertheless, the morphological model has been verified successfully at other sites - Avoca Lagoon and Lake Illawarra Entrance (for sand dominated systems) and Cairns and Bowen (for silt dominated systems).

The purpose of the modelling undertaken for this processes study has been to provide improved understanding of these morphological processes. Key areas of concern have been investigated, on relatively fine scales, to evaluate important processes that affect both public and private property within Brisbane Water. These key areas have been discussed below in Section 5.6.

The nature of Brisbane Water sediments and the forcing environmental processes that move them vary widely from silica sand at Ettalong in a relatively exposed wave environment, to catchment muds at Mudflat Creek in the north-eastern corner of Hardy's Bay. The latter site is sheltered from swell and generally also from local sea, but is affected by catchment runoff. On the other hand, sandy beaches are found also at Green Point in an area exposed to local sea, but free from swell and local catchment flows.

In other areas, such as The Rip, wave action is not particularly important, but very strong tidal currents that flow through this rocky constriction have scoured the seabed in the narrowest areas and formed nearby lateral shoals in more shallow areas and to the sides of the main flow-paths. The centre channel shoals at Ettalong are changing constantly, requiring NSW Maritime to shift the marker buoys defining the navigable waterway from Broken Bay into Brisbane Water on a regular basis.

Sediments ultimately settle in a more tranquil environment, typically in deeper areas, but notably not in The Rip area. Therefore, apart from areas protected from waves, such as inlets, long-term retention of silts in shallow areas is considered unlikely.

A number of figures are provided in CLT (2007b; Appendix C) showing the accumulation of fine sediments in different channels around the estuary, for 'wet' and 'dry' years (i.e. above/below average annual rainfall).

5.3 Bed Sediment Quality

Sediment quality can be used as a measure of ecosystem health, although the effects depend on the likely degree of disturbance or bioturbation. An important aspect of bed sediment quality relates to the degree of contamination associated with adsorbed pollutants, principally when there are a high proportion of silt and clay particles within the sediments (particle sizes less than 63µm). Sediments are important as both sources and sinks of dissolved contaminants (ANZECC, 2000). As well as interacting with water quality, bed sediments represent a potential source of bioavailable contaminants, principally nutrients, including nitrogen, phosphorous and carbon, through the benthic food chain.

The types of pollutants observed in benthic sediments include:

- Heavy metals
- Polycyclic aromatic hydrocarbons (PAHs) associated with heavy industry/combustion
- Pesticides, herbicides and fungicides
- Phenols used in chemical synthesis
- Polychlorinated biphenyls (PCBs).

Sediment chemistry can also be assessed to determine the history of ecosystem health and the likely sources of the contaminants. Analyses of this type are assisted by an understanding of the catchment load characteristics and the hydraulic transport pathways from the pollutant entry points to accumulated sediment bodies (e.g. Fagan's Bay, which is affected by contaminant loads delivered by Narara Creek). Sediments record and time-integrate the environmental status of an aquatic ecosystem (USEGG, 2007). These types of pollutants typically flocculate out of the water column, becoming attached to fine sediment particles, and are deposited on the bed of the waterway, mainly in more tranquil areas (as discussed in Section 5.2.1). Due to the high tidal flows through The Rip, little, if any, contaminated fine silt occurs in this location. Due to their chemical characteristics these types of pollutants tend to be persistent in the environment because they are typically quite stable.

Concentration gradients in surficial contaminated sediments may be used to identify a source of pollution, such as a particular discharge location or tributary. Conversely, particular locations may be pollutant sinks, due to their physical and biogeochemical characteristics, as well as their estuarine hydraulic characteristics. Alternatively, sediment cores may be taken to investigate the history of contamination in a waterway, or even to determine the pre-anthropogenic or background concentrations of a contaminant. This is important where contaminant sources are naturally occurring in the environment. For example, PAHs are associated with combustion and so a historical bushfire or volcanic eruption has the potential to introduce a large amount of PAHs into the environment.

Sediment chemistry has important implications for estuary management. For example, where dredging is planned, the degree of sedimentary contamination will determine the method by which dredge spoils are managed. Further, sediment quality guidelines such as those provided in ANZECC (2000) can be used as a starting point in the identification of contaminated areas requiring remediation or, alternatively, uncontaminated areas that require protection. Management of land use practices in the catchment, including the implementation of ameliorative measures, may also be considered as part of an overall management strategy.

Potential sedimentary contamination effects may be assessed against a range of guidelines, depending upon the objectives of the assessment. Where the aim is to identify potential impacts on aquatic ecological health, Interim Sediment Quality Guidelines (ISQG) developed by (Long *et al*., 1995), as advised by ANZECC (2000), are commonly used in Australia. Two guideline values are provided for each analyte:

- ISQG-Low (effects range low)
- ISQG-High (effects range high).

Where, for example, dredged sediments are being assessed for marine disposal, impacts on the receiving environment require assessment and this includes bioavailability due to re-suspension of sediments. In this case, guidelines provided in the *National Ocean Disposal Guidelines for Dredged Material* (Environment Australia, 2002) should be applied. Where ocean disposal is not possible for whatever reason, dredge material for land based disposal must be assessed against the *Environmental Guidelines: Assessment, Classification and Management of Liquid and Non-Liquid Wastes* (EPA, 1999).

As part of the Brisbane Water Estuary Processes Study, the University of Sydney Environmental Geology Group (USEGG) carried out an assessment of the distribution of heavy metals and sediment quality for the Brisbane Water Estuary (USEGG, 2007). The aims of their study were to determine the source and dispersion of heavy metals in Brisbane Water Estuary, to estimate the magnitude of anthropogenic change that has taken place in the waterway and catchment and to assess the quality of sediments in the estuary (USEGG, 2007). The key findings are summarised herein and the full report can be found in Appendix F.

The USEGG (2007) study involved the collection of a series of 40 estuarine sediment samples taken from Brisbane Water, 30 fluvial samples taken from tributaries and 3 estuarine cores in order to provide an assessment of the sedimentary characteristics of the Brisbane Water Estuary (see Figure 5.1). The heavy metals analysed were:

- Cadmium (Cd),
- Cobalt (Co),
- Chromium (Cr),
- Copper (Cu),
- Manganese (Mn),
- Nickel (Ni),
- Lead (Pb), and

- Zinc (Zn).

Of the toxic heavy metals listed above, a subset was identified as having a significant negative impact on the sediment quality of Brisbane Water Estuary. The metals Cu, Pb and Zn were present in higher (relative) concentrations and were more readily bio-available than the other heavy metals analysed (USEGG, 2007). Heavy metal distributions indicate that the main source of heavy metals found in estuarine sediments is Narara Creek, supplying approximately 70% of the total Cu, Pb and Zn delivered to the estuary (USEGG, 2007). This creek drains the moderately industrialised catchment in which a portion of the city of Gosford is located. A further 20% is derived from Erina Creek, suggesting that this tributary is also a contributor of heavy metals to the estuary, while Kincumber and Woy Woy Creeks essentially represent the sources of the remaining 10% of the loads of Cu, Pb and Zn delivered to the estuary (USEGG, 2007). These results were supported by enrichment analyses based on core samples.

High concentrations of heavy metals, particularly for Pb and Zn, in Narara and Erina Creeks, combined with large catchment areas and high runoff volumes (discussed in Section 3.2.7), led to the identification of these two catchments as playing a major role in the contribution of heavy metals to Brisbane Water Estuary (USEGG, 2007). Linking land use in the catchments, it was determined that residential areas were the major contributor of heavy metal loadings for Narara Creek, whereas agricultural land uses were more important in the Erina Creek catchment (USEGG, 2007). The major source of Cu, Pb and Zn in residential areas is motor vehicles and roads (e.g. Birch and Taylor, 1999). Figures 5.2 to 5.4 show concentrations of Cu, Pb and Zn normalised to catchment land use.

Enrichment levels were also found to support the observation that the northern reaches of the Brisbane Water Estuary are subjected to a higher degree of anthropogenic influence than the southern reaches (Figures 5.5 - 5.7). Higher heavy metal concentrations were recorded in both surficial sediment samples and cores taken from this general area (USEGG, 2007). However, it is noted that determination of background, pre-anthropogenic concentrations indicates that all areas of Brisbane Water Estuary have been affected by European settlement (USEGG, 2007).

Cores indicate that, historically, heavy metal enrichment began much earlier in the north of the estuary, when compared to Kincumber to the south. This is supported by observations made with reference to historical aerial photographs of the catchment (Section 3.2.2). Furthermore, the Kincumber area remained pristine for longer than the northern locations at which other cores were taken (USEGG, 2007). However, as noted by USEGG (2007), the most important finding is that concentrations have risen rapidly and continue to do so in the present day. This suggests the need for ameliorative measures in the catchments, focussing as a priority on the Narara and Erina Creek catchments.

In terms of ecological risk, it was determined that the risk of adverse effects on aquatic biota was minor, with the six estuarine samples that exceeded the ISQG – Low guideline being located in the north of the estuary (Figure 5.8; USEGG, 2007). The bio-availability of Cu, Pb and Zn was found to be high at ~40% for all three metals, although the relatively low overall concentrations of these metals in sediments led to the determination that risk of adverse effects on biota across the estuary was low.

However, studies conducted elsewhere have found that even at low concentrations, heavy metal pollution can cause environmental impacts. Previous studies, undertaken by Freewater (2004) in Wallis Lake, on the mid-north coast of NSW, have demonstrated that even low concentrations of sedimentary Cu contamination were influencing macrobenthic community assemblages. The more sensitive invertebrates, such as amphipods, were typically replaced with a higher abundance of more robust invertebrates, such as Capatellid worms. Similar patterns can be seen in Brisbane Water. Areas with higher concentrations of heavy metals, such as the Gosford area, were areas of lower biodiversity (see also Section 7.3.1; Chapter 10).

The findings of USEGG (2007) indicate that the sediment quality objectives should focus on reducing the loadings of pollutants entering the Brisbane Water Estuary. Therefore, any directed management action should focus on reducing catchment derived pollutant loads. The difficulty is that the major sources of heavy metals, being residential and agricultural areas, are highly diffuse sources. Nonetheless, catchment-based controls are still capable of effectively reducing pollutant loads in stormwater runoff.

5.4 Acid Sulfate Soils

Acid Sulfate Soils are widespread among low lying coastal areas of NSW, in estuarine floodplains and coastal lowlands. These are naturally occurring sediments and soils containing iron sulfides (mostly pyrite). Where these are exposed to the air by drainage of overlying water or excavation, the iron sulfides oxidise and form sulfuric acid.

Actual Acid Sulfate Soils (AASS) are soils that contain highly acidic soil layers, the oxidation of which produces acidity in excess of the sediment's capacity to neutralise the acidity resulting in soils of pH ≤ 4.0 (DECC, 2007). Potential Acid Sulfate Soils (PASS) contain sulfidic material that has not yet been exposed to air and oxidised. In their un-oxidised state the pH > 4.0 (DECC, 2007).

Where ASS are oxidised, the resultant acidity may mobilise into solution toxic quantities of iron and aluminium. A part of this process is the formation of iron flocs that affect water quality and can coat streambanks, benthic organisms and the gills of fish (DECC, 2007). Deoxygenation of water also occurs and the mobilisation of other compounds from the soil (such as silica) can lead to algal blooms. Buffering of acids will quickly strip calcium carbonate ($CaCO_3$) from the water and may also have impacts on calcareous organisms such as shellfish (DECC, 2007). Due to its lower buffering capacity, freshwater (pH ~6.5 – 7.7) is particularly affected by acid in comparison to ocean waters, which have a much higher buffering capacity (pH ~8.2). Other impacts include:

- Damage to infrastructure such as bridges and levees,
- The release of heavy metals from contaminated soils,
- Vegetation kills,
- Weed invasion by acid tolerant plants,
- Fish kills,
- Outbreaks of fish disease, and
- Decreased productivity of agricultural land.

Exposure of PASS can result in significant impacts on recreational fishing, commercial fishing, oyster farming and agricultural activities.

GHD LongMac (2004) undertook ASS investigations to assess the presence or otherwise of PASS conditions at a discrete number of sites in Brisbane Water Estuary. The full ASS Investigation report can be found in Appendix G.

Soil samples were taken to assess the ASS risk from 8 foreshore locations and 9 estuary bed locations located around the Brisbane Water Estuary (Figure 5.9; GHD LongMac, 2004). Foreshore and estuary samples were paired, except at St Hubert's Island, at which no foreshore sample was taken. The samples were tested to determine if they were PASS or AASS.

The findings of GHD LongMac's (2004) report were that PASS conditions were found for all estuarine bed locations at which samples were collected. However, PASS conditions did not occur for all foreshore samples. In addition, samples containing greater proportions of silt and clay were found to be more likely to be PASS than the more sandy samples (GHD LongMac, 2004).

These tests confirmed the high probability of PASS conditions occurring in the estuarine sediments. It was recommended that any planned work in these areas, which may expose or drain these sediments, should include a sampling plan to confirm whether or not sediments are PASS, and that this plan should be developed in accordance with ASSMAC guidelines (Stone *et al.,* 1998).

Mapping provided by Council provides an indication of areas for which there is a high risk or low risk of ASS occurring, and areas for which there is no known occurrence of ASS (Figure 5.10).

5.5 Bank Erosion and Shoreline Dynamics

Foreshore Protection Structures

As outlined in Section 4.4, bank or beach erosion can alter foreshore morphology and estuarine bathymetry. These changes can put coastal development at risk. Shoreline recession and erosion is an issue for Brisbane Water and has led to instances of uncontrolled construction of seawalls and other coastal protection works, as well as many planned revetments. Many older style dwellings around the foreshore are being replaced with newer, larger buildings. Some of these property owners are seeking to secure their investments (and the foreshore in front of those properties) by placing garden areas behind seawall type structures (Figure 5.11). These structures may cause significant impacts on the local sediment dynamics, public access to the foreshore and aquatic habitats (e.g. seagrass areas near the shoreline). Similarly, structures such as jetties and boat ramps can affect processes governing sediment transport.

Shoreline change (erosion and re-building) is part of the natural response of a beach or shoreline to changes in wave and water level conditions. Some erosion may take place due to processes occurring on a regular basis, such as long-shore or cross-shore transport, and which are dependent on the sediment characteristics, catchment inflows and local hydraulic processes. However, storm events typically move large amounts of sand over the duration of the storm (see discussion below).

Where shoreline areas are exposed to wave activity and have significant curvature in plan view, such as the shoreline at the north-east corner of Marina View Parade, St Hubert's Island, there is potential for significant local erosion. At this location make-shift local shoreline protection works have been undertaken to protect the seawall and property. There are also extensive shoreline revetments at Koolewong and Gosford.

Significant changes to some shoreline areas are caused by storm waves and may threaten shoreline property, for example near Bangalow Street (Ettalong), and Schnapper Road at Ettalong. The Bangalow Street area is the site for the proposed Ettalong Beach to Sydney Fast Ferry service terminal. The shoreline is protected by a rock revetment, but it is currently in a state of disrepair and it has been fenced to prevent public entry. The cause of this failure is likely to have been the lack of suitable filter layers. At Point Clare and Gosford, local sea erosion of the shoreline and the proximity of property have led to the need to construct revetments to prevent further damage to property.

Natural Shorelines

In contrast to the sections of the shoreline affected by foreshore protection structures, more natural shorelines are found at locations such as those indicated on Figure 4.9. These more natural locations were selected for storm bite analyses. Storm bite describes the process by which sand is lost from the beach face through offshore sediment transport processes caused by waves and high water levels under storm conditions. Generally speaking, current-caused erosion does not occur at the shoreline.

The morphological response of the shoreline due to storm wave conditions (storm bite) occurs over relatively short periods (hours). This response primarily involves the erosion of the normal sub-aerial beach face through offshore transport and deposition near the storm wave break point to form an offshore bar. This offshore bar will be small in the case of local sea in Brisbane Water. On open sea coasts the beach face slowly rebuilds as sand in the bar is transported shoreward during calmer weather under swell wave conditions with lower steepness. However, at the more sheltered sites in Brisbane Water there is generally no swell to assist shoreline rebuilding (see Section 4.4).

Modelling of six sites located around the Brisbane Water Estuary shoreline was undertaken to investigate recession due to storm bite (see Figure 4.9). These locations are located near Green Point, Koolewong, and Point Clare, with a further three sites located in the vicinity of Booker Bay. A site visit was undertaken in June 2004 and sediment samples taken at each site for grain size analysis. At that time, estimates of the intertidal and back-beach slopes were also recorded. Other parts of the lower beach profile were determined from the regional digital terrain model established for this study.

The LITPROF model was used for the storm bite analysis. LITPROF is a semi-empirical, dynamic equilibrium storm onshore/offshore erosion prediction model developed at the Danish Hydraulics Institute and is a module of the LITPACK coastal processes system. The bed level is determined by the continuity equation of sediment mass coupled with onshore/offshore transport. The model can be run with constant or time varying wave height and still water level.

The potential for shoreline recession in Brisbane Water Estuary is significant, as demonstrated by the large extent of revetments within the estuary. The results of the storm bite analyses are discussed in Section 4.4.

5.6 Key Hot Spots

5.6.1 St Hubert's Island – Shoreline Issues

St Hubert's Island was developed in the mid-1970s as an island-canal residential estate. It was formed by dredging sand from the bed of Brisbane Water south of Riley's Island to form an island about 1.4km in the north-west to south-east direction and 800m in the north-east to south-west direction (see Figure 5.12). The island includes a number of canals, commonly termed drainage channels by island residents. The shorelines were developed with sandy beaches and vertical concrete revetment walls at the rear. Reclamation levels in the order of 2.3m AHD were developed at the shoreline.

However, because of the initial plan alignment (or orientation) of some of these beaches and (in some cases) the construction of cross-beach structures such as boat-ramps, the local-sea wave conditions have caused detrimental changes to some beach areas. Although not of high energy, waves caused by periods of high winds can cause intermittent sediment transport along some areas of the perimeter beaches and along the canal beaches. This transport is often in one direction only, i.e. winds from other directions do not reverse the sediment transport processes because the fetches are too short. Hence there is no opportunity for shoreline recovery.

Two sites were selected to characterize these shoreline processes, as shown in Figure 5.12, and each is described individually in the following sections. However, it should be noted that all locations have some unique aspects.

Site 1 is located on the southern shoreline of St Hubert's Island, at Helmsman Boulevard. Generally, the shoreline here is in good condition. However, at one boat-ramp there is a distinct change in beach width, with the shoreline to the east of the boat ramp being denuded of sand due to a net eastward transport. Hence, there is a distinct spatial variation in beach condition affected by the low energy local sea and the presence of beach structures.

Site 2 lies on the north-eastern shoreline of St Hubert's Island, on Marina View Parade. There has been significant beach erosion near this site, relative to the initial design shoreline. In addition, several structures that affect coastal processes have been built, including boat-ramps and informal protection works for various properties. Some of these modifications to the canal environment will affect sediment transport processes. This site was subjected to a detailed analysis involving site specific survey and wave climate analyses, and also incorporated the effects of oyster lease areas to the north-east. It was found that longshore sediment transport moves sand from the heads of reclaimed areas into the canals, but that the rate of transport into the canals reduces as the canal beach becomes more sheltered from wave activity. Beach plan alignment is affected also by the presence of boat-ramps and other structures that can act as short, low groynes (which inhibit sediment transport). Generally, the bulk of this transport occurs during periods of high wind speed (local storms).

5.6.2 Hardy's Bay – Sedimentation

Hardy's Bay is affected by Mudflat Creek in the north (Killcare) and the smaller RSL Creek at Hardy's Bay. Residents have expressed concern about ongoing siltation, especially for Mudflat Creek. Amongst residents' concerns are the reported deterioration in water quality for both Hardy's Bay and Mudflat Creek and also the increase in the extent of mangrove trees. The latter condition is reportedly arising from increasing siltation rates and inter-tidal flat progradation. Many statements have been collected from long term Hardy's Bay residents and their responses generally support the view that there has been long term siltation that has reduced navigation into the lower reaches of Mudflat Creek. It is also reported that rainfall runoff transports terrestrial rubbish, such as glass and road-base, to the shoreline of Hardy's Bay. There is some visual evidence of this having occurred in the past.

Although there appears to be some suggestion amongst the residents that GCC has undertaken maintenance dredging, or at least relocated sediments by side-casting to provide navigational access, GCC appear to have no records of such activities.

Aerial photographs of varying quality and scales, from 1954 to the present time, are available at irregular intervals. A review of the 1954 (quality too poor to report) and 1999 photographs shows that there was little or no change over that period in the visible extent of sand along the Killcare jetty. That location was selected for analysis because it is a fixed, unchanged feature in both photographs. Other photographs, providing better definition of shoaled areas, show that the course of Mudflat Creek through the entrance shoals has changed over time and that the extent of bay siltation developed further westward, ~30m to 40m over the period between 1976 and 2004. These are estimates only, the photographs being at different projections and tide levels.

Hence, there is some evidence that siltation of Hardy's Bay near Mudflat Creek has occurred. The rate of this siltation was likely to have increased following European settlement and more so with development in the Killcare Heights area, which is quite steep. It is thought likely that the rate has now stabilised because most of that development has been completed. Both numerical catchment (MUSIC) modelling (Cardno Lawson Treloar, 2007a) and siltation modelling support to some extent the view of ongoing siltation. Quantification of historical siltation rates is more difficult. It may be undertaken using deep cores (1m to 2m) and radio-isotope dating (Pb_{210} is recommended by ANSTO for periods up to 200 years). The process works downward through the core in a relative sense, past the point at which shells, for example, are assumed to have been deposited in the last year or so. The analysis then depends on the relative Pb_{210} concentrations between the surface shells and those discovered in the core below. This is an expensive exercise and previous similar analyses are understood not to have been particularly successful, for example, Dee Why Lagoon (pers. comm. Louise Collier; Cardno Lawson Treloar, 2007).

5.6.3 Ettalong Foreshore

This region of Brisbane Water lies between Broken Bay and Booker Bay (see Figure 1.1). Much of the regional seabed is formed of sandy shoals that are generally mobile and free from seabed flora, but there are also shoals that have extensive sea grass growth, for example, near Pretty Beach. These seagrass beds have been identified in Section 7.3.5 as being important for larval recruitment. The shoreline of Ettalong Beach, from north of Ettalong Point in the south to Schnapper Road in the north, has undergone beach erosion for many decades, at least from the mid-1940s (Public Works, 1992). Beach re-nourishment was undertaken by dredging from the centre-channel shoals in the early 1980s and again in the 1990s, to a smaller extent, when sand became available from a construction site near Beach Street. That recent re-nourishment sand also included material unsuitable for beach amenity.

Public Works (1977) discusses a conceptual model of sediment transport within the Ettalong area. Generally, it was considered that sand was transported northward from near Ettalong Point by longshore wave-caused transport to about Schnapper Road, from where it moved offshore into the tidal shoal system to be transported downstream by ebb tidal currents to the Ettalong Point Shoal and eventually back onto the shoreline through onshore sediment transport caused by swell - general cycling of sand. The process was made more complex by offshore transport from the beach profile during storm events, with little, if any, onshore transport following storm abatement. It is also likely to be affected by catchment flows.

Lawson and Treloar (1996) investigated the longshore transport characteristics on Ettalong Beach. The highest tidal current speeds occur near high and low tide, rather than near mean water level. Therefore, near high water, there is an upstream flowing tidal current, which, when combined with the higher waves possible at high water (local sea wave generation and swell propagation not as restricted by the shoals as is the case at low water), leads to an upstream transport of sand along the beach. Sand transport along Ettalong Beach towards Booker Bay at low tide is less effective because of lower wave heights; also because wave incidence on the beach at low tide does not run up the beach face as high as it does at high tide, and hence is not as effective in removing sand from the back-beach area. This process of northward shoreline transport is consistent with the conceptual model proposed by Public Works (1977).

Lawson and Treloar (1999) estimated the average upstream longshore sediment transport rate caused by swell to be about 75m^3/year - near Bangalow Street. This is consistent with the general rate of beach profile change at the site, but is a relatively small transportation rate.

Shoreline sediment transport at Ettalong is dominated by the offshore transport that occurs during periods of higher water levels and waves. Unlike open coast beaches that are exposed to persistent swell, sand lost from the Ettalong Beach face by wave induced offshore transport is not transported back onshore to any significant extent. Hence the beach does not recover to the same extent as an open coastal beach.

Waterway sediment transport in this region is caused by strong downstream transport in the channel close to Kourung Gourung Point and especially in the Wagstaffe Point area. There is also distinct transport onto, but not off, the Ettalong Point Shoal and the central shoal at Ettalong. Waterway sediment transport is not wave dominated, but is tidally dominated. There is a general tendency for the main flow paths to be maintained and for the Ettalong Point Shoal to move in a south-westerly direction into Broken Bay. There is also a general westward migration of the centre-channel Ettalong shoal and accumulation of sand north-west of Half-Tide Rocks. The movement of the shoal is affected by Broken

Bay waves, which tend to transport sand northward onto the shoal and westward towards Umina.

5.6.4 Correa Bay – Siltation

Correa Bay lies in the south-western corner of Woy Woy Inlet. The Great Northern Railway passes along its southern shoreline and a number of historical photographs along the bay and track have been collated by the Correa Bay Water Quality Management Committee (2000).

The main creek entering Correa Bay is Woy Woy Creek, which flows down from the very steep (≈1:15 on average) hinterland and then meets the much flatter terrain of Correa Bay. As a result of the topography at this location, any silt and sand sediments that are transported from the catchment will deposit near the creek entrance. Other creeks, Tip, Railway Tunnel and Everglades, are smaller and are believed by the Committee to be relatively unimportant as sediment sources to Correa Bay.

However, the Committee believe that Woy Woy Creek, which flows by Bull's Hill Quarry, is a continuing, significant source of sand. Other finer sediments would come from other parts of the catchment. The quarry is a large area of exposed land that, in places where the surface is not rock, provides an easily erodible sediment source. The Committee report (2000) provides photographs of sediment laden runoff from the quarry to Woy Woy Creek. Although the Creek flows over varying terrain, including waterfalls, there are continuous deposits of sand in the flatter reaches because sand cannot be held on the bottom in steep areas. Therefore, it seems highly likely that catchment sediments will continue to be delivered to Correa Bay.

The Committee (2000) report also provides figures showing their estimated bathymetric changes at some points near the mouth of Woy Woy Creek, based on interpretation of a 1901 survey and a survey undertaken for the Committee by a registered surveyor in 1999. These results show depth reductions in the order of up to 2m near the mouth of Woy Woy Creek, with a very steep drop-off in a spatial sense. This is typical of a sandy sediment laden flow entering a broader waterway where current speeds reduce rapidly.

However, it is understood that neither GCC nor the State Government endorsed the findings of the Correa Bay Water Quality Management Committee (2000). It is considered that, in addition to Bull's Hill Quarry, there are extensive sources of sediment within the catchment that may contribute to siltation in Correa Bay (N. Kelleher (DECC), pers. comm.).

Modelled average siltation rates in Correa Bay are in the order of 20mm per decade. Near the outlet to Woy Woy Creek the siltation rate during average conditions is approximately 10mm per year. While detailed modelling suggests that siltation is concentrated near the entrance of Woy Woy Creek, these investigations are based on the current catchment land use and do not necessarily reflect siltation rates which may have historically occurred following major land use changes in the catchment.

5.7 Summary of Key Findings

The key findings relating to Brisbane Water Estuary morphology, sediments and siltation are as follows:

- **Sediment Transport:** Estuarine geomorphology is a result of interactions between catchment inputs and coastal/estuarine processes. Bed sediments may be sourced from catchment inflows (fluvial) or marine inputs. Where land use changes occur in the catchment, the annual volume of fluvial inputs will be affected. Similarly, the prevailing wave climate and/or tidal currents will affect sediment transport and deposition or erosion. Fine fluvial sediments are deposited in more tranquil (low energy) environments that form sediment sinks. Locations in which re-suspension of sediments occurs is discussed in Section 4.4.

- **Catchment Derived Sediments:** Human activities can have a significant impact on estuarine sedimentation. The present rate at which sediments are delivered to the catchment was determined to be 5.7 million kg/year. The contribution of various tributaries is discussed in Section 3.2.7. Some areas are thought to be subject to siltation (e.g. Correa Bay and Hardy's Bay). Siltation at certain locations, and with respect to the estuary as a whole, may be investigated through sediment cores.
- **Catchment Land Use:** Human activities also impact on the quality of sediments via the introduction of a range of pollutants, including heavy metals. Lead, copper and zinc were present in the highest concentrations. These metals are associated with roads and some industrial activities. The most significant source of heavy metal contaminants appeared to be Narara Creek, followed by Erina Creek. This concurs with the catchment modelling of TSS, TN and TP inputs (Section 3.2.7). The results are consistent with land use, high runoff volumes, high concentrations of contaminants and larger size of the respective sub-catchments. However, the entire estuary has been enriched with heavy metal contaminants since European settlement. This began in the northern reaches of Brisbane Water Estuary and these areas continue to be most significantly affected today.
- **Ecological Impacts:** An assessment of the effects of heavy metal contaminants on the estuarine ecology has determined that low range negative impacts on the biota can be expected. This is an important consideration given the conservation value of the estuarine ecology and the commercial value of some species - oysters in particular (these filter feeders generally bio-accumulate such pollutants). The impacts of human activities on the ecology of Brisbane Water Estuary are considered further in Section 7.
- **Catchment-based Controls:** Catchment-based controls are important tools for reducing anthropogenic impacts on natural rates of sedimentation, nutrient inputs and heavy metal pollution. A range of measures are likely to be required, including planning and regulation, development controls, erosion and sediment controls and stormwater quality improvement devices. In addition, controls will also need to target works that may disturb PASS, which are thought to occur throughout much of the estuary. PASS can have significant environmental impacts if disturbed. Control of development in foreshore areas likely to be affected by PASS has been problematic to date.
- **Regulation of Foreshore Development:** Human activities are also affecting estuarine morphology and coastal processes through the construction of foreshore structures, such as jetties, seawalls and boat ramps, a significant number of which have been unregulated. Foreshore structures directly impact on patterns of sediment transport by forming a physical barrier, but also indirectly by altering coastal processes (e.g. waves, currents) which govern sediment transport. This can lead to accretion in some areas and erosion in others. This issue is also discussed in Section 4.4.
- **Foreshore Recession:** Modelling indicates that natural shorelines are subject to a general trend of recession, with storm bite expected to result in around 1-2m of horizontal recession in a very severe storm. In general, there is a high potential for shoreline recession within Brisbane Water Estuary because post-storm beach recovery is limited. This issue provides further motivation for control of foreshore development. It is understood that, at present, where accretion is occurring, property owners may seek to extend their boundaries to the high water mark (P. Freewater, pers. comm., 09/08/07). This effectively encourages the progression of development in a seaward direction and also prohibits foreshore access for members of the public (see Section 9.4). Control of foreshore development is an important issue for Brisbane Water Estuary. Any future planning for foreshore areas should also take into account the potential impacts of global climate change on water levels, wave climate and foreshore inundation.
- **Geomorphology and Hydraulics:** Modelling indicates that the processes affecting the morphology of the Estuary are variable across specific locations and include depth, exposure, catchment runoff (e.g. Hardy's Bay), wave climate (e.g. Ettalong, Green Point) and tidal currents (e.g. The Rip). The processes create a dynamic, spatially

variable estuarine morphology which affects navigation, amenity and ecological processes.

6. WATER QUALITY PROCESSES

6.1 Overview

Ambient water quality represents the "normal" water quality of Brisbane Water Estuary, which can be measured against water quality guidelines provided by ANZECC (2000). These guidelines consider a number of waterway usage objectives in terms of pollutant concentration, ranging from aquatic ecosystem health, to primary and secondary contact recreation (e.g. swimming).

With respect to aquatic ecosystem health, trigger levels for various stressors may be used in conjunction with professional judgement to identify water quality issues leading up to or at the onset of unacceptable water quality. Where trigger values are exceeded, management interventions or further site-specific investigation should be initiated. Parameter values below the trigger levels indicate that there is a low risk that a problem exists in relation to that parameter. The ANZECC (2000) guidelines provide default trigger values for South-east Australian estuarine ecosystems. These trigger values are shown in Table 6.1. They have been used to provide an assessment of ambient water quality in Brisbane Water with respect to ecological health.

Table 6.1 Default Trigger Values for Physical and Chemical Stressors for South-East Australian Estuarine Ecosystems

Physical and Chemical Stressors	Trigger Values
Chlorophyll a	4 µg/L
Total Phosphorous	30 µg/L
Filterable Reactive Phosphorous (Orthophosphate)	5 µg/L
Total Nitrogen	300 µg/L
Oxidised Nitrogen	15 µg/L
Ammonium	15 µg/L
Dissolved Oxygen	Lower Limit: 80% Upper Limit: 110% (or >5mg/L)
pH	Lower Limit: 7.0 Upper Limit: 7.5
Turbidity	0.5-10 NTU

It is important to incorporate professional assessment of site specific characteristics when applying trigger values. The default trigger values presented above may need to be refined in relation to these site specific characteristics. For example, where pH values are recorded as being consistently below the lower limit trigger value and no negative ecological issues are observed, the lower limit trigger value will need to be refined to better represent that particular system. The important point to remember is that there is no one set of guidelines or trigger values that will adequately represent all systems while still functioning as an appropriate indicator of environmental stress.

ANZECC (2000) also aims to protect human health through the provision of water quality guidelines for primary and secondary contact recreation. Primary contact recreation includes swimming, while secondary contact recreation includes boating activities and paddling. In this case, the primary considerations are pathogens and toxic algae. The recreational guidelines are presented in Table 6.2. In addition, ANZECC (2000) also provides water quality guidelines for the protection of cultured and wild fish, molluscs and crustaceans. These guidelines ensure safety of seafood for human consumption.

Table 6.2 ANZECC (2000) Guidelines for Primary and Secondary Contact Recreation

	Primary Contact	Secondary Contact
Faecal Coliforms	Not to exceed 150 cfu/100mL for the season	Median value of 1,000 cfu/100mL
Enterococci	Not to exceed 35 cfu/100mL for the season	Median value of 230 cfu/100mL
Algal Species	Not to exceed 15,000-20,000 cells/L dependent on algal species	
pH	5-9	
Temperature	15-35˚C	

In contrast to ambient water quality, transient conditions describe the impact of rainfall events on the water quality of Brisbane Water Estuary. Rainfall events occur relatively sporadically and can have a significant, short-term impact on estuarine water quality. Therefore, it is considered inappropriate to compare transient water quality conditions to guidelines such as those provided by ANZECC (2000). Nonetheless, transient events can have a significant, albeit short term, effect on water quality and the aquatic ecology. For this reason, consideration of peak concentrations of water quality parameters is relevant.

Both ambient and transient water quality conditions are considered below, in Sections 6.2 and 6.3, respectively. This overview has been informed by regular water quality data collected by Council, in addition to specialist studies of water quality processes (Cardno Lawson Treloar, 2007d; Appendix E), catchment modelling (Cardno Lawson Treloar 2007a; Appendix B) and hydraulic processes (Cardno Lawson Treloar, 2007b; Appendix C).

6.2 Ambient Conditions - Mixing and Flushing

This review of the ambient water quality of Brisbane Water Estuary has been informed primarily by *Historical Water Quality Data Review and Analysis* (WBM Oceanics, 2003), which analysed water quality data collected as part of routine sampling by GCC for the period 1974 to June 2002. Additional water quality data for 2005 and 2006 has been included where available. This additional data has facilitated a comparison over time.

It is understood that the water quality data is simply collected on a monthly basis (SMEC, 2002), with no regard for weather conditions or state of the tide. Therefore, it is possible that some data points may have been collected during or immediately after a rainfall event, in which case these data points would be representative of transient conditions, rather than ambient conditions. For the purposes of this data analysis, it has been assumed that data collection has been conducted under dry weather/ambient conditions and may therefore be compared to the ANZECC (2000) guidelines. Further, given that the data analysed below is effectively a ‘snap shot’ of water quality in the estuary, it is difficult to identify any trends in water quality. Nonetheless, an attempt to do so has been made herein.

Data was collected from six sites within the estuary. The locations of the sampling sites used in WBM Oceanics’ (2003) analysis are shown in Figure 6.1.

The data compiled in GCC’s water quality database is analysed and presented in WBM Oceanics’ (2003) report. Analysis results of all parameters are provided on annual and seasonal bases. The water quality parameters considered include:

- Physical parameters –
  - Temperature
  - pH
  - Turbidity
  - Secchi Depth
  - Salinity
  - Dissolved Oxygen (DO)

- Chemical parameters –
  - Ammonia
  - Oxidised Nitrogen (nitrites and nitrates)
  - Total Nitrogen (TN)
  - Orthophosphates
  - Total Phosphorous (TP)
  - Chlorophyll a

It is noted that the sample sizes are generally small, particularly for the period January – March 2002, which consists of one sample. For this reason, the results should be treated with caution. It has been assumed that much of the water quality sampling has been conducted in more recent years (from 1994 onwards). It is also noted that the values reported represent a quarterly average. This method of reporting will obscure any changes in water quality that occur over shorter time periods and may be heavily influenced by individual records that represent an unusually high/low value for that parameter. As a consequence, all results should be treated with caution.

The water quality data for sites located in Brisbane Water Estuary is presented in Tables 6.3 to 6.13. Where ANZECC (2000) Guidelines are not available for a particular parameter, the observed range of values is discussed in general terms, based on experience.

Temperature

Quarterly water temperatures for the period April 2001 to June 2002 are considered in Table 6.3. Estuarine water temperatures generally follow seasonal patterns with lower temperatures observed in the winter period (Jul-Sep). Water temperatures may vary over smaller time scales due to upwelling events or freshwater inflows. There may also be inter-annual variations.

Table 6.3 Quarterly Mean Water Temperatures (˚C) for Brisbane Water Estuary

	Apr-Jun 2001	**Jul-Sep 2001**	**Oct-Dec 2001**	**Jan-Mar 2002**	**Apr-Jun 2002**
Site	*n=3*	*n=3*	*n=3*	*n=1*	*n=4*
Cockle Creek	19.2	16.3	22.2	24.0	17.6
Narara Creek	15.6	16.2	22.8	24.8	17.0
Booker Bay	17.8	16.3	21.7	24.1	17.7
Erina Creek	16.2	16.2	23.3	24.5	17.1
Kincumber Creek	14.8	14.6	22.1	23.9	16.0
Woy Woy Creek	16.9	16.6	23.1	24.1	16.9
Rainfall at Gosford (mm)	*445*	*174*	*189*	*735*	*150*

Table 6.4 Quarterly Means for Salinity Values (ppt) for Brisbane Water Estuary

	Apr-Jun 2001	Jul-Sep 2001	Oct-Dec 2001	Apr-Jun 2002	Jan-Mar 2002
Site	*n=3*	*n=3*	*n=3*	*n=4*	*n=1*
Cockle Creek	30.5	34.5	36.1	30.7	32.3
Narara Creek	16.5	26.6	34.5	8.8	27.0
Booker Bay	32.8	35.2	36.1	31.9	34.4
Erina Creek	13.4	24.5	34.1	6.0	25.7
Kincumber Creek	17.0	2.1	32.8	12.6	26.9
Woy Woy Creek	24.3	31.4	35.1	16.2	26.8

Salinity

Describing the interface between the marine and freshwater environments, salinity can be highly variable in space and time within an estuarine environment, particularly for a large estuary like Brisbane Water. Different parts of the estuary will be subject to lesser or greater influence of the tides and freshwater inflows. Following a freshwater inflow event and rapid salinity reduction, there is a slower recovery to higher more common salinity levels.

Generally speaking, salinity tolerances are highly variable amongst plant and animal species and many estuarine species are capable of moving across a range of salinity conditions. However, where salinity changes rapidly, organisms may be unable to either escape, or tolerate, that rate of change.

The quarterly mean salinity values for Brisbane Water Estuary over the period April 2001 to March 2002 are presented in Table 6.4. Marine waters in the Sydney-Gosford region typically have a salinity of 35ppt. Most of the water quality sampling sites are located in the near-shore area near tributary mouths. Hence the impact of freshwater inflows will be apparent in the data set. Values higher than 35ppt may be observed where evaporation exceeds freshwater inflows, creating a hypersaline environment. The effect of freshwater inflows and tidally induced saline intrusion are apparent in the data for Kincumber Creek shown in Table 6.4 for the period between July and December 2001. The higher rainfall for April to January 2001 has not unexpectedly led to salinities lower than for April to June 2002. However, the results do depend on the coincidence of rainfall events and sampling dates.

pH

The ANZECC (2000) trigger values for aquatic health are any pH records outside the range 7.0 to 7.5 (Table 6.1). The pH values recorded over the period April 2001 to June 2002 are presented in Table 6.5. A large number of records exceed this range (highlighted in pink) indicating that some aquatic organisms may be experiencing stress. However, all values fall within the acceptable range for recreational purposes (Table 6.2).

pH values may vary in relation to a range of factors including marine influence, catchment geology (Section 3.2.5) and algal blooms (Section 7.2.4). Given the consistency of the results reported below, it is possible that the observed values represent the natural range for Brisbane Water. It is noted that the ANZECC (2000) trigger values are for South-East Australian estuaries in general and, therefore, may not be entirely appropriate for Brisbane Water Estuary. Given the extent of marine influence in the estuary, as indicated by salinity, the ANZECC (2000) trigger values for marine ecosystems ($8.0<pH<8.4$) may also be considered. However, there are still several exceedences of this range (highlighted in pink).

Table 6.5 Quarterly Mean pH Values for Brisbane Water Estuary

	Apr-Jun 2001	Jul-Sep 2001	Oct-Dec 2001	Jan-Mar 2002	Apr-Jun 2002
Site	*n=3*	*n=3*	*n=3*	*n=1*	*n=4*
Cockle Creek	8.40	8.37	8.57	8.22	7.61
Narara Creek	7.88	8.28	8.59	8.06	7.47
Booker Bay	8.37	8.57	8.73	8.21	7.81
Erina Creek	8.07	8.21	8.58	8.34	7.16
Kincumber Creek	7.43	7.72	7.86	8.26	6.97
Woy Woy Creek	7.98	8.37	8.51	7.92	7.49

Table 6.6 Annual Medians for Secchi Depth (m) for Brisbane Water Estuary

	1999/2000	2000/2001
Site	*n=8*	*n=3*
Cockle Creek	1.73	1.95
Narara Creek	1.44	1.45
Booker Bay	2.02	2.02
Erina Creek	0.90	1.50
Kincumber Creek	0.70	0.90
Woy Woy Creek	1.00	2.00

Light Penetration

The Secchi depth is a measure of the amount of light penetration through the water column and is similar to turbidity, except that it is affected also by colour, such as tannin stains. Generally, about 90% of the light is absorbed at the Secchi depth. High Secchi depth readings indicate clearer water that allows sunlight to penetrate to greater depths. This depth below the surface is effectively the region in which photosynthesis may occur, known as the euphotic zone. The amount of light penetration is also important for primary producers like seagrasses (Section 7.2.3) and phytoplankton (Section 7.2.4), which can in turn influence the structure of assemblages of aquatic organisms, as has been found for Brisbane Water Estuary (Section 7).

The annual medians for 2000-2001 and 1999/2000 are presented in Table 6.6. The results shown above indicate that light penetrates down to deeper parts of the water column at the Booker Bay, Cockle Creek and Woy Woy Creek sites, suggesting that primary productivity may be, on average, greater at these sites (over the temporal scale at which the study was conducted). However, this assertion is not supported by phytoplankton monitoring conducted to date, with all sites reporting similarly low phytoplankton counts (Section 7.2.4). Although Booker Bay did support a higher diversity of phytoplankton, this was thought to be attributed to its proximity to the estuary mouth and a combination of estuarine and marine species. As such, it can be concluded that light penetration is not the limiting factor in terms of phytoplankton growth and that other factors govern plankton dynamics within Brisbane Water Estuary.

Table 6.7 Quarterly Mean Turbidity (NTU) Values for Brisbane Water Estuary

Site	Apr-Jun 2001	Jul-Sep 2001	Oct-Dec 2001	Jan-Mar 2002	Apr-Jun 2002	Jan-Mar 2006	Apr-Jun 2006	Aug-Sep 2006	Oct-Dec 2006	Jan-Mar 2007	Apr-Jun 2007
Cockle Creek	8.3	3.7	2.7	1.0	3.5	3.6	14.6	10.3	25.4	4.1	6.5
Narara Creek	14.3	11.0	4.3	6.0	20.3	1.9	15.1	12.6	10.6	5.3	6.5
Booker Bay	2.7	2.0	2.0	3.0	1.5	1.8	13.1	0.9	2.7	5.4	5.2
Erina Creek	16.7	9.3	8.3	7.0	23.0	8.5	20.5	12.4	2.6	0.9	5.8
Kincumber Creek	9.3	46.0	14.0	13.0	39.8	10.5	2.3	15.6	3.2	4.8	7.8
Woy Woy Creek	18.7	4.7	8.3	6.0	15.0	1.3	13.0	2.4	8.3	5.4	4.7

Turbidity

The ANZECC (2000) trigger values for aquatic ecosystem health indicate that turbidity should fall within the range 0.5-10.0 NTU. Turbidity levels are reported for April 2001-June 2002 and January 2006-June 2007 in Table 6.7. A number of values exceed the ANZECC (2000) trigger values, as shown highlighted in pink. In general those areas that are subject to higher rates of flushing (e.g. Booker Bay; Section 4.3) have lower levels of turbidity, while those sites adjacent to tributary mouths have reported higher turbidity levels (e.g. Erina Creek). Some quite high values have been reported for Cockle, Narara, Erina and Kincumber Creeks on occasion. This concurs with modelling of total suspended solids conducted by Cardno Lawson Treloar (2007a; Section 3.2.7).

These results indicate that, according to the ANZECC (2000) guidelines, turbidity levels are likely to compromise ecosystem health for the entire estuary on occasion, and for habitats located in proximity to the three major tributaries more frequently. In any case, the limited number of sites cannot be considered entirely representative of conditions in the entire estuary. It appears that turbidity levels were lower in the first half of 2007 when compared to previous years. This condition may be related to rainfall patterns.

Dissolved Oxygen

The ANZECC (2000) guidelines recommend a DO concentration >5 mg/L for estuarine ecosystem health. Table 6.8 shows quarterly average DO concentrations for April 2001-June 2002 and January 2006 to July 2007. A number of records (highlighted blue) fell below the ANZECC (2000) trigger value. Most of these records are for late 2001/early 2002. In addition, Kincumber Creek recorded some extremely low DO concentrations from April 2006 to June 2007, suggestive of hypoxic conditions. These results indicate that at those times DO levels were sufficiently low to trigger stress in some estuarine organisms, particularly immobile organisms. However, it is noted that the average DO concentrations reported in Table 6.8 are typically calculated from only one observation per month and are not necessarily representative of general estuarine conditions.

Table 6.8 Quarterly Mean Dissolved Oxygen Concentrations (mg/L) for Brisbane Water Estuary

Site	Apr-Jun 2001	Jul-Sep 2001	Oct-Dec 2001	Jan-Mar 2002	Apr-Jun 2002	Jan-Mar 2006	Apr-Jun 2006	Aug-Sep 2006	Oct-Dec 2006	Jan-Mar 2007	Apr-Jun 2007
Cockle Creek	8.7	7.0	5.7	4.5	7.5	5.4	7.6	7.1	6.0	6.7	6.4
Narara Creek	6.9	5.8	5.9	4.6	6.1	5.2	7.7	8.1	6.0	5.3	6.2
Booker Bay	6.9	6.9	6.7	5.8	6.9	6.2	7.4	7.3	5.8	5.9	6.5
Erina Creek	6.8	6.2	5.7	4.8	6.2	5.4	7.8	7.8	5.3	5.7	6.8
Kincumber Creek	6.0	6.7	3.4	2.8	5.5	0.03	0.03	0.04	0.04	0.03	0.03
Woy Woy Creek	6.3	5.9	4.6	4.0	6.4	5.5	7.6	7.7	5.6	5.5	6.6

Nutrients

Data on quarterly averaged nutrient concentrations (TN, TP, ammonia, oxidised nitrates and orthophosphate) for April 2001-June 2002 and January 2006-June 2007 are presented in Tables 6.9 to 6.13 (respectively).

Observed average TN concentrations exceed the ANZECC (2000) trigger value of 0.3 mg/L for all records for 2001 and 2002 (Table 6.9, highlighted pink). On consideration of corresponding quarterly averaged ammonia and oxidised nitrate concentrations (bioavailable nitrates), it appears that inorganic nitrogen is the primary contributor to the high average TN concentrations. However, the ANZECC (2000) trigger value for estuarine ecosystem stress for oxidised nitrates is 0.015 mg/L. Cells highlighted in pink in Table 6.12 indicate those quarterly averages that exceed this trigger value. Average concentrations of both TN and bioavailable nitrates appear to consistently be sufficiently high to cause ecosystem stress in Brisbane Water Estuary.

Quarterly averaged concentrations of TN appear to drop significantly for the period January 2006 to June 2007, representing a drop in the concentration of inorganic nitrogen. Similarly, the average concentrations of oxidised nutrients are also reduced over this period.

It is important to note that nutrient dynamics are such that not all of the TN and TP recorded will be readily available to organisms. Oxidised nitrogen (nitrates and nitrites) and orthophosphate represent the bio-available fractions of TN and TP, respectively. Therefore, the concentrations of bio-available nutrients are relevant to considerations of ecological impacts. With respect to quarterly averaged TP concentrations (Table 6.10) a number of sites exceed the ANZECC (2000) trigger value of 0.03 mg/L for estuarine ecosystem stress. A higher proportion of exceedences is observed for the period April 2001 to June 2002, than for January 2006 to June 2007. This suggests an improvement in TP inputs associated with catchment runoff. The ANZECC (2000) trigger value for orthophosphates (the bioavailable fraction) is 0.005 mg/L. Exceedences were observed for almost all quarterly averaged concentrations of orthophosphate (Table 6.13, highlighted pink). As has been discussed elsewhere (Section 7), such high nutrient concentrations have the potential to result in a range of ecological impacts, such as phytoplankton blooms. With respect to the potential for phytoplankton blooms, it is understood that plankton cell counts are generally low and that algal blooms have not been particularly problematic to date (Section 7.2.4).

In 2001 and 2002, the highest nutrient concentrations were observed at Narara, Erina and Kincumber Creeks, consistent with catchment modelling (Section 3.2.7). Narara and Erina Creek also recorded higher average nutrient concentrations in 2006 and 2007. However, Woy Woy and Cockle Creeks also appear to be important sources of TN and TP. In general, Booker Bay has lower average nutrient concentrations, likely due to higher rates of flushing at this location by marine water (Section 4.3).

It is noted that the sampling sites are largely located adjacent to the creek mouths, and are not necessarily representative of general estuarine conditions.

The observed pattern of generally lower nutrient concentrations in recent years, compared to 2001-2002 may be the result of several factors; including catchment based processes and rainfall pattern changes, that is, the recent drought. According to the Bureau of Meteorology (2007), 2001 was characterised by higher rainfall due to the prevalence of La Nina conditions. All other years were characterised by El Niño conditions, which led to drought conditions. The year 2006 experienced fairly strong El Niño conditions (Bureau of Meteorology, 2007). However, it is noted that Council's *Supplementary Sustainability Report* (2005) also notes that several water quality control measures have been implemented in the catchment.

Table 6.9 Quarterly Mean Concentrations of Total Nitrogen (mg/L) for Brisbane Water Estuary

Site	Apr-Jun 2001	Jul-Sep 2001	Oct-Dec 2001	Jan-Mar 2002	Apr-Jun 2002	Jan-Mar 2006	Apr-Jun 2006	Jul-Sep 2006	Oct-Dec 2006	Jan-Mar 2007	Apr-Jun 2007
Cockle Creek	1.00	1.50	1.03	0.50	0.83	All BDL	0.90	0.08	0.85	0.10	0.20
Narara Creek	4.43	1.27	0.80	0.40	4.15	All BDL	0.20	0.50	0.30	0.10	0.40
Booker Bay	0.70	1.47	0.90	0.40	1.00	All BDL	0.20	0.03	0.10	0.20	0.10
Erina Creek	18.0*	1.00	0.80	1.00	2.35	All BDL	0.30	0.50	0.40	0.10	0.30
Kincumber Creek	2.70	3.10	1.00	0.07	2.33	All BDL	0.20	0.30	0.10	0.03	0.30
Woy Woy Creek	1.47	2.63	0.73	0.60	1.20	All BDL	0.30	0.30	0.10	0.20	0.20

*Due to one high record (52.4mg/L) from a sample collected May 2001.
BDL = Below Detection Limits

Table 6.10 Quarterly Mean Concentrations of Total Phosphorous (mg/L) for Brisbane Water Estuary

Site	Apr-Jun 2001	Jul-Sep 2001	Oct-Dec 2001	Jan-Mar 2002	Apr-Jun 2002	Jan-Mar 2006	Apr-Jun 2006	Jul-Sep 2006	Oct-Dec 2006	Jan-Mar 2007	Apr-Jun 2007
Cockle Creek	0.07	0.05	0.03	0.01	0.18	0.03	0.03	0.05	0.05	0.02	0.02
Narara Creek	0.06	0.05	0.04	0.01	0.08	0.05	0.04	0.04	0.05	0.06	0.04
Booker Bay	0.05	0.04	0.05	0.01	0.04	0.03	0.03	0.02	0.03	0.03	0.08
Erina Creek	0.08	0.04	0.05	0.03	0.12	0.05	0.03	0.05	0.05	0.05	0.04
Kincumber Creek	0.07	0.14	0.05	0.01	0.14	0.03	0.03	0.04	0.04	0.03	0.03
Woy Woy Creek	0.10	0.17	0.04	0.02	0.13	0.04	0.04	0.02	0.04	0.04	0.03

Table 6.11 Quarterly Mean Concentrations of Ammonia (mg/L) for Brisbane Water Estuary

Site	Apr-Jun 2001	Jul-Sep 2001	Oct-Dec 2001	Jan-Mar 2002	Apr-Jun 2002	Jan-Mar 2006	Apr-Jun 2006	Jul-Sep 2006	Oct-Dec 2006	Jan-Mar 2007	Apr-Jun 2007
Cockle Creek	0.015	0.011	0.012	0.013	0.034	0.01	0.03	0.04	0.03	0.01	0.02
Narara Creek	0.024	0.018	0.017	0.017	0.046	0.02	0.04	0.06	0.02	0.04	0.06
Booker Bay	0.013	0.010	0.010	0.008	0.022	0.02	0.02	0.03	0.03	0.02	0.02
Erina Creek	0.024	0.015	0.018	0.019	0.047	0.01	0.04	0.08	0.05	0.03	0.03
Kincumber Creek	0.034	0.021	0.022	0.028	0.067	0.02	0.01	0.01	0.02	All BDL	0.09
Woy Woy Creek	0.024	0.015	0.027	0.027	0.048	0.01	0.01	0.05	0.02	0.02	0.02

Table 6.12 Quarterly Average Concentrations of Oxidised Nitrogen (Total Nitrates and Nitrites; mg/L) for Brisbane Water Estuary

Site	Apr-Jun 2001	Jul-Sep 2001	Oct-Dec 2001	Jan-Mar 2002	Apr-Jun 2002	Jan-Mar 2006	Apr-Jun 2006	Jul-Sep 2006	Oct-Dec 2006	Jan-Mar 2007	Apr-Jun 2007
Cockle Creek	0.04	0.03	0.04	0.04	0.07	All BDL	0.02	0.09	0.01	0.02	0.01
Narara Creek	0.06	0.04	0.05	0.03	0.15	All BDL	0.06	0.21	0.01	0.06	0.06
Booker Bay	0.02	0.02	0.02	0.02	0.03	All BDL	0.02	0.07	0.01	0.02	0.01
Erina Creek	0.05	0.03	0.05	0.02	0.09	All BDL	0.03	0.19	0.05	0.02	0.03
Kincumber Creek	0.06	0.04	0.06	0.04	0.14	All BDL	0.02	0.07	0.01	0.02	0.24
Woy Woy Creek	0.04	0.02	0.04	0.04	0.08	All BDL	0.01	0.11	0.02	0.02	0.04

Table 6.13 Quarterly Average Concentrations of (Filterable) Orthophosphate (mg/L)for Brisbane Water Estuary

Site	Apr-Jun 2001	Jul-Sep 2001	Oct-Dec 2001	Jan-Mar 2002	Apr-Jun 2002	Jan-Mar 2006	Apr-Jun 2006	Jul-Sep 2006	Oct-Dec 2006	Jan-Mar 2007	Apr-Jun 2007
Cockle Creek	0.02	0.01	0.01	0.01	0.03	0.02	All BDL	All BDL	All BDL	0.01	All BDL
Narara Creek	0.02	0.01	0.01	0.01	0.02	0.03	0.02	0.01	0.02	0.03	0.04
Booker Bay	0.01	0.01	0.01	0.002	0.01	0.02	0.01	All BDL	0.01	0.01	0.02
Erina Creek	0.02	0.01	0.01	0.01	0.03	0.03	0.02	0.01	0.03	0.03	0.03
Kincumber Creek	0.02	0.02	0.01	0.01	0.03	0.03	All BDL	All BDL	0.02	0.01	0.01
Woy Woy Creek	0.02	0.02	0.02	0.004	0.03	0.02	0.01	All BDL	0.01	0.03	0.02

Primary Productivity in the Water Column

Chlorophyll *a* is the chief pigment used in photosynthesis and is therefore a measure of primary productivity in the water column. It can be considered a proxy for the presence of phytoplankton. Due to the relationship between phytoplankton growth and the availability of nutrients and light (Section 7.2.4), chlorophyll *a* concentrations are likely to be related to rainfall and show seasonal patterns. However, it is noted that there is a range of factors that influence phytoplankton abundance (Section 7.2.4) and that the data provided is insufficient to isolate anything other than general seasonal patterns.

The quarterly averaged concentrations of chlorophyll *a* for the period April 2004 to June 2007 are shown in Table 6.14. The ANZECC (2000) trigger level for estuarine ecosystem stress for chlorophyll *a* is 4 µg/L. Concentrations exceeding this trigger level are highlighted in pink.

Chlorophyll *a* concentrations appear, in general, to be higher for the period January to June, most probably a reflection of peak phytoplankton productivity due to higher water temperatures, more summer rainfall and higher levels of solar radiation. A number of very high chlorophyll a concentrations were observed, particularly for the first half of 2006. A comparison of the corresponding nutrient data for 2006 and 2007 shows that peaks in nutrient concentrations did not strictly coincide with peak chlorophyll *a* concentrations, although this is a difficult comparison to make, given the temporal resolution of the water quality data.

It is also difficult to discern any spatial patterns in the concentration of chlorophyll *a*, with several sites showing peak concentrations for any given period, although Erina Creek did record a higher number of exceedences than any other site.

Table 6.14 Quarterly Averaged Chlorophyll *a* Concentrations (µg/L) for Brisbane Water Estuary

Site	Apr-Jun 2004	Jul-Sep 2004	Oct-Dec 2004	Jan-Mar 2005	Apr-Jun 2005	Jul-Sep 2005	Oct-Dec 2005	Jan-Mar 2006	Apr-Jun 2006	Jul-Sep 2006	Oct-Dec 2006	Jan-Mar 2007	Apr-Jun 2007
Cockle Creek	0.5	0.5	4	3	3	1	2	2	7	1	2	1	3
Narara Creek	0.7	0.5	2	4	3	3	2	6	6	All <1	3	3	1
Booker Bay	0.5	1	2	1	2	2	2	4	17	1	2	2	2
Erina Creek	0.5	0.7	3	15	3	3	2	8	7	1	2	4	5
Kincumber Creek	0.5	0.7	4	4	4	2	2	7	4	2	2	3	10
Woy Woy Creek	0.5	0.5	2	4	4	2	2.	7	5	2	2	4	4

Recreational water quality has been monitored within the Brisbane Water Estuary as part of the Beachwatch Partnership Pilot Program (EPA, 2007), whereby GCC works with the NSW Environment Protection Agency to monitor faecal coliforms at key swimming locations within the Estuary. Faecal coliform counts are an indication of sewage contamination and are typically associated with sewer surcharges or overflows. These events are more problematic during wet weather. Where faecal coliform counts exceed the ANZECC (2000) recreational guidelines, primary contact recreational activities should be avoided and GCC may advise residents not to swim in affected locations. People engage in a range of water-based recreational activities in Brisbane Water (see Section 9.1).

The sites monitored under the Beachwatch Program include:

- Davistown Baths (in Cockle Channel)
- Ettalong Channel
- Copacabana Rock Pool
- Yattalunga Baths
- Woy Woy Baths
- Killcare Rock Pool
- Pretty Beach Baths.

Over the period from October 2005 to April 2006, faecal coliform counts for water quality samples collected at the above sites complied with the ANZECC (2000) recreational guidelines 100% of the time (EPA, 2007). These findings indicate that faecal coliform levels within the Estuary are generally of an acceptable level and that water quality is of a standard suitable for recreational purposes. However, it is noted that rainfall levels over the monitoring period were low due to persistent drought conditions. Given that high rainfall events often result in sewer overflows, it is possible that a return to average rainfall conditions could cause in an increase in the faecal coliform levels.

Toxicants such as heavy metals, aromatic hydrocarbons, pesticides and herbicides, in addition to being found in the benthic sediments (as discussed in Section 5.3), may also be present in the water column. Trigger values for fresh and marine water are also provided by ANZECC (2000) in order to assess the likelihood of toxicity affecting aquatic biota.

6.3 Transient Conditions - Freshwater Inflows

Transient conditions are the result of water quality changes that occur over a short time frame and then return to ambient levels. Typically, such short term impacts are related to freshwater inflows due to rainfall events in the catchment, and sewer overflows, from time-to-time. These freshwater inflows affect water quality by altering the salinity of estuarine waters, leading to stratification, whereby the less dense, fresh water sits on top of the saltier, denser estuarine waters. In addition, sediments, nutrients and other pollutants contained in stormwater runoff are delivered in the freshwater inflows, affecting water quality. These conditions will persist until the receiving waters undergo mixing and flushing. Flushing times for various parts of the Brisbane Water Estuary are discussed in Section 4.3.

Cardno Lawson Treloar defined the catchment loads of nutrients discharged from the sub-catchments of Brisbane Water in Section 3.2.7 for a range of wet weather events (under wet, dry and average annual rainfall conditions) and investigated the transport of those nutrients from a large number of source locations (tributaries) for average annual freshwater flow conditions. The nutrients considered were Total Phosphorous (TP) and Total Nitrogen (TN). The results are reported in *Brisbane Water Estuary Processes Study Water Quality Modelling, Appendix E* (Cardno Lawson Treloar, 2007d), provided in full in Appendix E.

TN and TP introduced to the Estuary by freshwater inflows were generally found to exhibit similar characteristics. There was a noticeable stratification effect in nutrient concentrations, no doubt related to salinity stratification. Tidal flows are one of the primary factors governing mixing and flushing in estuarine environments. In the lower reaches of the Estuary (Paddy's Channel, Lintern Channel, St Hubert's Island, The Rip, Entrance Channel and Pretty Beach) nutrient concentrations fluctuated with the tides and waters appeared well mixed with little difference between surface and bed waters. This concurs with the findings relating to flushing times presented in Section 4.3, which found that flushing times for locations south of The Rip were of the order of 2 to 3 days.

However, tidal influence was less pronounced for more enclosed areas, particularly in the upper estuary. At these locations stratification of the water column was evident with higher concentrations of nutrients observed in the upper levels of the water column. In addition, while a tidal signal was detected, with nutrient concentrations fluctuating in response to tidal currents, there was no evident spring-neap tidal effect. Therefore, despite larger tidal inflows and water level variations, flushing times do not appear to be reduced during spring tides, and flushing times remain relatively consistent over the course of the monthly tidal cycle.

Spatial Patterns in Water Quality

Spatial patterns in water quality were also investigated for freshwater inflows to Brisbane Water Estuary. The highest nutrient concentrations occurred upstream of Woy Woy Bay, notably in Correa Bay and in The Broadwater (near the mouths of Narara and Erina Creeks). There are also high nutrient concentrations observed near the mouth of Kincumber Creek. Peak TN concentrations ranged from 1.32 mg/L in Fagan's Bay, to 0.5 mg/L in Hardy's Bay, The Entrance Channel and Pretty Beach. Peak TP concentrations ranged from 0.08 mg/L in The Broadwater to 0.05 mg/L in Hardy's Bay, The Rip and Pretty Bay. The locations with the highest nutrient concentrations were generally related to the largest tributary, Narara Creek.

The spatial patterns in transient water quality concur with those observed for ambient water quality (Section 6.2). The water quality data for ambient conditions found that monitoring sites located closest to Narara and Erina Creeks had the highest nutrient concentrations, followed by Kincumber. This supports the results of the MUSIC modelling of catchment inputs, which found that Narara Creek contributed the largest amounts of nutrients and suspended solids to Brisbane Water Estuary (Cardno Lawson Treloar, 2007a; Section 3.2). This is due to land use in the respective catchments, being the focus of residential, commercial and industrial development. Figures 6.2 and 6.3 show the results of modelling over summer for a representative dry year for TN and TP.

However, observed peak ambient nutrient concentrations (reported in Section 6.2) are generally higher than those modelled for transient (i.e. wet weather) conditions. Peak TN concentrations reported for ambient conditions ranged from 18mg/L near Erina Creek to 0.17mg/L in Booker Bay. Peak TP concentrations reported for ambient conditions ranged from 0.175mg/L near Cockle Creek to 0.063mg/L in Booker Bay. The expectation is that peak nutrient concentrations would be higher under transient, or wet weather conditions (i.e. as modelled), than under ambient conditions. As expected, *in situ* peak nutrient concentrations in Booker Bay under ambient conditions were lower than those under transient conditions. However, peak nutrient concentrations under observed ambient conditions for the worst affected sites were much higher than those for modelled transient conditions. It is thought that this is due to the ambient water quality data sampling methodology. The limitations of the ambient water quality data have already been discussed in Section 6.2. In addition, it is understood that most of the sites are located in close proximity to a creek mouth and that samples are collected from the shore where nutrient concentrations are likely to be highest.

It is noted that modelling of rainfall events indicates that upstream of Ettalong the concentrations of TN and TP exceed the ANZECC (2000) guidelines of 0.3 mg/L and 0.03 mg/L, respectively. This concurs with the water quality data analysed in Section 6.2. Along with the observed long flushing times for some areas (of around 30 days) and tidal attenuation at this point (Cardno Lawson Treloar, 2007b; Sections 4.2 and 4.3), there is potential for ecological impacts such as algal blooms further up-estuary from Ettalong, both in association with rainfall (transient) events and under ambient conditions.

20-Years ARI Rainfall Event – Spatial and Temporal Patterns

Under 20-years ARI rainfall conditions, where the MUSIC model was again used to estimate catchment loads, modelling results showed a rapid increase (<1 day) in ambient concentrations that persist for longer than the adopted 2-weeks simulation period. Again, this relates to long flushing times (> 30 days for some areas, see Section 4.3) and tidal attenuation above Ettalong (see Section 4.2), and has the potential to have ecological impacts.

In The Broadwater, concentrations of TN and TP increased to as much as twice ambient concentrations. Fagan's Bay showed a similar rapid increase, although concentrations of TN and TP were not as high as for The Broadwater.

The areas of St Hubert's Island and The Rip showed rapid returns to pre-storm nutrient concentrations and large tidally induced variations in the concentration of TN and TP. This reflects the greater influence of tidal flow at these locations (Section 4.2). The model indicated that recovery to ambient (background) concentrations is quick and that wet weather events have a smaller impact here than for other locations.

These findings suggest that site specific management actions should be implemented for tributaries coincident with parts of the estuary that experience longer flushing times.

Comparison Between Wet and Dry Years

'Wet' years are defined as those with higher than average rainfall and 'dry' years are those with lower than average rainfall. For the purposes of comparing wet and dry years, the results of TN modelling over summer for representative average and wet years have also been provided in Figures 6.4 and 6.5, respectively. Modelling of rainfall conditions showed that wet years (that is, annual rainfall in the catchment of ~1600mm) lead to higher nutrient concentrations than dry years (i.e. annual rainfall in the catchment of ~800mm). This is not surprising given that higher levels of rainfall are likely to deliver a larger amount of nutrients and sediments to the estuary. This effect was particularly apparent at sites such as Brisbane Water and Woy Woy Inlet, which are close to major drains or creeks. Brisbane Water is the common receiving water body for Narara and Erina Creeks. These two creeks have the largest sub-catchments and have also been demonstrated to be the most significant contributors of nutrients to the Estuary (Section 3.2.7).

These findings have implications with respect to climate change. As discussed in Section 3.2.9, it is anticipated that climate change will affect rainfall conditions such that, while average annual rainfall is likely to decrease, rainfall is likely to be concentrated into a few more intense events. Given the marked difference observed between wet and dry years in terms of the delivery of nutrients to estuarine receiving waters, it is possible that the impacts of climate change on estuarine water quality will include:

- Lower average annual catchment derived sediment and nutrient inputs.
- The concentration of sediment and nutrient inputs associated with rainfall events into fewer, more intense pulses.
- An associated decline in transient water quality in locations proximal to creeks or drains.
- Higher variability in the amount of nutrients delivered to the estuary over any one year.

Freshwater inflows may also affect estuarine circulation due to the salinity difference between inflows and estuarine waters. However, freshwater inflows were generally found to have no overall effects on the bulk hydraulics of the Estuary. Apart from near the creek and drain entrances, there were no noticeable changes to the current structure of the Estuary. However, surface layer salinity (that is approximately the top 1m of the water column) can be noticeably reduced over much of the Estuary during wet years.

6.4 Summary of Key Findings

Key findings of the detailed water quality processes assessments include:

- **Monitoring and Evaluation:** The water quality data collected to date provides a ‘snap-shot’ in time and it is understood that there is limited consistency with respect to location and tidal phase of sampling sites. Therefore, it is difficult to identify trends in water quality for Brisbane Water Estuary for either ambient or transient conditions. However, certain assumptions about nutrient inputs and advection and dispersion throughout the estuary can be made based on the findings of hydraulic (Section 4) and catchment modelling (Section 3.2.7), which have been used to inform water quality modelling of transient conditions.
- **Water Quality Dynamics:** The extent of oceanic influence in the estuary to some extent governs water quality processes within Brisbane Water Estuary, whereby flushing times are much longer in the upper-estuary due to the attenuation of tidal flow and distance from Broken Bay (Section 4.3). This is evident in the salinity data presented in Table 6.4, with salinity generally lower and showing a higher variability for stations located adjacent to creek mouths. In addition, those locations, in which flushing occurs over a longer time period are also generally coincident with the major population and commercial/industrial centres (Section 3.2.1). For these reasons, the upper-estuary, particularly The Broadwater, is subject to generally poorer water quality and longer recovery times after a rainfall event. Nonetheless, it appears that there may have been a general trend towards water quality improvement in more recent years, although whether this is due to catchment based controls or rainfall patterns is unclear.
- **Ecological and Recreational Impacts:** Based on the water quality data used to assess ambient water quality, as well as modelling of transient conditions, it is apparent that water quality is an issue in Brisbane Water Estuary, particularly with respect to nutrient and sediment inputs. This has the potential to lead to a range of environmental impacts, such as eutrophication, algal blooms (Section 7.2.4) and a decline in seagrasses (Section 7.2.3), and may alter the community dynamics in a range of estuarine habitats (see Section 7). Similarly, water quality also impacts on recreational usage of the waterway (see Section 9.1). Whilst the data presented herein suggests that water quality is currently of a standard suitable for recreational

purposes, it is important that monitoring continues to ensure public health and safety and that human waste be prevented from entering the estuary.

- **Climate Change Scenarios:** A comparison between wet and dry years suggests that predicted changes in rainfall patterns may lead to a decline in water quality in relation to individual rainfall events. Should this occur, this process will be exacerbated by the projected population increase for the Gosford region (Section 3.2.2) and future planning should carefully consider patterns of land use and catchment based controls on water quality.

7. ECOLOGICAL PROCESSES

7.1 Overview

A number of biological studies were undertaken as part of this study in order to understand ecological processes occurring in Brisbane Water Estuary. The majority of these studies investigated spatial and temporal patterns of distribution and abundance for the flora and fauna of Brisbane Water. Other studies investigated processes to explain these patterns. Collectively, these studies demonstrate links between catchment and estuarine processes and ecological phenomena. These studies are referred to in the list provided in Section 1.

Estuaries such as Brisbane Water are dynamic ecosystems, effectively open at either end and under the influence of a complexity of physical, chemical and biological processes. They are influenced by freshwater input from rivers, creeks, groundwater and stormwater runoff. These inflows vary in volume, rates of flow and chemical and biological content depending upon climate, geology, geography and land use within the drainage catchment. Marine processes, such as tidal and oceanic currents, as well as their associated chemical and biological content, also influence estuarine ecosystems.

The estuary represents the interface between a range of different environments: marine and freshwater, terrestrial and aquatic. Within these broad categories are a number of different habitats ranging from terrestrial habitats (bushland), to intertidal habitats (wetlands / saltmarsh, Casuarina forest, mangroves, mudflats and rock platforms), and aquatic habitats (seagrass beds, submerged rock platforms and sandy or muddy estuarine beds). Although Brisbane Water has been largely modified by urban encroachment, it remains an area of considerable biodiversity.

A search of the NSW NPWS Wildlife Atlas for threatened species (under the *Threatened Species Conservation (TSC) Act 1995*) returned a total of 98 threatened species records (conducted 13 September 2007) for the entire the Gosford LGA, including:

- 60 Vulnerable Species of animals, such as the Osprey (*Pandion haliaetus*), Humpback Whale (*Megaptera novaeangliae*) and Green Turtle (*Chelonia mydas*);
- 14 Endangered Species of animals, such as the Green and Golden Bell Frog (*Litoria aurea*), Bush Stone-curlew (*Burhinus grallarius*) and Giant Dragonfly (*Petalura gigantean*);
- 16 Vulnerable plant species, such as the Magenta Lilly Pilly (*Syzygium paniculatum*); and
- 8 Endangered plant species, such as the Tranquility Mintbush (*Prostanthera askania*).

While these records refer to the entire LGA, it can be reasonably assumed that many of them occur specifically within the Brisbane Water catchment.

Active conservation and habitat protection is undertaken in the following parts of the catchment:

- Brisbane Water National Park
- Bouddi National Park
- Riley's Island Nature Reserve
- Pelican Island Nature Reserve
- Cockle Bay Nature Reserve
- Kincumber Mountain Reserve
- Rumbalara Reserve.

The location of National Parks is shown in Figure 3.4.

This report focuses on the estuarine ecology. The characteristics of flora and fauna found in the estuary are discussed with reference to the impacts of human activities and future conservation priorities.

7.2 Flora

An overview of the terrestrial vegetation and forest communities of the Brisbane Water Catchment has been provided in Section 3.2.4. It was noted that the conservation of these natural areas is critical to the longer term maintenance of the estuarine ecosystem. Terrestrial vegetation plays an important role in providing habitat for animals that travel between the terrestrial and aquatic environments, such as birds, reptiles, mammals and invertebrates. It is also provides important ecosystem functions, such as the binding of sediments to prevent erosion, water cycling and filtration, climate control and so on. The terrestrial vegetation of the Gosford area has been mapped in detail by Bell (2004) and the value of this natural resource has been reported widely.

This section of the Brisbane Water Processes Study focuses specifically on the estuarine vegetation. Flora is evaluated in the following categories:

- Overview of shoreline ecology
- Saltmarsh / Wetlands
- Mangroves
- Seagrass / Macroalgae
- Phytoplankton.

An assessment of the disturbance to natural shorelines (Sainty and Roberts, 2007) presents an overview of the general state of foreshore vegetation around Brisbane Water Estuary and provides an insight into the causes of degradation of these habitats (summarised below). The full report is provided in Appendix H.

The foreshore of Brisbane Water is the interface between the terrestrial and aquatic environments and includes the estuarine beaches, saltmarshes and wetlands, public reserves and privately owned land. It is where the community's interaction with the estuary begins and their perceptions about the “health” of the estuary are developed. The Brisbane Water Estuary has had significant modifications to its natural foreshores since European colonisation and the extent of this modification has not previously been quantified. Prior to large-scale development of the Brisbane Water estuary, the foreshores and shallow intertidal areas were dominated by Casuarina forests, saltmarsh and mangrove habitat.

The assessment of shoreline vegetation was conducted by surveying aerial photography and complemented by ground-truthing. A disturbance index was applied to sections of the shoreline (Table 7.1).

Table 7.1 Disturbance Index Used to Assess Each Section of the Foreshore (after Sainty and Roberts, 2007)

Index	Description
1	Highly disturbed/modified foreshore. Includes seawalls with limited ecological niches e.g. vertical concrete or stone. Includes buildings in close proximity to the seawall, often with jetties and stormwater inlets. Catchment substantially developed.
2	Disturbed/modified foreshore. Seawall with limited ecological niches. Includes foreshore with scattered mangroves. Saltmarsh limited to narrow discontinuous strip. Catchment substantially developed.
3	Modified foreshore. Seawall absent. Includes irregular saltmarsh strip or natural rock platform associated with a variable width forest, contiguous to water's edge. Catchment partly/variably developed.
4	Unmodified foreshore. Rock platform, seagrass, mangrove, saltmarsh, forest on water's edge. Catchment partially or wholly developed.
5	Unmodified foreshore. Rock platform, seagrass, mangrove, saltmarsh, forest on water's edge. Catchment with no development.

The foreshore of Brisbane Water extends for approximately 89 km. The shoreline ranges from an unmodified tidal interface with a catchment that has little or negligible development, to an extensively modified foreshore and catchment. A total of 145 different sections of foreshore were identified using aerial photography and ground-truthing.

Of the 89 km of Brisbane Water foreshore, 23 km or 26% was given a Disturbance Index of 1, whilst 24 km or 27% was given a Disturbance Index of 2 (Table 7.2). These highly disturbed sections of the foreshore were invariably where development was close to the foreshore with seawalls constructed to prevent erosion. Under these conditions, residents appear to generally keep the foreshore clear of native vegetation and exotic lawns prevailed. Only 8 km or 9% of the foreshores around the estuary were found to be in an unmodified condition and these received a disturbance index of 5.

Table 7.2 The Number of Locations, Percentage of Total Foreshore Lands and Kilometres Represented by Each Disturbance Index (after Sainty and Roberts, 2007)

Disturbance Index	Number	Percentage	Kilometres
1	42	26	23
2	35	27	24
3	35	19	17
4	17	19	17
5	16	9	8
TOTAL	145	100	89

The major issue identified in this assessment was the significant amount of seawalls within the estuary (approximately 18 km). They are generally built to prevent erosion. However, in many estuaries they have been constructed with the aim of enhancing the amenity value of residential property. Seawalls have the potential to supplement natural habitat in terms of species composition and abundance of some marine organisms. Although not quantified, the seawalls in Brisbane Water did not appear to provide extensive habitat for intertidal or subtidal organisms. The common practice of building seawalls and infilling the area behind (e.g. Figure 5.11) has resulted in a significant change to the natural shoreline of the estuary. The impact of foreshore structures on the morphology of Brisbane Water Estuary has previously been discussed in (Section 9.5). This foreshore land was once dominated by saltmarsh, mangroves and *Casuarina* sp. forest. The land is now sufficiently elevated to prevent tidal inundation and as such the previous productivity and habitat within the estuary has been lost.

Natural foreshores also have the ability to assimilate seagrass wrack that is washed in to the shore. Modified foreshores are not generally suited to wrack assimilation and instead tend to trap wrack in the water against the foreshore creating both access and amenity issues (see literature review by Sainty and Roberts, 2007). Furthermore, once the wrack has accumulated against the foreshore, the underlying seagrass and benthic ecology begins to deteriorate. This leads to a build up in organic sediments, that impact on invertebrate communities, generally resulting in lower biodiversity. These sediments are generally low in dissolved oxygen, produce sulphides and are associated with noxious odours.

Mangroves, saltmarsh and intertidal rock platforms were, prior to European settlement, present along the entire Brisbane water foreshore. The removal of mangrove and saltmarsh habitat from the foreshore lowers the ecological value of the estuary by reducing habitat and potential food source availability for birds and other animals (see Section 7.3.5). Furthermore, the mangroves and saltmarsh help to protect the shoreline from wave erosion whilst trapping sediments and recycling nutrients. The presence and/or size of mangrove and saltmarsh habitat were therefore given a high ranking in the assessment process.

Other types of natural shoreline included unmodified rock platforms, which extend over a significant length (approximately 12 km) of Brisbane Water foreshore. There were excellent examples of this interface with foreshore land in Woy Woy Bay. A good example of an intertidal rock platform was also identified at Wagstaffe Point opposite Umina. Rock platforms are ecologically important habitats, providing habitat for a range of intertidal organisms including algae, molluscs, crustaceans and fishes. These habitats are generally not widespread in NSW estuaries, which provide a greater incentive for their conservation and protection in Brisbane Water.

Other hard structures that dominated the estuary included jetties and pier pylons. There are many hundreds of jetties in Brisbane Water, which cause ongoing disturbance to the shallow areas adjacent to the shoreline (see Section 9.5). Jetties cause shading of seagrass habitat and this has been identified as an issue for estuary managers. Also, overseas studies on the impacts of jetties indicate that propeller scarring from boats tied alongside jetties can cause considerable damage to seagrass beds.

Weeds introduced to the freshwater / saline interface by birds, humans, wind and water are also a major issue for the foreshores of the estuary. Some of these weeds, notably Morning Glory, Asparagus and Lantana, have blanketed the understorey of the forest-foreshore interface. The impacts of disturbance on saltmarsh habitats are discussed in Section 7.2.1.

A number of other foreshore issues were identified as important in this study. Examples included the disturbance to foreshores associated with maintenance of parks and roads and the construction of buildings close to the edge of the water. Untreated and unmanaged stormwater entering the estuary was also considered to reduce the ecological value of many foreshore areas.

Two islands within the estuary, Pelican Island and Riley's Island, remain largely unaffected by development. In contrast, St Hubert's Island is almost completely urbanised and has numerous canals. Pelican Island and Riley's Island suffer from unwelcome visits from the boating community and even the occasional fox. Whilst there has been some disturbance on Pelican Island and Riley's Island, they still provide important habitats for waterbirds and other native estuarine species. The saltmarsh and mangrove habitat on these islands was in good condition at the time of the survey, although weeds were found to be invading some areas. The notable weed species on Pelican Island is *Juncus acutus*.

Mosquitoes are common and occur naturally in an estuary. The most productive areas for mosquitoes appear to be in saltmarsh that is infrequently flooded. Depressions in these areas are temporarily filled with rain or saltwater, depending on elevation, but are sufficiently ephemeral that they do not have insect and fish predators. These depressions are generally a result of some form of anthropogenic disturbance. Depressions located along a section of foreshore at Kincumber South (Kincumber Broadwater) were found to contain tens of thousands of mosquito larvae. These depressions were a direct result of works associated with mangrove and foreshore clearing.

7.2.1 Saltmarsh / Wetlands

Wetland environments are important in providing shelter, food, breeding grounds, nursery areas and migratory corridors for marine life, as well as functioning in water storage, buffering water quality and resisting storm-related erosion (OzEstuaries, 2007).

The extent of saltmarsh vegetation in Brisbane Water Estuary is shown in Figure 7.1.

State Environmental Planning Policy (SEPP) No. 14 provides protection for coastal wetlands. This SEPP was instituted to ensure the preservation and protection of wetlands for environmental and economic purposes. Development is controlled in listed wetlands and SEPP 14 restricts the types of development that may occur (such as reclamation, draining, etc) and the consent authority (DoP) must take into account the potential impact of any works on ecological function. The extent of SEPP 14 wetlands has been mapped for NSW and those located within Brisbane Water Estuary is shown in Figure 7.2. These SEPP14 wetlands are coincident with many of the mangrove and saltmarsh communities in Brisbane Water Estuary mapped in Figure 7.1.

Saltmarshes are more common in temperate regions, often in environments that would typically be colonised by mangroves in tropical regions (OzEstuaries, 2007). In Australia, where mangroves and saltmarsh coexist, saltmarsh will tend to be located at higher elevations where they are inundated less frequently.

Saltmarsh environments consist of high-intertidal to supra-tidal halophytic (“salt loving”) vegetation such as salt tolerant grasses, reeds, sedges and small shrubs (OzEstuaries, 2007). Saltmarshes and associated vegetation proved habitat for a wide range of bioturbating infaunal and epifaunal invertebrates, as well as low-tide and high-tide visitors, such as fish and water birds (OzEstuaries, 2007). Typically the sediment found in saltmarshes consists of poorly-sorted anoxic sandy silts and clays with high concentrations of iron sulfides associated with ASS (see Section 5.2). Carbon concentrations are low and concentrations of organic matter in the soil material are generally high.

Saltmarshes are important for:

- Primary productivity and a support resource for estuarine food webs, particularly for juvenile fish and crustaceans.
- Mediating a balance of nutrients and organic matter between saltmarsh and other interacting, estuarine ecosystems.
- Coastal protection from storm erosion and extreme tides.
- Trapping and binding sediments in the process of land progradation.
- Maintenance of general estuarine ecosystem function (OzEstuaries, 2007).

For these reasons, saltmarshes have been identified as important indicators for *State of the Environment* reporting in Australia.

NSW Fisheries (2007) state that saltmarshes play an important role as a juvenile habitat for a number of species, including bream and mullet. Crabs are common in saltmarsh communities and are significant sources of food for bream and other species. Some species, such as Common Galaxias (*Galaxias maculatus*), are known to deposit their eggs in saltmarshes (NSW Fisheries, 2007).

Saltmarshes may be lost due to human activities such as land reclamation, infilling, trampling, urban run-off, sedimentation, weed propagation, grazing, rubbish dumping, engineering works and pollution (Cappo *et al.,* 1995, Saintilan and Williams, 1999; cited OzEstuaries, 2007). Other processes that can negatively impact on saltmarshes (which may or may not be related to human activities) include sea level rise, regional climatic changes and changes to the tidal regime. Increased tidal amplitudes are associated with expansion of mangroves (Adam, 1994; cited OzEstuaries, 2007). In many areas, saltmarshes have declined significantly.

Roberts and Sainty (2005) undertook an assessment of variation in Brisbane Water saltmarsh habitats associated with the tidal regime and anthropogenic disturbance. This report aimed to examine the distribution and abundance of various saltmarshes at different spatial scales and to assess the effects of disturbance on both low- and high-level marsh habitats. Their findings are summarised below and the full report is provided in Appendix I.

A total of 14 saltmarshes were sampled throughout Brisbane Water Estuary, some of which were subject to human disturbance and others that were relatively undisturbed. Some photographs of undisturbed low and high marshes and a disturbed marsh habitat are shown in Figure 7.3.

Those sampling sites that were relatively undisturbed included Erina Creek wetland, Riley's Island, Cockle Bay Nature Reserve, Cockle Bay wetland, Kincumber Creek, Pelican Island and Davistown saltmarsh. Those sampling sites which were observed to have experienced disturbance were Egan Creek saltmarsh, Saratoga wetland, Lintern saltmarsh, Empire Bay wetland, Davistown wetland and Saratoga saltmarsh. Bensville saltmarsh has suffered some disturbance.

The observed agents of disturbance were:

- Weeds,
- Trail bikes,
- Bicycle tracks,
- Competition with other vegetation types (e.g. mangroves or melaleuca),
- Grazing horses, and
- Urban runoff.

The saltmarshes around Brisbane Water were diverse and abundant, with over 30 plant species identified within the 14 sampling sites. In general, low (elevation) marsh habitats were dominated by *Sarcocornia quiqueflora* and *Sporobolus virginicus*. Other species that were also recorded in low marsh habitats were *Samolus repens*, *Triglochin striatum*, *Cotula coronopifolia* and the Grey Mangrove, *Avicennia marina*. The high (elevation) marsh habitats were generally dominated by *Juncus kraussii* or *Juncus acutus* and *S. virginicus*. Other species included *Selliera radicans*, *Suaeda australis*, *S. repens* and *Casuarina glauca*. These types of general patterns have been described for saltmarsh elsewhere (e.g. Harty, 1994; cited Roberts and Sainty, 2005).

Influence of the Tidal Regime

According to Roberts and Sainty (2006), areas that had restricted tidal exchange away from the main tidal flow within the estuary, i.e. Cockle Bay and Kincumber Broadwater, were found to have greater covers of saltmarsh within the low marsh habitat. However, because of their remote locations, these areas are also subject to less anthropogenic disturbance. These areas tended to be dominated by *S. quiqueflora*. It was suggested that this species tends to be more abundant at the lowest elevation and generally situated behind mangrove forests.

Tidal regime did appear to have an influence on patterns of saltmarsh distribution for high marsh habitat. This was not considered surprising as these habitats are only infrequently inundated and, therefore, a different set of processes would influence patterns of distribution in high marshes. High shore levels in saltmarshes are physically stressful because of infrequent inundation by the tide, potentially large concentrations of salt in the soil and long periods of desiccation. Such factors will influence the growth and diversity of plant communities by introducing a greater potential for biological interactions, such as competition between species. The study found that high level salt marshes were generally more diverse than low level marshes.

The productivity of saltmarsh increases with more water and nutrients, and ideally this is supplied by tidal inundation and catchment runoff. Published literature suggests that vegetated saltmarsh has a higher nursery value than unvegetated saltmarsh, but a lower nursery value than seagrass habitats. However, these comparisons are complicated by tidal dynamics and the movement of nekton among components of the marsh and, therefore, the value of saltmarsh as a nursery is highly dependent on geography, salinity regimes and tidal amplitude.

The Influence of Anthropogenic Disturbance

Significant patterns associated with anthropogenic disturbance within the low marsh habitats were observed. *S. quinqueflora* was present at lower rates of coverage within disturbed locations as compared to undisturbed locations. The cover of *J. kraussii* was greater in undisturbed locations, while the introduced noxious species, *J. acutus*, was more abundant in disturbed locations. Increasingly, high marsh is being over-run by weeds and many of these weeds have moderate tolerance to salt. Examples of semi-tolerant exotic (weed) plants that were identified in the high marsh habitats of Brisbane Water Estuary include: *J. acutus* (Spiny Rush), Buffalo Grass (*Solanum rostratum*), Lantana (*Lantana camara*), Bitou Bush (*Chrysanthemoides monilifera*), *Ipomoea carioca*, Alligator Weed (*Alternanthera philoxeroides*) and species of Asparagus. There are several problems associated with weed invasions and in some of the marshes surveyed, *J. acutus* is a significant problem. This species was also found on Pelican Island, where its proliferation has been encouraged by the activities of NPWS officers, whom were under the impression that the species was native and made it a habit to collect and cast the seeds. *J. kraussii and J. acutus* look very similar, though the latter has a stiffer leaf that makes walking amongst them uncomfortable when wearing shorts.

Whilst it is understood that there is a great deal of literature that describes the loss of saltmarshes due to anthropogenic disturbance at the scale of whole estuaries, Roberts and Sainty (2005) were unable to identify any studies from NSW that quantify the effects of disturbance at smaller spatial scales. Consequently, anthropogenic disturbance to saltmarsh habitats needs to be factored into management decisions for all spatial scales.

Although much of the shoreline of Brisbane Water Estuary has been modified and large areas filled for housing, excellent areas of saltmarsh still remain. Some saltmarshes (e.g. in the Erina Creek area) are in excellent condition and have a good marsh / forest interface. Others (e.g. at Davistown) have been affected by disturbances and have a poor interface with the urban area. The vigour of saltmarsh can be significantly reduced where small banks are constructed (eg. sewerage pipelines) and tidal inundation is restricted. A bank of only 10 cm in height can be sufficient to prevent or reduce local tidal inundation.

Many saltmarsh species can easily be crushed by trampling and or wheels. Field inspections yielded many examples of disturbance to the marshes associated with vehicular use including cars, motorcycles and pushbikes. *S. quinqueflora* is especially susceptible to the effects of physical disturbance such as trampling. Grazing cattle were also observed within some marshes and this particular activity can cause significant damage to the marsh. In the marsh at Bensville horses had been allowed access from the high marsh down to the water's edge. They had caused damage to low marsh and had eaten and destroyed the mangroves. The substratum of the marsh had also been significantly damage by their hard hooves.

Relatively large areas of non-fragmented marsh have the potential to be of a high ecological value and yet there is limited awareness of the importance of saltmarsh to estuarine processes. The ideal interface on the edge of an estuary is a zonation of (moving from higher to lower elevation):

Forest > high marsh > low marsh > mangroves > seagrass.

There are few areas left in Brisbane Water that fit this criterion, but where they exist (e.g. Cockle Bay) change of any type within the catchment should be resisted and appropriate management plans put in place to protect them into the future.

Educating the community about the importance of saltmarsh to the Brisbane Water Estuary has been supported by Council and local environmental groups through rehabilitation programmes, such as the Kincumber Creek Rehabilitation Project (GCC, 2007). Unfortunately, there is often conflict between this assemblage of plants and residential development objectives. Residential development has, in some cases, had an observable direct impact on saltmarshes.

For example, in the Saratoga and Davistown area, the direct effects of residential development can be observed. These areas were former saltmarsh, as evidenced by the domination of the stormwater system by saltmarsh species. Other key issues that occasionally impact on saltmarshes is that they are associated with certain disease carrying mosquitoes, which can proliferate in some of these wetlands, and so are undesirable for residents in properties adjacent to saltmarsh areas. However, the cause of mosquito issues in these marshes can often be associated with previous disturbance and changes to inundation patterns within the marsh.

7.2.2 Mangroves

The term 'mangrove' is used to describe both an individual mangrove plant and the habitat in which it lives. Mangrove plants are very diverse, consisting of several species of trees and shrubs that grow along sheltered intertidal shores, mainly in tropical & subtropical coastal waterways (OzEstuaries, 2007). However, in Eastern Australia, mangroves do extend along temperate coastlines where their distribution overlaps with saltmarsh communities, as discussed in Section 7.2.1. Australia has 39 mangrove species, which is more than half the global number (OzEstuaries, 2007).

Plants such as saltmarsh and mangroves that grow in the intertidal zone are subject to large environmental fluctuations in salinity, water temperature, nutrients and oxygen. Mangroves are adapted to the salt-water environment and to anoxic and sulfidic-rich sediments (see Section 5.4). These adaptations include:

- Breathing roots (i.e. pneumatophores) which obtain oxygen directly from the atmosphere when exposed at low tide,
- Buttresses and prop roots for support,
- Salt excretion from leaf pores, and
- Floating seedlings (viviparous propagules) (OzEstuaries, 2007).

Similar to saltmarsh habitats, where seagrass beds are found adjacent to mangroves, their habitats share many links, including shared plant and animal communities. Changes in the distribution of mangroves have also been identified as an important indicator of broader environmental change for *State of the Environment* reporting (OzEstuaries, 2007).

Mangroves perform a range of important functions:

- Providing shoreline protection from storms and waves,
- Sediment accretion / trapping,

- Nutrient cycling,
- Buffering of water quality,
- Acting as a major source of primary productivity in coastal environments,
- Providing important nursery habitat for many marine species, including commercially important fish and prawn species,
- Acting as a sink for atmospheric carbon (and thereby mitigating climate change), and
- Acting as an indicator for monitoring change in coastal environments (OzEstuaries, 2007).

Mangroves are important habitats for fish, crabs, birds and other animals. Mangrove trees provide large amounts of organic matter, which is consumed by many small aquatic animals known as detritivores, which are eaten by larger carnivorous fish and other animals (DPI - NSW Fisheries, 2007).

Mangrove communities may be lost or degraded due to a range of human activities, such as: pollution, *Phytothera* (a fungal disease) – commonly introduced from landfill sites, trampling, increased tidal amplitudes (due to activities such as dredging and climate change), freshwater runoff and invasive weeds (OzEstuaries, 2007). In addition, declining water quality due to pollution and contamination can lead to changes in water and sediment chemistry, and also cause genetic modification of the mangrove genome. Roberts and Sainty (2006) provide a literature review that outlines large scale declines in the extent of mangrove forests in NSW estuaries.

An assessment of variation in Brisbane Water mangrove habitats associated with a range of variables was undertaken. It included the mangrove density, height and canopy over the mangrove forest, as well as the number of seedlings, pneumatophores and crab holes within the mangrove forest (the latter two of which were used as an indication of the relative 'health' of forest floor). This report aimed to develop models about the ecological processes occurring within the mangroves. A total of 15 mangrove sampling sites located around Brisbane Water Estuary were used. Their findings are summarised below and the full report is provided in Appendix I.

The extent of mangroves within Brisbane Water Estuary is indicated in Figure 7.1, which provides the most recent mapping undertaken by NSW Fisheries. Harty and Cheng (2003) estimate that there has been an overall increase of approximately 4% in the spatial extent of mangroves within the Brisbane Water Estuary up until 1995, thought to have resulted in a decline in the extent of saltmarshes.

There are two mangrove species found in the estuary: the Grey Mangrove (*Avicennia marina*) and the River Mangrove (*Aegiceras corniculatum*), shown in Figure 7.4. *A. marina*, which tends to form extensive forests adjacent to the shallow edges of the estuary, is the dominant species in Brisbane Water. This species is one of the most widely spread mangrove species in Australia due to its tolerance of cool conditions and is commonly found on the seaward edge of the mangroves, but can be found in almost all mangrove environments (Lovelock, 1993). *A. corniculatum* was primarily found growing along creek lines and occasionally within the *A. marina* forest, but in much smaller densities. *A. corniculatum* is one of the most common mangrove species (Lovelock, 1993). It is found along river banks over a wide range of salinities.

There were significant differences in the derived variables for mangroves at most of the spatial scales examined (kilometres, 100's of metres, metres). Whilst the density of mature *A. marina* trees within forests did not vary at the scale of locations / sites, there were differences among these locations at smaller spatial scales (e.g. 100's metres). There were also differences in the height of the forest and its canopy cover at various scales. The density of mangroves and extent of their canopy cover may vary due to hydrodynamic processes operating within a location and/or the effects of anthropogenic disturbance. Tidal inundation is probably one of the most important physical factors that have allowed mangroves to be successful within estuarine systems. Their reproductive strategy of producing seeds that float with tidal currents helps to distribute mangroves throughout the estuary and between different estuaries.

The soft, muddy estuarine sediments in which mangroves grow is often water logged and generally low in oxygen. The pneumatophores of *A. marina* have evolved to provide oxygen to the tree under these conditions. A literature review undertaken by Roberts and Sainty (2006) indicated that if pneumatophores are damaged or smothered, then the mangroves may die. The pneumatophores of *A. marina* were found at all locations. The pneumatophores were generally in good condition and did not show any symptoms of stress.

Mangrove forests are considered vital to the biological productivity of Australia's coastal waters (Lovelock, 1993). The floor and sediments of the mangrove forest provides habitat for extensive numbers of macrobenthic invertebrates, which includes crabs, molluscs and worms. A diverse assemblage of benthic macrofauna is considered to be essential for a healthy estuarine system. Crabs and other macrofauna are important components of estuarine systems as they provide food for fish and birds and perform a vital function in breaking down organic matter and cycling nutrient, thereby introducing them back into the estuarine food web. The number of crab holes (burrows) has been used as an indicator for the abundance of crabs within estuarine environments. In general, there appeared to be some patterns in the number of crab holes at different mangrove locations within the estuary. The greatest number of crab holes was generally found in mangrove forests within the highly flushed channels and on the islands. The mangrove forests at these locations are more likely to experience greater tidal flushing, providing potentially greater amounts of food for animals such as crabs. However, these conclusions need to be tested.

Anthropogenic disturbance can also produce impacts at small spatial scales, thus altering the ecological processes that are operating at those scales. For example, changes to the structure of mangroves have been linked by others (see Roberts and Sainty, 2006) with changes to the macrofauna that inhabit the forest. There were significant interactions at small spatial scales for many of the mangrove variables that were examined. These interactions are ecologically important and show how assemblages experience patchiness in their distributions at different spatial scales.

It is important to conduct studies at a variety of spatial scales as the factors affecting ecological processes will also vary over time and space. This is relevant to the detection of anthropogenic disturbance, as this can also operate at different spatial scales. The investigations conducted for this estuary processes study form an important first step in identifying spatial scales of importance within the mangroves forests in Brisbane Water. Identifying temporal changes within these forests is the next step in furthering the scientific knowledge associated with mangroves. Information on temporal changes would be useful for future decisions regarding mangroves and wetlands within the estuary.

7.2.3 Seagrass / Macroalgae

Seagrasses are aquatic flowering plants that form meadows in soft sediments in near-shore estuarine or coastal waters in temperate and tropical regions (OzEstuaries, 2007). Australia has the highest diversity of seagrasses in the world (Kuo and McComb, 1989; cited in OzEstuaries, 2007). Seagrass species are generally differentiated into temperate and tropical species and may also differ in the breadth of their distributional ranges (i.e. broad vs. restricted), their reproductive strategies (e.g. rapid seeding, seed banks and vegetative reproduction), the degree of their persistence (i.e. ephemeral vs. persistent), physiology, and their ecological interactions (OzEstuaries, 2007).

Seagrass species can form meadows and changes in the species composition of these meadows may indicate slow but important changes in the environment. For these reasons, seagrasses are suggested as indicators for *State of the Environment* reporting (OzEstuaries, 2007). Estuarine seagrass habitats can be intertidal or subtidal and are subject to episodic inflows of terrestrial runoff with pulses of nutrients, turbidity and reduced salinity. The species composition of estuarine seagrass meadows may change in response to variable resilience of the different species to burial, anoxia and to light reduction caused by suspended sediments and eutrophication (OzEstuaries, 2007). For example, increased nutrient inputs to estuaries associated with sewage outfalls and agricultural and industrial runoff often leads to degradation of seagrass beds due to eutrophication, which is associated with excessive growth of epiphytes (Boyland, 2006).

NSW Fisheries (2007) state that there have been dramatic losses of seagrasses in Australia, including NSW, due to erosion of river beds and banks in coastal catchments, which leads to elevated sediments and turbidity and subsequently deprives the seagrass of light. Other contributing factors include dredging, land reclamation and the grazing of stock around mangroves and saltmarshes. A literature review by Boyland (2006) identified the following threats to seagrass:

- Increased turbidity, which reduces light penetration, thereby decreasing the photosynthetic capacity of seagrasses,
- Smothering,
- Increased nutrient inputs, which can lead to eutrophication, algal blooms and/or increased growth rates of epiphytic organisms, all of which are associated with subsequent shading of seagrasses,
- Boating impacts such as damage by moorings and propellers, and
- Dredging.

The first three points above may be associated with works (such as construction in the catchment) or diffuse stormwater runoff (see Section 3.2.1). Boyland (2006) reports on observations of boat damage to seagrass beds located in Brisbane Water Estuary.

Jane Jelbart examined the historical loss of seagrass meadows and its influence on the fauna in the estuary for her PhD thesis (*University of Western Sydney*). Her thesis study was supported with a grant from GCC. She found that *Posidonia australis* meadows in Brisbane Water had decreased by almost 50 % over the past 20 years. It was considered that sedimentation within the estuary favours *Zostera capricorni* over *P. australis* and that the former had increased by approximately 8 % over the same period. The two seagrass species support different faunal communities and the change in distribution of the different types of seagrass will result in changes in the distribution and abundance of the estuaries fishes and invertebrate species. The full report (Jelbart and Ross, 2006) is provided in Appendix I.

Larkum *et al.* (1989; cited Boyland, 2006) identified six important ecological functions of seagrasses:

- Influences on the immediate physical environment,
- Stabilisation of sediments,
- Nutrient cycling,
- High levels of primary productivity,
- Provision of food and shelter, and
- Acting as a nursery ground for numerous estuarine and marine species.

NSW Fisheries (2007) state that seagrasses contribute organic matter to the food chain and remove nutrients and sediments from the water, which improves water quality. Many invertebrate species are associated with seagrass beds, which provide a range of microhabitats due to their structural complexity. As such, seagrass beds provide habitat for many other estuarine and coastal organisms, including commercially and recreationally important fish, mollusc and crustacean species, which use seagrass beds as feeding grounds, nurseries or refugia (NSW Fisheries, 2007).

The most common species in NSW are Eelgrass (*Zostera capricorni*) and Paddleweed (*Halophila* spp.). Strapweed (*Posidonia australis*) is limited to the more marine dominated estuaries of NSW and is of particular concern as it does not recolonise areas from which it has been eliminated (NSW Fisheries, 2007). The extent of seagrass within Brisbane Water Estuary is shown in Figure 7.1. All three of these species are found in the estuary, although *H. australis* is the least prevalent in terms of spatial coverage.

Macroalgae (“seaweeds”) are an ancient class of plants that resemble vascular plants but lack the complex tissues used for reproduction and water transport (OzEstuaries, 2007). They are important elements of shallow coastal waterways. Macroalgae thrive in waters that receive nutrient pollution and macroalgal blooms can have significant impacts on the natural environment (OzEstuaries, 2007). Decomposing mats of macroalgae can deplete the water column of dissolved oxygen, which can lead to fish kills. Macroalgae are often used as indicators of water quality. Seagrasses commonly have epiphytic macroalgae growing on the leaf blades. Algae are also plants, but form a different group from flowering plants such as seagrass. Epiphytic macroalgal dynamics can have a significant impact on seagrasses. As discussed above, macroalgal loads may increase due to elevated nutrients, which can negatively impact on seagrass photosynthesis through shading (NSW Fisheries, 2007). However, macroalgae and other organisms epiphytic on seagrasses are important components of seagrass beds as (for example) a food source to animals and improving water quality.

The epiphytic macroinvertebrate species associated with seagrass are considered in Section 7.3.1.

Boyland (2006) investigated the relationship between seagrass bed structure and fish assemblages in Brisbane Water Estuary. The results of that study with respect to seagrass bed structure are summarised below and the full report can be found in Appendix J. Boyland (2006) surveyed seagrass beds in each of the five main waterways in the estuary. Seagrass bed structure of *Z. capricorni* beds was determined by recording shoot density, leaf length, percentage cover of seagrass and percentage cover of seagrass epiphytes.

Shoot density was found to be significantly higher in the late-summer / early-autumn sampling period than the late-autumn / early-winter sampling period. This was found to concur with other studies and was thought to be attributable to dieback over the winter period, followed by germination of new seedlings during summer. Similarly, the percentage cover of seagrass beds was significantly higher in the late-summer / early-autumn sampling period. There was also a significant difference between sites (100’s m apart). With respect to the leaf length of *Z. capricorni*, there were no significant differences between sampling periods. However, there was a general trend to increasing length in late-summer / early-autumn sampling period. The percentage cover of macroalgal epiphytes was lower in the later-summer / early-autumn period. It was unsure as to why this was the case and whether it might be due to nutrient levels or grazing by invertebrates. However, Boyland (2006) demonstrated that epiphyte cover was strongly correlated with invertebrate density, whereby grazing by invertebrates reduced the epiphyte load on *Z. capricorni* seagrasses.

The relationships between those variables representing bed structure were also examined. There was a negative relationship between shoot density and leaf length. This finding concurred with the supporting literature discussed in Boyland (2006), which suggested that both these variables are related to water depth, whereby at greater depths the shoot density decreases and the leaf length increases. There was a negative relationship between leaf length and epiphyte cover, which was also attributed to depth. As stated previously, leaf length increases with depth. The biomass of epiphytic macroalgae decreases with depth, thought to be due to the attenuation of light. This suggests that epiphytic macroalgae are less able to tolerate low light intensities than seagrasses.

These findings indicate that seagrass bed structure for *Z. capricorni* varies over the course of the year, with depth and may also vary over relatively small spatial scales. These findings provide an indication of the complex interplay of factors that influence the health, structure and function of seagrass beds. In reality a great many more additional factors influence seagrass community dynamics and rates of growth / attrition. Given the important ecological functions that these habitats perform, it is important to gain a greater understanding of seagrass dynamics and the role that human activities may play.

7.2.4 Phytoplankton

Phytoplankton are the microscopic plants that are suspended in the water column. Being photosynthetic organisms, phytoplankton are found in the euphotic zone (the 'well lit' surface layer) of the water column. It is thought that, through photosynthesis, they produce up to 90% of the oxygen in the Earth's atmosphere. Phytoplankton forms the basis of the marine food web and so there is a strong correlation between plankton abundance and fish production (NSW Fisheries, 2007).

Where present in high enough numbers, phytoplankton may discolour the water. This is called an algal bloom and examples include so-called "red tides", which is a bloom of the *Noctiluca* species. However, phytoplankton are dependent on nutrients and minerals for growth. The absence of sufficient nutrients or minerals will limit phytoplankton growth and therefore the opportunities for 'red tides'. The coastal waters of Australia are commonly nutrient deficient due a combination of factors. Australia is geographically isolated from the nutrient rich sub-Antarctic water found further south. Wind-induced upwellings, which are associated with enhanced productivity elsewhere in the world, are made ineffective in the tropical waters of Australia due to the confusion of land masses and islands to the north (Rochford, 1975). In addition, terrestrial nutrient inputs (via runoff) are relatively negligible due to the poor quality of Australian soils (CSIRO, 1978). Therefore, on the east coast of Australia, where algal blooms do occur they are typically associated with East Australia Current (EAC) driven upwelling events.

There are a number of groups that make up phytoplankton, including Diatoms, Cyanobacteria and Dinoflagellates. There are a range of factors that influence the species composition and abundance of a phytoplankton community. In Australian waters, there is a successional pattern whereby there is a spring bloom of diatoms, coinciding with an initial pulse of dinoflagellates, which become more established later in spring once silica becomes limiting (Hallegraeff and Reid, 1986; Jeffrey and Carpenter, 1974), silica being a limiting mineral for diatom growth. There is a secondary diatom bloom in autumn and a winter minima is observed for all species. This process is effectively controlled by the delivery of nutrients to the euphotic zone. However, successional patterns will also be influenced by other factors such as temperature, light availability, water movement, light absorptive capacity of algal pigments, predation, life histories and morphology (Jeffrey and Hallegraeff, 1990).

There are approximately 80 species of phytoplankton that can cause human illness due to the toxins they contain (Hallegraeff, 2003), particularly when present in large numbers. Many of these species are found in Australian waters. Bivalve shellfish, such as oysters, in filtering phytoplankton from the water during feeding, can accumulate algal toxins. Once eaten, contaminated shellfish can cause serious illness, or even death, in humans. It is impossible to distinguish by colour or smell between contaminated and uncontaminated shellfish once harvested.

Monitoring of Brisbane Water phytoplankton has been undertaken in the past due to the risk of toxic algal blooms. Seven sampling sites are located in Brisbane Water at the mouth of the larger creeks, in the main body of Brisbane Water and near the ocean entrance (ET, 2000a, 2000b; Insearch Ltd, 2000). No map of sampling locations was available and so approximate locations of sampling sites have been mapped in Figure 7.1. As the aim of the program was to monitor potentially toxic algal species, the monitoring focused on Diatoms, Dinoflagellates, Flagellates and Cyanobacteria.

One observation of the monitoring program for the period August 1999 to May 2000 was the high variability in abundance and diversity of plankton from site to site, although samples collected near the entrance had the highest diversity, likely to be due to the mix of oceanic and estuarine species found at this site. The most common species observed were:

- the Dinoflagellates *Gymnodinium, Protocentrum* and *Peredinium*;
- the Diatom *Skeletonema*;
- the Flagellate *Cryptomonas;* and
- the Cyanobacteria *Oscillatoria* (when present).

Rapid temporal changes in abundance were observed at creek mouths (ET, 2000a; 2000b; Insearch Ltd, 2000), which is likely due the influx of runoff related to rainfall events. Rainfall events result in the delivery of nutrients to the estuary via runoff. Despite the high temporal variability, the absolute cell count of any phytoplankton species remained relatively low at less than 2000 cells/L (ET, 2000a; 2000b; Insearch Ltd, 2000).

Insearch Limited (2000) proposed several interactions to explain the low phytoplankton counts recorded during monitoring:

- Consumption of phytoplankton by zooplankton sufficient to suppress phytoplankton numbers;
- Suppression of phytoplankton by macrophytes (e.g. seagrass) via the production of allelopathic substances (used in chemical competition) and competition for nutrients; and
- Consumption of phytoplankton by bacteria and competition for resources. On the other hand, bacteria were said to consume oxygen, resulting in the release of nutrients from bottom sediments.

Potentially toxic dinoflagellates were present as an important component of the phytoplankton ecology, but cell counts were not high and the observed species were not generally regarded as toxic (ET, 2000a; 2000b; Insearch Ltd, 2000).

Ford *et al.* (2006; full report provided in Appendix K) conducted a plankton study for Brisbane Water Estuary. This study found generally low concentrations of phytoplankton as compared to ANZECC trigger values for chlorophyll *a* (ANZECC, 2000), suggestive of relatively good water quality in Brisbane Water. However, due to drought conditions at the time of sampling, the phytoplankton concentrations found in the study should be treated as baseline data indicative of conditions during low freshwater flow and low to moderate water temperatures (spring temperatures). However, algal bloom conditions may occur after rain events, particularly with increasing urbanisation of the catchment. Consistent with the phytoplankton results, zooplankton shows no evidence of eutrophication and bottom-up enhancement of zooplankton populations.

It was recommended by Ford *et al.* (2006) that further phytoplankton monitoring be conducted in Brisbane Water, particularly during winter or after rainfall events.

During the course of the preparation of this report, on 8 October 2006, the Metro-South Coast Regional Algal Committee issued an algal alert. This alert affected the Riley's Island shellfish harvesting area due to the presence of potentially paralytic shellfish poison (PSP) producing *Alexandrium catenella*. The alert was lifted on the 24 October 2006. This incident demonstrates the potential for phytoplankton related shellfish toxicity and poisoning in Brisbane Water, and highlights the need to continue monitoring with a view to developing an understanding of the driving features of phytoplankton dynamics for the estuary.

7.2.5 Caulerpa taxifolia

Caulerpa taxifolia is a fast-growing marine seaweed that is normally found in warm tropical waters. However, it also has the potential to invade temperate waters and has become established in several areas that do not form part of its normal range of distribution (DPI 2007). According to the DPI (2007a) it has been detected in ten estuaries in NSW. *C. taxifolia* has the potential to rapidly grow and establish itself in a location, thereby altering marine habitats and impacting on biodiversity.

NSW Fisheries have resolved to monitor *Caulerpa taxifolia* but are no longer attempting to control it. The known distribution of *C. taxifolia* in Brisbane Water is provided in Figure 7.5.

There are two key characteristics of the *C. taxifolia* that have helped it to establish and spread in NSW waters:

- It has a rapid growth capability and can out-compete and outgrow native flora such as seagrasses.
- It can produce toxic substances (caulerpenynes) that act as deterrents against many epiphytes and herbivores thus limiting grazing (NSW Fisheries 2007).

The Minister for Fisheries declared *C. taxifolia* Noxious Marine Vegetation from 1 October 2000 under the *Fisheries Management Act 1994*, in recognition of its potential negative impacts on fisheries habitat resources. It is now an offence to possess the algae in coastal waters or to sell it within NSW. According to NSW Fisheries (2007), the origin of the NSW population is uncertain, whilst the species is native to warmer tropical Australian water's, it is not native to NSW water and was possibly introduced from aquaria release.

7.3 Fauna

Fauna are described in this report in terms of:

- Macrobenthic Invertebrates
- Avifauna (birds)
- Fish and prawns
- Oyster leases
- Larval movement.

7.3.1 Macrobenthic Invertebrates

According to Ponder *et al.* (2002), marine invertebrates maintain environmental health through the performance of a range of ecosystem functions, such as:

- They play an important role in cycling nutrients;
- Are essential in the breakdown of detritus and other organic matter;
- Form the basis of many food chains (particularly benthic invertebrates);
- Provide habitat for many species;
- Regulate populations of other organisms through predation, parasitism and herbivory; and
- Help maintain water quality by filtering large amounts of water during feeding.

Freewater (2004) reviews the use of macroinvertebrates as key indicators of estuarine health. Some researchers have speculated that species richness and diversity is greatest at the mouths of estuaries and decreases upstream. However, this generalisation can easily be confounded by the interplay of numerous physical, chemical and biological processes operating at a variety of spatial and temporal scales. The distribution of benthic macroinvertebrates in estuaries is better described as a spatial and temporal mosaic (Freewater, 2004).

There are a myriad of biotic processes that also influence the establishment, distribution and community structure of the macrobenthos, such as:

- Dispersal and recruitment;
- Genetic structure;
- Competition; and
- Interactions with substratum characteristics.

The dispersal and migration of benthic macroinvertebates is governed by complex interactions between physical and biotic processes (Freewater, 2004). Stochastic factors causing variations in recruitment can influence patterns of succession, community structure and composition. Immigration patterns for planktonic larvae are strongly influenced by prevailing hydrodynamic conditions. The “jetting” of larvae along topographically stable fronts on flood tides has been shown to influence the spatial patterns of recruitment in estuaries (Kingsford and Suthers, 1996; cited by Freewater, 2004). After the planktonic larvae of macroinvertebrates have been carried into an estuary their ultimate success depends on settlement and establishment. Substratum has been shown to influence patterns of establishment and change (Freewater, 2004).

A benthic community is the assemblage of bottom dwelling species at a particular time and place. Infaunal benthic invertebrates are subdivided according to sieve mesh size into micro (<0.04mm) meio (0.04-0.1mm), macro (0.5-2.0mm) and megafaunal (>2.0mm) components (Freewater 2004).

Various models have been espoused to describe the different levels of macroinvertebrate communities. Macroinvertebrate communities in soft substrata have been termed “low-grade” communities, largely controlled by physical conditions or organic loadings, with less influence from biological interactions (Freewater, 2004). These fauna are apparently made up of a spatial mosaic of communities at different stages of maturity, constantly being “reset” by localised, small-scale disturbance. They are characterised by low diversity, high abundance and small size strata. However, many of these models come from a few investigations and a handful of observations. Because of the heterogeneous nature of macroinvertebrate assemblages, it is often more sensible to ignore broad generalisations about community structure and evolution and consider each estuarine ecosystem as unique.

Benthic macroinvertebrates have been used successfully as indicators of disturbance to marine ecosystems (Freewater, 2004). Community structure, biomass and relative abundance of trophic groups and indicator species have been developed and used for this purpose. Measures of community structure are problematic because of gaps in understanding about interactions controlling diversity of communities and stability and resilience of the ecosystems. Species richness, diversity indices and measures of biomass are among the most commonly used indicators but there also exist problems with interpretation of the measurements. There are advantages and disadvantages of using macrobenthic assemblages as environmental indicators. The advantages include:

- Numerous species are found together in very small patches of habitat;
- Benthic macroinvertebrates come from a wide variety of types of fauna, notably polychaetes, molluscs and crustaceans, which means they represent a substantial element of local biodiversity;
- Methods of sampling and quantifying them are well known;
- Work on local species (particularly molluscs and crustaceans) has allowed development of experimental techniques to determine what causes changes in their composition and abundances; and
- Research in other parts of the world continuously adds knowledge, understanding and predictive capacity about their ecology and ecological responses to disturbances.

Four separate studies were undertaken to survey macrobenthic invertebrate assemblages in Brisbane Water Estuary:

- *Spatial and Temporal Variation in the Biodiversity of Macroinvertebrates in Brisbane Water Estuary and its Relation to Environmental Variables* (Gladstone, 2006): This report describes the spatial variation that occurs in the biodiversity of macroinvertebrates in intertidal and subtidal vegetated and unvegetated habitats and relationships to environmental variables.
- *Spatial and Habitat-Related Patterns in Biodiversity of Brisbane Water Estuary: a Tool for Sustainable Estuary Management* (Gladstone, 2007): This report describes macroinvertebrate biodiversity occurring in mangroves, seagrass, intertidal rock (natural and constructed rock walls), intertidal sediment and subtidal sediment habitats; and environmental variation occurring in each of these habitats.
- *Sessile Benthic Invertebrates of Brisbane Water: Patterns in Sponges and Ascidians* (Barnes, 2006); and
- *Spatial Patterns in the Macrobenthic Fauna of Mangrove Forests in Brisbane Water Estuary* (Roberts, 2006).

These reports are summarised below, with the full reports presented in Appendices J and L.

Spatial and Temporal Variation in the Biodiversity of Macroinvertebrates in Brisbane Water Estuary and its Relation to Environmental Variables

Gladstone (2006) investigated the spatial variation that occurs in the biodiversity of benthic macroinvertebrates of Brisbane Water Estuary and its relationship to environmental variables. Benthic macroinvertebrates were chosen as an indicator of the overall diversity of the estuary. The specific objectives of the study were:

- To quantify patterns in the distribution and abundance of species and assemblages of benthic macroinvertebrates at a variety of spatial scales within Brisbane Water Estuary in *Z. capricorni* seagrass beds and in subtidal unvegetated habitats.
- To identify the role of environmental variables in explaining the observed spatial and temporal variation in the abundance of species of macrobenthic invertebrates.
- To identify the role of environmental variables in explaining the observed spatial and temporal variation in the structure of assemblages of macrobenthic invertebrates.

Macroinvertebrates were sampled in the following habitats:

- *Z. capricorni* seagrass beds;
- Unvegetated subtidal sediment;
- Unvegetated intertidal sediment;
- Mangroves; and
- Intertidal hard substrates (rocky reefs and man-made structures).

Zostera seagrass beds were 1m deep at low tide and the subtidal unvegetated habitats ranged from 4-6m deep. Details of the survey methods and statistical analyses conducted are provided in full in the report (Gladstone, 2006).

A total of 138 species (13,772 individuals) were recorded, representing 6 phyla;

- Platyhleminthes (flatworms; 1 species)
- Nemertea (ribbon worms; 1 species)
- Annelida (segmented worms, such as polychaetes or beachworms; 48 species)
- Arthropoda (includes the crustaceans; 24 species)
- Mollusca (snails, bivalves, octopods, cuttlefish, squids etc.; 63 species)

- Echinodermata (sea stars, sea slugs, sea urchins and brittle stars; 2 species).

The types of assemblages found in each habitat type and the manner in which they varied (spatio-temporally and in relation to environmental variables) is discussed in full in Gladstone (2006).

It was determined that high species richness was to be likely related to habitat diversity of the estuary and the influence of environmental variation. Locations that had similar assemblage structures tended to separate from one another based on their position within the sea-estuary-creek gradient. This result is in accordance with studies conducted in other estuaries. Spatial variation was predominantly associated with three environmental variables:

- Concentration of phaeopigments (breakdown product of chlorophyll) in sediments,
- Chlorophyll *a* concentration, and
- pH.

The first two variables are effectively related to primary productivity. Primary productivity is affected by the availability of light and nutrients. High planktonic primary production has previously been associated with nutrients introduced via runoff from catchments (see Section 7.2.4). The pH of water is affected by a range of factors. The pH of natural freshwaters is typically 6.5-8.0, while marine waters are typically around 8.2 (ANZECC, 2000). Therefore, pH will to some extent relate to the degree of oceanic versus freshwater influence, or put simply, proximity to the estuary entrance. The pH of freshwaters may also vary in relation to the catchment characteristics, such as the geological composition of the catchment. Catchments with high proportions of sandstone will produce slightly more acidic runoff.

Management actions or interventions should therefore be directed at minimising impacts on the processes controlling these three environmental variables. This could be achieved by concentrating on controlling the quantity and quality of runoff entering Brisbane Water and by maintaining the natural hydrological processes operating in the estuary.

The results of the study were found to have implications for the use of macroinvertebrates in estuarine monitoring programs and the assessment of the impacts of human activities. The following points were noted:

- The number of replicate samples used in the study was appropriate (n=6), as many significant differences were detected.
- A limited number of places randomly chosen as controls cannot be regarded as sufficiently representative of other un-sampled areas for the purposes of testing a significant change at a potentially impacted place.
- An impact will have to cause a very large change in a variable to be detected as a significant change in the difference between the impacted and control places in their natural patterns of spatio-temporal variability.
- Variability at several smaller nested temporal scales (e.g. between days, weeks) may be required to ensure that differences in temporal scales (months, years) are not confounded by greater differences at smaller temporal scales.
- The existence of significant variability at all of the spatial scales examined indicates that monitoring which targets several species will need to include several nested spatial scales and therefore represent a considerable sampling effort.

Regression analyses correlating the diversity of macroinvertebrates with a range of environmental variables were conducted. The implications for the management of Brisbane Water Estuary from this analysis are that:

- Management should aim to maintain the existing estuary-wide variation in environmental variables.

- Environmental variables that appear to be of more importance for management (because they are potentially altered by human activities and are consistently and significantly associated with spatial variation in macroinvertebrates) include the silt/clay content of sediment, turbidity, wrack biomass, seagrass biomass, water column chlorophyll and sediment photosynthetic pigments. The variables may be related to catchment sediment inputs, sediment re-suspension, seagrass floristics, phytoplankton productivity and the productivity of algae living on the estuary bed (the latter two being related to sunlight and nutrient inputs).
- The greatest species richness of macroinvertebrates in seagrass occurred in the Koolewong-Yattalunga area.
- The most distinctive assemblages of macroinvertebrates in seagrass occurred in Fagan's Bay and Hardy's Bay-Wagstaffe.
- The greatest species richness of macroinvertebrates in unvegetated subtidal sediments occurred in Wagstaffe.
- The most distinctive assemblages of macroinvertebrates in unvegetated subtidal sediments occurred in Koolewong and St Hubert's Island.

Gladstone (2006) also investigated the rates of change in the diversity and abundance of species in Brisbane Water estuary. It is important to understand rates of change in order to be able to monitor estuarine assemblages and detect impacts. The variation in assemblages occurs over a range of spatial and temporal scales, ranging from metres to kilometres, and days to decades. In order to ascertain which environmental factors and processes affect assemblage structure, it is necessary to determine the scales at which change occurs.

Gladstone (2006) found that the macroinvertebrates of seagrass and unvegetated sediments changed between sampling occasions, and the temporal changes within each habitat were not spatially congruent. These changes were due to significant changes in biomass at many sites. This was unexpected as biomass is considered a more stable property of macroinvertebrate assemblages in estuaries than density (see review by Gladstone, 2006).

The study found that at the temporal scale examined, the macroinvertebrate assemblages of seagrass beds and unvegetated sediments were highly dynamic and exhibited complex interactions with spatial scale. In contrast with studies conducted elsewhere (see Gladstone, 2006), the magnitudes of spatial and temporal changes were not correlated, indicating that species are responding to different environmental factors that vary in intensity over a period of 6 months (the time between sampling periods) and are spatially patchy at scales of 100s m or kms. However, it is possible that the observed temporal variation may, in fact, reflect sampling error.

The study found that the major source of spatial variation occurred over a relatively small scale of 1-2m in seagrass and 3-5m in unvegetated sediments, as has been found for other estuaries (see review by Gladstone, 2006). This result was thought to be due to a number of factors, such as the small size of the sampling unit relative to the mobility of some taxa, the random distribution of some macroinvertebrates and small scale patchiness in resource availability and intensity of inter-specific interactions.

As discussed above, the implications of this is that variability at several smaller nested temporal scales (e.g. between days, weeks) need to be targeted in future sampling programs to ensure that differences in temporal scales (months, years) are not confounded by greater differences at smaller temporal scales. In addition, the existence of significant variability at all of the spatial scales examined indicates that monitoring which targets several species will need to include several nested spatial scales and therefore represent a considerable sampling effort.

The rationale behind describing scales of spatial and temporal variability in estuarine biodiversity and describing its relationship to environmental variation is to provide guidance to estuary managers about how they might intervene in an attempt to maintain natural patterns and processes. The results of this study highlight the complexity of this process.

Different organisms will respond to the same suite of environmental variables in different ways. Therefore, it is important to consider each group / type of organisms separately. This was done by Gladstone (2007), who undertook further statistical analyses of all the ecological data collected as part of the Brisbane Water Estuary Process Study. The focus was on testing for relationships between spatial variability in assemblages of different types of organisms and spatial variation in measured environmental and habitat features. The latter test was done by canonical correspondence analysis (CCA). The results are presented below.

Spatial and habitat-related patterns in biodiversity of Brisbane Water estuary: a tool for sustainable estuary management

The objectives of this study were:

1. To survey the macroinvertebrate biodiversity occurring in representative habitats throughout Brisbane Water estuary, including mangroves, seagrass, intertidal rock (natural and constructed rock walls), intertidal sediment and subtidal sediment
2. To survey the environmental variation occurring in subtidal sediment throughout Brisbane Water estuary and to test for its relationship to spatial variation in the macroinvertebrate assemblages of this habitat
3. To use the results of (1) to quantify variation in conservation value throughout Brisbane Water estuary
4. To prepare GIS layers from the data collected in (1) and (2).

A comprehensive sampling program was undertaken throughout Brisbane Water estuary, focusing on the biodiversity of macroinvertebrates. The total area of the estuary was divided into 36 grids of 1km × 1km squares in order to provide a uniform degree of sampling resolution. Each habitat present in each grid was sampled for macroinvertebrates. Habitats present in the estuary included: mangroves, *Z. capricorni* seagrass beds, unvegetated subtidal sediment, unvegetated intertidal sediment, intertidal rocky reef and human-made hard substrate (e.g. rock walls). Grid cells extended from the entrances of three creeks entering the estuary (Narara, Erina, Kincumber), the central water body of the estuary, three adjoining water bodies (Fagan's Bay; Woy Woy Bay; and Kincumber Broadwater) and the seaward limit of the estuary at Ettalong-Umina.

Five habitats were sampled throughout the estuary: *Z. capricorni* seagrass meadows, subtidal unvegetated sediment, intertidal mud flats, intertidal hard substrates (natural and anthropogenic) and mangroves. Habitats were represented throughout Brisbane Water in the following pattern: subtidal unvegetated substrates (present in 36 grid cells), intertidal mud flats (33 grid cells), *Z. capricorni* seagrass meadow (30 grid cells), intertidal hard substrates (28 grid cells) and mangroves (27 grid cells).

Identification of invertebrates was assisted by staff from the Australian Museum and the resulting collection now forms part of their invertebrate collection. A total of 324 species (72,524 individuals) were recorded, representing 16 phyla:

- Foraminifera (1 species),
- Porifera (2 species),
- Ectoprocta (2 species),
- Chordata (3 species),
- Cnidaria (3 species),
- Platyhelminthes (1 species),

- Nematoda (2 species),
- Nemertea (1 species),
- Annelida (74 species),
- Sipuncula (2 species),
- Arthropoda (66 species),
- Echinodermata (7 species),
- Mollusca (141 species),
- Chlorophyta (5 species),
- Phaeophyta (5 species), and
- Rhodophyta (9 species).

The polychaete worm *Bispira sp*. (Polychaeta: Sabellidae) was a new record from NSW. This species had been previously reported only from Queensland (P Hutchings, Australian Museum, pers. comm).

The greatest number of species was recorded in Fagan's Bay (112 species). The least number of species was recorded in the area extending between Point Frederick and Green Point (23 species).

One hundred and eighty-eight species were recorded from *Z. capricorni* seagrass meadows habitat with an average of 40 species (range 21-56 species) per grid cell. The greatest number of species (56 species) in the seagrass habitat was recorded at Yattalunga and Ettalong.

One hundred and eight species were recorded from intertidal mud flats with an average of 14 species (range 1-28 species) per grid cell. The greatest number of 4 species (28 species) in the intertidal mud flat was recorded in Woy Woy – St. Hubert's Island.

A total of 124 species were recorded from mangrove habitat with an average of 27 species (range 1-40 species) per grid cell. The greatest number of species in the mangrove habitat was recorded in Point Clare, Koolewong and Saratoga (40 species).

A total of 160 species were recorded from subtidal unvegetated sediment with an average of 22 species (range 2-51 species) per grid cell. The greatest number of species in the submerged unvegetated habitat was recorded in Woy Woy Bay – Pelican Island (51 species).

A total of 73 species were recorded from intertidal hard substrates with an average of 17 species (range 5-35 species) per grid cell. The greatest number of species in the intertidal hard substrates habitat was recorded in Ettalong (35 species).

Five assemblages of macroinvertebrates occurred in Brisbane Water estuary:

1. Entrance to Narara Creek;
2. The marine boundary with the estuary between Wagstaffe and near Pearl Beach;
3. The entrance to Kincumber Creek and the adjacent Kincumber Broadwater;
4. The central section of the estuary; and
5. All remaining grid cells.

This spatial pattern in assemblage structure was significantly related to: concentration of phaeopigments in the sediment, concentration of chlorophyll a in surface water and pH of surface water.

The conservation value of different parts of the estuary was quantified as the contribution of each grid cell to the conservation target of representing each species in Brisbane Water estuary (i.e. the complementarity approach). A simulated conservation planning exercise found that the 5 top five grid cells, which together included 74% of all recorded species, were Ettalong, Narara Creek, Koolewong, Woy Woy Bay-Pelican Island and Umina. The grid cell with the highest conservation value in Brisbane Water estuary (Ettalong) included 34.5% of all species. A total of 25 grid cells (representing 69% of the area of Brisbane Water estuary) included all species recorded in the study.

Conservation of the biodiversity of Brisbane Water estuary must be based on the objective of maintaining the existing spatial patterns of biodiversity. This can be done by conserving the ecological processes and environmental factors underlying the spatial patterns in biodiversity, by managing human uses to minimize changes to these factors and processes.

The identification of a suite of environmental variables underlying the spatial variation in biodiversity (silt/clay content of sediment, conductivity, depth, sediment phaeopigments, surface water chlorophyll *a* and pH) suggests that management should attempt to ensure minimal disturbance to their natural patterns of variation. Human activities likely to alter these variables therefore need careful assessment and management. Five grid cells were identified as being highly important for the representation of the species biodiversity of Brisbane Water estuary macroinvertebrates: Ettalong, Narara Creek, Koolewong, Woy Woy Bay-Pelican Island and Umina. These grid cells require a high priority for management action to minimize impacts of human activities.

The grid cell with the second-highest conservation value occurred in Narara Creek. This area will require special management attention, if the high conservation value is to be conserved, due to the range of human uses currently occurring along the banks and within the catchment of Narara Creek.

Sponges and Ascidians

Sponges and ascidians are sessile, benthic filter-feeding invertebrates. They are often brightly coloured and generally present in high numbers in Australian estuaries, but represent some of the most poorly described and least understood animals.

The survey undertaken for the purposes of this study aimed to describe the basic patterns of diversity and abundance of sponges and ascidians in Brisbane Water. Of the 20 locations surveyed, only 6 were found to have any sponge or ascidian species. Species were patchily distributed and none were widespread. A total of 2 ascidian species and 5 sponge species were observed.

The most abundant sponge in all 6 locations was *Mycale* sp., which was found at densities of approximately 1-25 individuals/100m². *Mycale* sp. was most abundant on the leaf blades of seagrasses *Posidonia* and *Zostera* at sites located near the estuary entrance. *Mycale* sp. was also relatively abundant on *Posidonia* in the Cockle Broadwater and The Broadwater. The remaining sponge species were represented by a single or only a few individuals at 1 or 2 locations. Of the patchily distributed sponges, *Niphates* sp. and *Desmapsamma* sp. were found near the base and on the leaves of *Posidonia* near the entrance. *Haliclona* sp. was observed living on mussels within a dense bed *of Posidonia* near Point Clare. Additionally, a single upright *Spongia* sp. was found amongst a dense bed of *Posidonia* to the south of Green Point. *Spongia* sp. is typically of marine origin and is susceptible to changes in water quality (see literature review by Barnes, 2006).

Only a few individuals of the ascidian *Eudostoma* sp. were found, in this case near the estuary entrance. Although not particularly abundant, the most common ascidian was the non-native *Styela plicata*, which was found in the Cockle Broadwater and The Broadwater. *S. plicata* is widely distributed on coasts of the warmer parts of the Atlantic, Pacific and Indian Oceans and may be spread to other locations after fouling the hulls of vessels. Whilst it is rarely classified as a pest species, some management options are available for controlling its abundance (Global Invasive Species Database, 2007). Different stages of the life cycle of *S. plicata* have different habitat requirements. Impacts associated with this species include the inhibition of recruitment and growth of other species, destabilising the benthic community, and the species may also act as a vector for other invasive marine species.

A full list of the species observed and their habitat associations is provided in Barnes (2006). Sponges and ascidians were commonly found in locations with 100% cover of *Posidonia*, compared to locations dominated by *Zostera*, *Halophila* or macroalgae. Further, sponges and ascidians were not found in the channels around Pelican Island, Riley's Island or St Hubert's Island, but rather near the estuary entrance or in broader expanses of water (eg The Broadwater, the Cockle Broadwater). This may be due to their filter-feeding lifestyle. Figure 7.6 shows some of the sponge and ascidian species found by Barnes (2006).

A literature review provided in Barnes (2006) indicates that the diversity of sponges and ascidians varies with estuary size and entrance characteristics. Brisbane Water Estuary was found to be similar to other large NSW estuaries with oceanic exchange restricted to some extent, such as Lake Macquarie and Wallis Lake. In the case of Brisbane Water, this may relate to the relatively low flushing times observed in some parts of the estuary (Section 4.3).

It is important to note that assemblages of sponges and ascidians in some NSW coastal lakes and estuaries have been known to undergo dramatic changes from time to time (see Barnes, 2006). The literature review provided in Barnes (2006) suggests that local extinctions and declines are not uncommon. Therefore, replication of the survey over time is required to gain a more advanced understanding of these assemblages in Brisbane Water Estuary. It is important to assess rates of change in order to detect environmental impacts and the effects of climate change over time.

Sponges and ascidians are known to be highly variable seasonally and on longer temporal scales. The survey discussed herein represents a single sampling time and therefore the results should be treated with caution.

Mangrove Forest Macrobenthic Invertebrates

As previously discussed, the macrobenthic faunal assemblages of mangrove forests were also assessed (Roberts, 2006). Mangrove forests are highly diverse ecosystems. A number of different feeding groups can be found in these habitats:

- Epifaunal suspension-feeders,
- Infaunal suspension-feeders,
- Surface deposit-feeders,
- Grazers,
- Predators, and
- Scavengers.

The dominant trophic groupings are the suspension-feeders and deposit-feeders. The feeding, burrowing and ventilatory activities of mangrove forest dwelling macroinvertebrates can have a profound effect on the sedimentary environment and the storage, transfer and release of nutrients to the overlying water column (see literature review by Roberts, 2006).

As discussed in Section 7.2.2, human activities have impacted negatively on aquatic communities. These communities are subject to a variety of stresses from pollution (contamination and nutrient enrichment) and physical stressors (dredging, reclamation and recreational activities). It is understood that anthropogenic disturbances can alter the structure and dynamics of mangrove communities and this is often manifested as high variation in the diversity and abundance of organisms at different spatial and temporal scales. Literature cited by Roberts (2006) indicates that macrobenthic organisms are sensitive to anthropogenic disturbance and are therefore a good bio-indicator of potential environmental impacts.

A survey of the macrobenthic (>0.5mm) invertebrate fauna was conducted at 15 locations around Brisbane Water Estuary, with 2 randomly nested sites at each location (i.e. a total of 30 sites. The aim was to quantify patterns of species richness and abundance over these spatial scales.

A total of 616 individuals from several groups were found, including worms, molluscs (shellfish) and crustaceans. The most abundant species was the bivalve (two hinged shells) mollusc *Glauconome plankta*. Other common taxa included the gastropod (snail) *Battilaria australis*, the crabs *Paragrapsus laevis* and *Heloecius cordiformes* and the amphipod Family Talitridae.

There were significant differences in the richness and abundance of invertebrate species amongst locations. The macrobenthic invertebrate assemblage structure differed between the 15 locations. A few of these locations had similar characteristics, but overall there was no observable pattern. This is not surprising as many physical and biological differences occur at different locations (see Roberts, 2006). For example, differences include variations in the hydrodynamic tidal regime, which delivers nutrients and larvae to a particular location. Lintern Channel had the highest number of taxa and individuals and Fagan's Bay also had relatively high species richness and abundances.

There was not a significant difference between the separate sites within a single location. At this spatial scale the observable patterns of diversity and abundance were less complex and relatively consistent within a particular location.

It was demonstrated that the bivalve mollusc *G. plankta* was the most important species contributing to the structure of assemblages at most locations. The crab *P. laevis* was also an important contributor at some locations.

It was concluded that mangrove forests have diverse assemblages of macrobenthic invertebrates. The most common taxa were also recorded for other NSW estuaries and in previous studies in the Brisbane Water Estuary (see Roberts, 2006). The most common taxa are bivalve and gastropod molluscs, crustaceans (e.g. crabs and amphipods) and numerous species of polychaete worms (bristle or beach worms). The structural complexity of mangrove forests is associated with the high diversity and mangrove forests are known to support communities with higher diversity than other less structurally complex habitats (see review by Roberts, 2006). Additionally, vegetated habitats, such as mangroves, provide higher amounts of organic matter for food.

The physical structure of mangrove forests, such as the density of trees and canopy cover can influence the amount of light available for algal growth on the forest floor and leaf litter production. The density of pneumatophores of *A. marina* can also influence the assemblage structure. Biological interactions between fauna may also influence assemblages. For example, the burrowing activity of crabs aerates the sediments, which assists other organisms in colonising the sediment (refer to literature review by Roberts, 2006).

The data was also analysed using Canonical Correspondence Analysis (CCA; Gladstone, 2007). Fifteen locations representing mangrove (*Avicennia marina*) habitat throughout Brisbane Water estuary were sampled for macrobenthic organisms and for the features of the mangrove forest. CCA found that the assemblages of macrobenthic organisms occurring in *A. marina* mangrove forests showed considerable spatial variation in assemblage composition. However, despite the existence of significant spatial variation in habitat features none of the measured mangrove habitat features explained a significant amount of the spatial variation in macrobenthic assemblage structure.

7.3.2 Avifauna

Robinson (2006) undertook an assessment of the avifauna of Brisbane Water Estuary. A literature review and systematic field survey were undertaken during the preparation of that report. The findings of that report are summarised here and the full report can be found in Appendix J.

The Brisbane Water Estuary provides a diverse array of habitats suitable for birds and, though near a major city (Sydney) and the regional centre of Gosford, its bird assemblage is poorly studied. The Estuary is on the route of the East Asian-Australasian Flyway which is used by shorebirds to move between Australia / New Zealand, East Asia and the Arctic region of the northern hemisphere. The estuary has been observed to be used as habitat by 21 species of regular migrant shorebirds, which represent 58% of the migratory shorebird species documented in Australia. Migratory birds are protected primarily by the China Australia Migratory Bird Agreement (CAMBA) and/or the Japan Australia Migratory Bird Agreement (JAMBA). Brisbane Water is a stopping-off point for birds travelling between wetlands. Brisbane water is one of five estuaries that occur between two significant Sydney Basin Bioregion coastal estuaries that have been identified as Ramsar wetlands (Robinson 2006). These wetlands of internationally significance are the Towra Point NR in Botany Bay and Kooragang Island NR in the Hunter River estuary (Robinson 2006).

Brisbane Water Estuary is habitat to a variety of shorebirds, waterbirds and forest birds. There are at least 110 species (including 4 exotic species) from 23 Orders, 34 Families (including 1 exotic family) and 79 Genera (including 3 exotic Genera) documented from the estuary. The 8 species of resident shorebirds observed represent 44% of all Australian resident shorebird species. These results provide an indication of the importance of Brisbane Water Estuary for both regional and national avifauna conservation.

Birds are an important part of the overall biodiversity of the estuary and may also be valued for their functional role in ecological processes such as nutrient cycling, seed dispersal and population regulation (including both predation and herbivory). However, the main attributes used to profile the conservation status of bird species in Brisbane Water Estuary were:

- Threatened Species,
- Declining Species,
- Regionally Significant Species, and
- Species recognised in international treaties to which Australia is signatory.

Amongst the species recorded in the estuarine habitats, there are 25 species whose populations are thought to have increased across Australia. The Brisbane Water estuarine bird assemblage includes 15 species that have declined nationally and 28 species that reach their southern geographic limit in the Sydney Basin Bioregion. Therefore, the protection and conservation of suitable habitat for these species is very important as part of national and international conservation initiatives.

Threatened Species

Of the bird species recorded, 11 are listed on the schedules of the TSC Act, of which 2 are Endangered and 9 are Vulnerable. There are no threatened species as listed under the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act*. However, the Eastern Curlew (*Numenius madagascariensis*), Bush Stone-Curlew (*Burhinus grallarius*) and Lewins Rail (*Rallus pectoralis*) have been listed as Near-Threatened on the World Conservation Union’s (IUCN) Red List of Threatened Species (IUCN, 2007). Table 7.3 summarises the occurrence of TSC Act listed species in Brisbane Water. Further information is provided in Robinson (2006) on these threatened species.

Table 7.3 Species Listed Under the *Threatened Species Conservation Act 1995* for Brisbane Water Estuary (after Robinson, 2006)

Common Name	Scientific Name	TSC Act (NSW)
Bush Stone-curlew	*Burhinus grallarius*	E
Little Tern	*Sterna albifrons*	E
Black Bittern	*Ixobrychus flavicollis*	V
Black-tailed Godwit	*Limosa limosa*	V
Broad-billed Sandpiper	*Limicola falcinellus*	V
Lesser Sand Plover	*Charadrius mongolus*	V
Osprey	*Pandion haliaetus*	V
Pied Oystercatcher	*Haematopus longirostris*	V
Sanderling	*Calidris alba*	V
Sooty Oystercatcher	*Haematopus fuliginosus*	V
Terek Sandpiper	*Xenus cinereus*	V

E = Endangered, V=Vulnerable

Declining Species

An analysis undertaken by Robinson (2006) indicated that at least 15 species previously recorded in Brisbane Water Estuary have declined nationally over a period of approximately 25 years (see Table 7.4). This includes 3 species listed as Vulnerable under the TSC Act. The majority of these birds in decline are waterbirds (67%), including shorebirds (6 migratory species), large wading birds (2 species), 1 medium-sized wading bird species and 1 piscivore (fish eater). Five of the other declining birds are raptors, of which 1 piscivorous species.

Table 7.4 Avifauna with Populations in Decline on a National and Regional Basis (after Robinson, 2006)

Common Name	National	% Change	Sydney Basin
Black-tailed Godwit (V)	Declining (no regional variation)	-35	Not provided
Pacific Golden Plover	Declining (no regional variation)	-33	Not provided
Terek Sandpiper (V)	Declining (no regional variation)	-29	Not provided
Curlew Sandpiper	Declining (no regional variation)	-26	Not provided
White-necked Heron	Declining species (regional variation)	-58	>20% decrease
Nankeen Kestrel	Declining species (regional variation)	-44	>20% decrease
Brown Falcon	Declining species (regional variation)	-38	>20% decrease
Lesser Sand Plover (V)	Declining species (regional variation)	-37	>20% decrease
Great Cormorant	Declining species (regional variation)	-31	Not provided
Wedge-tailed Eagle	Declining species (regional variation)	-28	>20% decrease
Sharp-tailed Sandpiper	Declining species (regional variation)	-24	>20% decrease
Nankeen Night Heron	Declining species (regional variation)	-17	Insufficient data
Whistling Kite	Declining species (regional variation)	-16	>20% decrease
Little Eagle	Declining species (regional variation)	-14	No significant change
White-faced Heron	Declining species (regional variation)	-13	>20% decrease

Regionally Significant Species

In addition to the 29 bird species that have declined in the Sydney Basin Bioregion, there are several species in Brisbane Water Estuary that could be considered regionally significant within the bioregion. This includes the Brahiminy Kite (*Haliastur indus*), the Mangrove Greygone (*Greygone levigaster*) and the Brown Honeyeater (*Lichmera indistincta*). Further details on these species are provided in the full report in Appendix J (Roberts, 2006).

Species Recognised in International Treaties

As outlined above, Australia is a signatory to bilateral agreements with Japan (JAMBA, 1981) and China (CAMBA, 1988). These agreements specifically target migratory species using the East Asian-Australasian Flyway and their habitat. Brisbane Water Estuary is habitat for at least 26 JAMBA and 24 CAMBA listed species (Table 7.5).

Table 7.5 JAMBA and CAMBA Listed Species (after Robinson, 2006)

Common Name	Scientific Name	JAMBA / CAMBA
Short-tailed Shearwater	*Puffinus tenuirostris*	J
Cattle Egret	*Ardea ibis*	J / C
Great Egret	*Ardea alba*	J / C
Latham's Snipe	*Gallinago hardwickii*	J / C
Black-tailed Godwit	*Limosa limosa*	J / C
Little Curlew	*Numenius minutus*	J / C
Whimbrel	*Numenius phaeopus*	J / C
Eastern Curlew	*Numenius madagascariensis*	J / C
Marsh Sandpiper	*Tringa stagnatilis*	J / C
Common Greenshank	*Tringa nebularia*	J / C
Terek Sandpiper	*Xenus cinereus*	J / C
Common Sandpiper	*Actitis hypoleucos*	J
Grey-tailed Tattler	*Heteroscelus brevipes*	J
Ruddy Turnstone	*Arenaria interpres*	J / C
Red Knot	*Calidris canutus*	J / C
Sanderling	*Calidris alba*	J / C
Red-necked Stint	*Calidris ruficollis*	J / C
Sharp-tailed Sandpiper	*Calidris acuminate*	J / C
Curlew Sandpiper	*Calidris ferruginea*	J / C
Broad-billed Sandpiper	*Limicola falcinellus*	J / C
Pacific Golden Plover	*Pluvialis fulva*	J / C
Grey Plover	*Pluvialis squatarola*	J / C
Lesser Sand Plover	*Charadrius mongolus*	J / C
Capian Tern	*Sterna caspia*	C
Crested Tern	*Sterna bergii*	J
Little Tern	*Sterna albifrons*	J / C
White-bellied Sea-eagle	*Haliaetus leucogaster*	C

Management Issues

The key management issues for estuarine bird assemblages in Brisbane Water include:

- Disturbance,
- Predation,
- Climate change,
- Weed invasion,
- Estuarine vegetation dynamics,
- Oyster leases and jetties, and
- Avian influenza.

Disturbance

Robinson (2006) does not provide a detailed assessment of the effects of disturbance on avifauna, but provides a general overview of the types of disturbance observed and known to occur.

Saltmarsh habitat appears to be the most vulnerable to habitat perturbations (see Section 7.2.1). Any immediate to long-term effect of saltmarsh habitat degradation on the estuarine bird assemblage is unknown. It is expected that vehicular, motorcycle and bicycle disturbance frequency itself will have a more immediate impact on bird biology by either disruption to activities while the disturbance is occurring or by affecting habitat regeneration. Pedestrian and pet walking activities disturbing avifauna has been identified as a concern by others. It has been suggested that continual disturbance of waders may limit their food intake, affecting the fat reserves that are needed during their lengthy return to Palearctic breeding areas (Smith, 1991; cited Robinson, 2006). A literature review by Robinson (2006) suggests that the activities of people significantly reduce foraging times; particularly in the presence of off-leash dogs and that birds avoid areas with large numbers of people or forage at night to avoid periods of peak usage. Dogs that are off-leash would typically run along the water's edge and disrupt the foraging birds which would then take to the wing.

It is understood that no systematic study of the effect of pedestrian / pet walking on birds for Brisbane Water has been undertaken. However, Robinson (2006) notes many personal observations of this effect. While pedestrian activity (including dog walking) along foreshore reserves did not always elicit a negative response (cessation of foraging or taking flight), observations to this effect were generally recorded. Watercraft travelling in an erratic fashion at speed can have a more significant impact, with jet skis that may enter shallow waters being of particular concern. Casual observations made by Robinson (2006) indicate that the magnitude of the effect varies with speed. Birds either ignore the passing vessel or stop foraging and scurry from the boat wake as it washed over the mudflats.

The frequency and extent of disturbance of avifauna in Brisbane Water Estuary is unknown.

Predation

The primary threat to avifauna is predation by feral and domestic animals. A literature review by Robinson (2006) provides details of the extent of predation on bird species in Brisbane Water Estuary, including the following details:

- At least 186 species eaten by cats (*Felis catus*) including waterbirds and seabirds.
- Hunting of native birds and damage of nests of ground nesting species.
- Predation of Lewins Rails, Bush Stone-curlews, White necked Heron and ground-dwelling Brown Quail by cats and/or foxes (*Vulpes vulpes*).

Most of these species are known to be in decline or threatened species (see above).

Personal observations made by Robinson (2006) included dog prints in saltmarsh and mudflat areas, a Fox sighting in saltmarsh at Bensville and a dead, partially consumed White-faced Heron at Davistown. The proximity of estuarine and urban habitats, as can be observed at Brisbane Water Estuary, is stated to be of concern for avifauna.

Climate Change

Climate change has been identified as a major threat to wetland bird species due to changed rainfall and sea levels, as this will affect the geomorphological processes and spatial configuration of estuarine habitats, such as mudflats. Climate change is a particular challenge to estuarine environments such as Brisbane Water, as they are typically situated adjacent to major urban centres. Responses to climate change, such as migration, may be inhibited due to the presence of human structures. This applies more to the bird's habitat, than the birds themselves, as they are generally highly mobile animals.

Whilst climate change has been recognised as an issue for avifauna conservation, it is understood that there has been little discussion or modelling on its impact on Australian avifauna. A recent Australian paper (Chambers et al, 2005; cited Robinson, 2006) identified the following potential impacts of climate change on Australian avifauna:

- Changes in the distribution of species both latitudinal and altitudinal,
- Changed movement patterns,
- Changes in abundances of species, including some local extinctions,
- Changes in phenology (timing of life cycle events),

- Changes in community composition, and
- Changes in physiology, morphology and behaviour.

Robinson (2006) provides a literature review of some evidence that these processes are already occurring.

While all of these effects may not be applicable to the estuarine birds of Brisbane Water, some issues may be pertinent. Coastal inundation due to sea level rise and changes in patterns of rainfall / flooding may result in loss of habitat for both resident and migratory species. In the uncertain future facing coastal wetland habitats under global climate change, it is expected that Brisbane Water Estuary will provide some functional role in supporting estuarine bird populations.

Estuarine Vegetation Dynamics

Estuarine vegetation dynamics are a complex processes involving the interplay of factors such as tidal inundation, ocean currents, evaporation, rainfall, substrate, competition, available flora, salinity, elevation, sedimentation and seed predation. Some of these processes are considered elsewhere (see Sections 7.2). The field survey conducted by Robinson (2006) was not considered sufficient to discern any changes to bird assemblages as a result of mangrove colonisation of saltmarsh. However, this may be due to limitations on the time available to conduct surveys. Saltmarsh is an important habitat for a number of species including the Sharp-tailed Sandpiper (*Calidris acuminata*), an infrequently recorded species in Brisbane Water Estuary.

Oyster Leases and Jetties

The survey did not target oyster leases and jetties despite the fact that they constitute extensive artificial habitats in Brisbane Water Estuary. At least 17 bird species were observed using oyster leases as habitat, including the threatened Pied Oystercatcher and several migratory waders.

It is understood that there are no empirical studies on the effects of oyster leases on the physical or biological attributes of Australian estuaries. However, a literature review by Robinson (2006) of overseas studies reports on significant changes in the macrofaunal community under oyster leases and increases in organic and silt composition and reduced depth of the oxygenated water layer associated with oyster leases. In general, nutrient enrichment was not reported as being a problem due to dispersion and dilution by tidal flows. It is understood that the environmental impacts associated with oyster cultivation are more severe in areas of large scale (hectares) cultivation. Studies conducted overseas also found that the community structure of birds was altered for species using oyster bed habitats (see Robinson, 2006).

It is suggested that management of the oyster industry in Brisbane Water Estuary give consideration to the effects of oyster leases on estuarine habitats and bird populations. The current annual production of oysters in NSW is around 106 million oysters and is worth approximately $30 million (NSW Fisheries, 2007).

7.3.3 Fish and Prawns

The previously discussed thesis by Boyland (2006; Section 7.2.3) also investigated the link between seagrass bed structure and fish assemblages. The results of that study are summarised below, with the full report available in Appendix J.

A literature review conducted by Boyland (2006) identified the following important relationships between fish / crustaceans and seagrass beds:

- Seagrass beds are a feeding ground. Fish typically eat plankton, crustaceans and (to a lesser extent) the epiphytic macroalgae found growing on seagrasses.
- Providing a range of microhabitats which are used as shelter by small cryptic fish, marine juveniles and larger, more mobile fish species.
- Nursery grounds for many juvenile and post-larval fish species, due to their function as refugia and feeding grounds (for example Yellow-fin Bream, Luderick and Leatherjackets).

The study targeted all five major waterways in Brisbane Water Estuary, in each of which two locations consisting of *Z. capricorni* seagrass beds were surveyed. There were two sites nested within each location (i.e. a total of four sites). Fish and crustacean assemblages were sampled by seine netting (8mm mesh size). The fish species targeted for analysis are shown in Table 7.6.

Table 7.6 Recreationally Important Fish Species Analysed (after Boyland, 2006)

Family	Targeted Species
Hemiramphidae	*Hyporhampus australis* (Eastern Garfish)
Sparidae	*Acanthopagrus australis* (Yellow-finned Bream)
	Rhabdosagrus sarba (Tarwhine)
Girellidae	*Girella tricuspidata* (Luderick)

These fish species were further divided into ecotrophic guilds to examine their role in the ecology of seagrass beds.

Spatio-temporal Patterns in Fish Assemblages

This study showed that the diversity of fish assemblages occupying *Zostera* seagrass beds increased over time, while there was no change in fish abundance. This was found to concur with other studies. Examination of different spatial scales showed that fish assemblage structure, fish diversity and invertebrate diversity varied amongst locations, but not at the smaller scale of sites. This indicates that efforts to conserve the diversity of fish and invertebrates in Brisbane Water Estuary will be more effective when several key, complementary sites located in different parts of the estuary are protected.

The data was also analysed using CCA (Gladstone, 2007). Assemblages of fishes occurring within *Z. capricorni* seagrass beds were not structured by the position of seagrass beds within the estuary. Assemblages from adjacent locations (~ 1 km apart) or from adjacent sites (~ 500 m apart) were not more similar to one another than to assemblages from other locations or sites.

CCA found that spatial variation in fish assemblages was significantly associated with spatial variation in two features of seagrass beds: average percent cover and average length of *Z. capricorni* leaves. These 2 features together explained 21% of the total spatial variation in the fish assemblages. Therefore 79% of the spatial variation in fish assemblages is not explained by the features of seagrass tested.

The CCA revealed distinct assemblages of fishes associated with combinations of features of seagrass beds. For example, the species assemblage occurring in seagrass with low percent cover and intermediate length of seagrass leaves includes *Achoerodus viridis* (Blue Grouper), *Hippocampus whitei* (White's Seahorse), *Meuschenia freycineti* (Six-Spine Leatherjacket) and *Parupeneus signatus* (Black-Spot Goatfish).

Fish diversity and abundance increased when comparing the first sampling period (late spring/early winter) to the second (late summer/early autumn). This may relate to a number of variables such as water temperature, rainfall patterns, life cycles of the target fish and the seasonal growth of seagrasses (Boyland, 2006). At the spatial scale of locations there were no significant differences over time, but at the smaller scale of sites there were significant differences in these variables.

The ecotrophic guilds examined included ecological guilds (estuarine residents, marine adventitious visitors and marine juvenile visitors) and vertical guilds (benthic, dermersal and pelagic) (Boyland, 2006). Both the ecological and vertical guilds varied amongst locations within the estuary, similar to fish assemblages. When examining temporal changes, it is apparent that estuarine residents and marine adventitious visitors increased, while marine juveniles decreased when comparing the first sampling period and the second.

Again, this may relate to seasonal factors as well as the general breeding / recruitment cycle of the different ecological guilds. In the case of marine adventitious residents, it is not surprising that they vary amongst locations within the estuary as these species are more likely to be found in proximity to the estuary entrance and the open ocean. This can relate to a number of factors such as the distance travelled, water temperature and salinity. The observed spatial variation in vertical guilds may vary due to the different lifestyles and feeding strategies of the different groups.

Relationships Between Seagrasses and Fish Assemblages

There was a negative relationship between seagrass coverage and the diversity of fish and invertebrates. As previously discussed (Section 7.2.3) there is a complex interplay between seagrass cover, shoot density, leaf length and depth. Therefore, the decline in fish and invertebrate diversity and with increasing seagrass coverage is likely a function of all these factors, as well as other environmental variables. The percentage cover of epiphytes on seagrasses had no relationship to fish assemblages. This finding is not unexpected as few fish species feed on macroalgae. However, the diversity and abundance of invertebrates decreased significantly with increasing epiphyte cover. It is thought that this relates to grazing by invertebrates, i.e. where there are invertebrates are abundant, they graze down the biomass of epiphytes on seagrasses.

When considering the ecotrophic guilds, a similar pattern was observed for estuarine residents and the pelagic vertical guild. Both groups declined in abundance with increasing seagrass cover, shoot density and leaf length, which are related to depth. This is likely to be related to their food preferences. Marine adventitious species increased with seagrass cover (and depth). This relationship was greatly influenced by the most common marine adventitious visitor, *Hyporhampus australis*, and was attributed to the fact that this represents ideal habitat for this species. The most common marine juvenile species, *G. tricuspidate*, *A. australis* and *R. sarba*, were observed to be abundant over seagrass beds with a high percent coverage, which was related to their dietary preferences. The vertical guild represented by the demersal grouping declined with increasing epiphyte cover, presumably due to a lack of prey, but had no relationship with seagrass coverage, shoot density or leaf length. The benthic group had a relationship with only one variable, being epiphyte coverage. Benthic species are typically invertebrate grazers and, as discussed above, invertebrate abundance increases with decreasing epiphyte cover. In addition, epiphyte cover was shown to have a negative relationship with leaf length (Section 7.2.3), which translates to low epiphyte biomass for deeper seagrass beds.

In summary, fish assemblages associated with deeper seagrass beds contrast with those associated with shallow seagrass beds. Shallow seagrass beds typically have:

- More structural complexity and therefore a wider variety of microhabitats;
- More diverse assemblages of fish and invertebrates;

- A lower biomass of epiphytes;
- Higher abundances of the ecological guilds described as estuarine residents and marine juveniles, and lower abundances of marine adventitious species;
- Higher abundances of the pelagic vertical guild; and
- Higher abundances of fish from the benthic and demersal vertical guilds.

While it is noted that the protection of seagrass beds for the purpose of fish conservation is a complex issue, given the floristic characteristics of seagrass beds can be influenced by a range of environmental variables, these results suggest that maintenance of the abundance and diversity of fish assemblages within the estuary can be achieved by providing some form of protection for shallow seagrass beds.

7.3.4 Oyster Leases and Pearl Farming

The current annual production of oysters (*Saccostrea glomerata*) in NSW is around 106 million oysters and is worth approximately $30 million (NSW Fisheries, 2007). Oyster farming has been the most valuable aquaculture industry in NSW for over 100 years. There are a number of oyster leases operating in Brisbane Water Estuary, the locations of which are shown in Figure 7.7. Brisbane Water Estuary has a history of oyster farming and also has an annual Brisbane Water Oyster Festival which is held in November. More recently, the effects of the QX disease have been far reaching.

Oysters are bivalve molluscs which feed by filtering phytoplankton, bacteria and nutrients from the surrounding water. In this manner, oysters can improve the water quality of an estuary. They reproduce by spawning, with fertilisation taking place in the water column. The larvae grow and develop in the water column for a further 3-4 weeks before settling on a clean, hard surface, at which point they are known as ‘spats’ (NSW Fisheries, 2007). Survival rates during the larval stage are as low as 0.1%.

NSW Fisheries (2007) describes oysters as the “canary of the estuary” in that they are excellent indicators of environmental stress, declining water quality in particular. Monitoring of wild and cultured oysters can reveal environmental impacts before otherwise apparent. Being bio-accumulating organisms, they are also good indicators of contamination.

Oyster leases can function to provide valuable habitat for a range of species, including fish (particularly juvenile fish) which shelter amongst the leases (NSW Fisheries, 2007). As discussed in Section 7.3.2, oysters and the habitats associated with oyster leases may be important resources for other species, such as birds.

In 1978, mandatory depuration of oysters was introduced to ensure that any food taken in by the oysters, including bacteria, will be excreted within a short period of time, thereby ensuring they are safe for human consumption (NSW Fisheries, 2007). In addition, toxic algae ingested by the oysters may make them unsafe for consumption without depuration, as discussed in Section 7.2.4. It is understood that there are a number of depuration plants located around the Brisbane Water Estuary.

Oysters may be affected by a range of diseases and other problems, associated with:

- Winter mortality, caused by the protist *Microcytos roughleyi*;
- Mudworm, due to siltation of oyster beds. This has largely been eradicated due to the implementation of intertidal farming techniques;
- QX-disease (*Marteilia sydneyi*), which is caused by a protozoan parasite. It is understood that the State Government is assisting farmers in establishing QX resistant oysters; and
- Flatworm.

Oysters may also be affected by acidification of estuarine waters related to ASS (see Section 5.4).

QX (Queensland Unknown) disease has the potential to devastate oyster leases. QX is seasonal and infections of oysters usually occur January-April, with diseased oysters losing condition and dying over winter (DPI, 2007). QX has a life-cycle which is thought to involve two hosts. The oyster is one and the other is an as yet unidentified alternate host (DPI 2007), which makes control of disease outbreaks difficult.

The NSW Department of Primary Industries (DPI) found in June 2004 that an outbreak of QX disease was prevalent in the Lower Hawkesbury River (Hornsby Shire Council 2006). The NSW Government established a QX Taskforce to manage the impacts of the disease event in the Hawkesbury River. An Operational Plan was developed to consider clean-up, bio-security, social and business welfare issues (Hornsby Shire Council 2006).

The re-establishment of oyster farming within the Lower Hawkesbury area requires farmers to switch to the cultivation of either sterile triploid Pacific oysters (QX resistant oysters) or selectively bred QX resistant Sydney rock oysters.

Akoya pearl oysters, *Pinctada imbricata*, are also being cultivated in Brisbane Water Estuary. It is important to note that this species is indigenous to Brisbane Water and NSW estuaries in general. Following the dramatic decline in Japanese pearl production resulting from a number of issues including disease, an opportunity arose to develop the pearling industry in NSW (NSW Fisheries, 2007). After successful trials in Port Stephens, several additional sites for culturing *P. imbricata* have been established, including one in Brisbane Water. NSW Fisheries currently monitors the major farming sites to ensure no damage to the surrounding environment is occurring and to research growth, survival, reproduction and nacre quality (NSW Fisheries, 2007).

7.3.5 Larval Movement

Recruitment to and maintenance of (both permanent and temporary) populations of many estuarine and marine species resident in estuaries is achieved by larval movement. A period of larval development is a part of the early life history for many coastal species. Larvae of different species remain in the water column for periods of time ranging from days to months and during this time may move long distances by passively drifting or actively swimming in currents. It is thought that recruitment is governed by a range of factors such as larval swimming ability, environmental cues and hydraulic processes. On a more local scale, recruitment will occur preferentially to habitats that act as refugia and provide food resources. Such habitats include mangroves and saltmarshes (Section 7.2.2) and seagrasses (Section 7.2.3).

The management implications of understanding controls on larval recruitment are that certain areas or locations may be identified for protection based on their role as sources or sinks of larval recruits, i.e. source populations/spawning grounds or recruitment beds. This is important in terms of maintaining biodiversity and ecosystem function within the estuary, but also in terms of maintaining the economic viability of fisheries for species such as oysters, prawns and fish.

Two specialist studies were undertaken to investigate the larval dynamics within Brisbane Water Estuary:

- Ford *et al.* (2006) investigated the spatial and temporal distribution of larval and juvenile fish amongst seagrass beds.
- Freewater *et al.* (2006) quantified the volume of crab zoeae exported from a saltmarsh-mangrove complex and its importance for fish species. This study also examined advection and dispersion of larvae throughout the estuary.

These studies are summarised below. The full reports can be found in Appendix K.

Larval and Juvenile Fish Settlement in Seagrass Beds

Ford *et al.* (2006) investigated the spatial and temporal distribution of larval and juvenile fish among seagrass beds of Brisbane Water Estuary. An attempt was made to identify any recruitment "hotspots". The aims of the study were to:

- Assess larval distributions against seagrass quality, geographic position and the maximum shear index (MSI; a measure of the change in current velocity moving from a channel to a particular site);
- Compare the abundances of larval and juvenile fish to investigate the migration of individuals into the estuary with development; and
- Compare recruitment in Brisbane Waters to similar estuaries on the NSW coast.

The secondary aims of the study were to determine the baseline levels of phytoplankton and zooplankton communities in Brisbane Water, as measures of water quality.

The species composition and abundance of larval and juvenile fish was highly variable, although, generally, estuary-spawned species remained more consistent temporally and spatially than coastally-spawned species. Several coastally-spawned species showed monthly pulses in recruitment. However, spawning events in the coastal ocean and favourable hydrodynamics are said to drive larval supply of these species to the estuary (Appendix K).

The distribution of coastally-spawned species showed no relationship to seagrass quality, location or MSI. This finding may be the result of highly variable abundances of larvae at any given site. The lack of a relationship with seagrass quality was attributed to the supposition that the presence of structure, rather than the quality of habitat, is likely to be the primary determinate of larval / juvenile fish occurrence. MSI has been a good indicator of coastally-spawned larval settlement elsewhere. However, this was not the case for Brisbane Water Estuary. This is thought to be due the particular characteristics of the estuary. Brisbane Water channels the majority of tidal flow through a single dominant channel, along the sides of which seagrass beds are abundant (Section 4.2). Therefore, the majority of larvae will pass through this channel and are directed to a large area of seagrass habitat. The presence of a particular recruitment hotspot is likely due to the dilution of larval recruits over this large area. Based on the results of modelling, it was recommended that seagrass beds located adjacent to the channel, halfway up its length, be further investigated as these sites could have higher abundances of coastally-spawned larval fish.

However, some species-specific responses were observed in relation to distance from the ocean. Seagrass habitat near the estuary mouth was shown to be the main habitat for the Eastern Blue Grouper (*Achoerodus viridis*) and Fortescue (*Centropogon australis*), and also had proportionately higher densities of lagoon-spawned gobies, pipefish and pygmy squid. This location, located near Ettalong Beach, may be a staging area for newly arrived larval fish, a refuge for fish carried towards the mouth on the ebb tide and could also act as an isolated bastion of habitat in an otherwise high energy, highly disturbed location. It was hypothesised that coastally-spawned juveniles moved further into the estuary, into low-energy seagrass environments found in the Broadwater and its tributaries. Conservation and protection efforts should therefore be directed at the seagrass beds located near Ettalong Beach.

The species composition of larval recruits to Brisbane Water Estuary was similar to other NSW estuaries. Lower densities of fish in Brisbane Water were attributed to the lower volume of tidal exchange and the large amount of seagrass adjacent to the channel available for settlement. Essentially, Brisbane Water was said to have smaller numbers of fish being advected into the estuary and a larger area of seagrass through which they were distributed.

Crab Zoeae and their Importance to Fish

Crab larvae (zoeae) are the early life history stages of crabs. Freewater *et al.* (2006) studied the export and dispersal of crab zoeae from saltmarsh-mangrove complexes in Brisbane Water to illustrate their connectivity with estuarine habitats and their importance to fish.

The stated aims of the study of crab zoeae by Freewater *et al.* (2006) were as follows:

- To quantify the volume of crab zoeae exported from a saltmarsh-mangrove complex in Brisbane Water Estuary by burrowing crab species;
- To quantify trophic links between crab zoeae and fish by examining fish gut contents; and
- To model the passive transport of larvae from a saltmarsh-mangrove complex and investigate connectivity throughout the estuary.

The study was conducted in Cockle Bay, located in Cockle Bay Nature Reserve. It showed that crab larvae (zoeae), which arise from burrowing crab species within a saltmarsh-mangrove complex in Brisbane Water, were released in large numbers on the all but the first day of a spring tide event in February 2006. It is likely that the two crab species that are abundant in such habitats (e.g. *Helograpsus haswellianus* and *Sesarma erythrodactyla)* have acted as the source for these zoeae. These results were said to concur with the findings of studies conducted elsewhere.

The zooplankton communities were sampled at nearshore and more offshore locations at Palmers Lane in Cockle Bay (Brisbane Water Estuary). The study showed that the concentrations of very small and planktonic stages of gastropods (microgastropods) increased during the spring tide event. The densities of copepods were higher on the flood tide than on the ebb tide, which supports other studies (see Freewater *et al.,* 2006) that found that saltmarshes can act as a sink for copepods, in contrast to crab zoeae and micro gastropods, which are exported from these systems.

A total of 12 fish species, comprising 612 individuals, were collected on the ebb tide from saltmarsh habitat in order to investigate the importance of this habitat to fish. *Ambassis jacksoniensis* (the Port Jackson Glassfish) was by far the most abundant, followed by the Hardyhead *Atherinosoma microstoma*. These two species, like four of the remaining species (Blue-eye *Pseudomugil signifer*, the Hardyhead *Craterocephalus mugiloides* and three Gobies, *Mugilogobius paludis, Pseudogobius olorum* and *Redigobius* sp.), reach only a small size, (i.e. less than 70 mm in total length). Small numbers of the juveniles of the Mullet *Liza argentea*, and single individuals of the two Sparids *Acanthopagrus australis* and *Rhabdosargus sarba* and the Silver Biddy *Gerres subfasciatus* were recorded, while large individuals of the Toadfish *Tetratcenos hamiltoni* were also captured. The fact that such large numbers of fish are found in such a transient saltmarsh habitat, which is inundated by water for approximately 3 days on each spring tide event, highlights the importance of this habitat type and the associated crab zoeae to these fish species and is similar to that recorded for other sites in Australia (refer to literature review in Freewater *et al.,* 2006).

The crab zoeae that were released in large numbers on the second and third days of the high tide sequence formed the basis of the diets of three of the 12 species of fish that utilised the saltmarsh habitat at this time. Thus, the majority of individuals of *A. jacksoniensis* and *A. microstoma,* which were abundant in the saltmarsh environment, and of the small goby *Redigobius* sp., of which only two individuals were captured, consumed either mainly or exclusively crab zoeae. This highlights the importance of crab zoeae as a food source for a number of fish species and estuarine food webs in general.

Apart from crab zoeae, other taxa that were ingested by fish included foraminiferans and insects (ingested by *P. signifer*), polychaetes (ingested by *P. olorum* and *G. subfasciatus*), copepods (ingested by *C. mugiloides*), plant material (ingested by *R. sarba*) and detritus (ingested by *L. argentea* and *P. olorum*). Such results concur with those for the same or similar species in other estuaries (refer to Freewater *et al*., 2006). Gastropods were recorded in only two fish species and in negligible amounts, which concurs with the results reported elsewhere (see Freewater *et al.,* 2006). However, crabs contributed nearly 85% to the volume of the diets of the Toadfish *T. hamiltoni* with, on one occasion, an individual being captured with a crab (*H. haswellianus)* in its mouth, which shows that adult crabs can also act as an important food source for estuarine fish.

A small size-related change was also observed in *A. jacksoniensis*. Thus, while small it fed nearly exclusively on crab zoeae but once this species exceeded 50 mm in size, it began to broaden its diet to include copepods and also more benthic prey, such as polychaetes and detritus. Changes in diet are common as a fish reaches maturity. The wide diversity of prey ingested by the 12 fish species in the saltmarsh environment demonstrates that these fish species show a strong partitioning of the food resources in the saltmarsh habitats, with the exception of those three species that ingest mainly crab zoeae. In this case, any potential for competition for this food resource would be ameliorated by its superabundance at the time. *A. jacksoniensis* has since been found to be the most abundant fish in NSW estuaries. It is a critical prey item for the larger fishes (e.g. bream, flathead and jewfish) and feeds almost exclusively on crab zoeae (pers. comm. Dr D. Mazumder). Therefore, the conservation of saltmarsh and their burrowing crabs may be critical for estuarine food webs and for the consideration of management.

Drogue tracking investigations within the numerical modelling studies indicated that some saltmarsh areas were isolated from others and larvae released from these locations would not be dispersed far beyond the saltmarsh-mangrove complex. Figures 7.8 and 7.9 provide an indication of differences in the extent of passive larval transport from two sites in Brisbane Water Estuary: Cockle Bay and Cockle Channel/St Hubert’s Island. These figures represent the extent of passive transport of a particle/drogue after three successive high spring tides, with none released on the first spring ebb, three released on the first ebb and three on the second ebb tide.

The following limitations are associated with the drogue modelling. The exact release point was chosen as being in close proximity to a saltmarsh location. However, due to the configuration (resolution) of the model, were the release point to be shifted as little as 10-15m, the outcome of the drogue tracking investigation could potentially have been quite different (i.e. track and final location of the drogue) because the modelling is an iterative process and this small difference would be cumulative in effect. In addition, it is noted that the saltmarshes are located at different elevations in the intertidal zone, and while efforts were made to adjust the model to account for delayed inundation, the effect of saltmarsh habitat elevation may have led to some confounding of the results.

Nonetheless, the drogue tracking simulation provides a useful model of the extent to which propagules may travel from a source point. Drogue tracking from Cockle Channel/St Hubert’s Island saltmarsh habitat indicates high levels of larval advection and dispersal and, therefore, connectivity with other saltmarsh habitats in Brisbane Water (Figure 7.9). In contrast, drogue tracking in Cockle Bay suggests low levels of connectivity (Figure 7.8). This would present challenges for the management of these habitats because it suggests that they may be particularly vulnerable to disturbances and have little opportunity to recover. Should these isolated habitats become significantly degraded they could not be assisted in recovery by the recruitment of new stock from other areas of the estuary. Therefore, these habitats would require special consideration for protection and conservation.

However, the results of the different modelling, using advection-dispersion algorithms, which included a decay coefficient to account for fish predation, partly contradicted these findings. The model simulated the release of crab zoeae from 15 locations (2,000 discharge points) with the ebbing of the second spring high tide and consecutive tides greater than 1.8 mAHD over the same February spring tide event. The simulation ran for a period of two weeks to reflect the pelagic stage of the zoeae. The advection-dispersion simulations indicated that the hydrodynamics of the system would probably transport the larvae to most corners of the estuary. It was found through the modelling that the hydrodynamic processes alone are sufficient to provide larvae the opportunity to recolonise degraded or impacted saltmarsh and mangrove habitats in Brisbane Water (*Freewater et al.,* 2006).

Figures 7.10, 7.11 and 7.12 show the results of advection-dispersion modelling with drogue track information at the conclusion of the first ebb tide, second ebb tide and third ebb tide respectively. The propagation of larvae throughout the estuary is observable over this time frame. The advection-dispersion model simulations indicated that the hydrodynamics of the system would probably transport the larvae to most corners of the estuary. Indeed, these simulations suggested that the larvae would be exported beyond the boundaries of the estuary and be able to colonise other habitats and the larvae would undoubtedly be prey for fishes beyond Brisbane Water.

However, the limitations that applied to the drogue tracking investigations also apply here. In addition, the model incorporated a simple decay algorithm to account for larval mortality, arbitrarily set at 50%. This may reasonably be considered a conservative estimate of larval mortality. Larval mortality may be attributed to predation or failure to recruit to a settlement site.

Freewater *et al.* (2006) indicates that the study was limited in scope and that these limitations were considered to preclude the reaching of sound conclusions on the patterns of dispersal of crab larvae exported from saltmarshes. For example, some crab zoeae are known to respond to environmental stimuli by rising or sinking through the water column. The modelling did not include this phenomenon but rather used depth average values for the concentration of zoeae. The simulations did not include wind induced currents either. Thus, the advection-dispersion simulations were a first pass at this system and did not fully incorporate the behaviour of the larvae into the model. For example, some zooplankton are known to migrate through the water column to either avoid the sunlight or to swim towards it. There may be other environmental cues that trigger vertical migration. Consideration of the movement of currents at differing depths needs to be incorporated in the development of simulation models. Differences in the spatio-temporal distribution of *Helograpsus haswellianus* and *Sesarma erythrodactyla* in the water column are not known. Further work could also be conducted to examine the influence of different wind regimes on larval transport.

This work does, however, provide a good foundation to progress the understanding of connectivity processes within Brisbane Water and to extrapolate this understanding to other estuarine environments in NSW. It can be used towards assessment of management decisions regarding conservation effort and future planning for Brisbane Water and its catchments. This work demonstrates the importance of saltmarsh and their resident crabs in the supply of food to certain fishes, which in turn are important links in the food web of temperate estuaries in NSW.

7.4 Summary of Key Findings

The key findings relating to the ecological processes of Brisbane Water Estuary are listed below. These findings have been developed in relation to the findings of the biological studies described in Section 7, as well as those of other studies reported in this document.

- **Foreshore Development and Planning:** The foreshore assessment found that over 50% of the estuary foreshore was adjacent to substantially developed catchments and was considered disturbed – highly disturbed. The main cause of loss of intertidal habitats is the construction of seawalls, jetties and piers. While these structures enhance amenity for an individual residential property, they often have the effect of precluding public access to the foreshore (see Sections 5.5 and 9.4), have poor habitat value (Section 7.2) and also impact on sediment dynamics (Section 5.5). Loss and degradation of foreshore vegetated habitats results in loss of the ecological function that saltmarsh and mangroves provide, for example, shoreline protection, nutrient cycling, buffering water quality and sediment trapping. As stated elsewhere, controls on foreshore development need to be reassessed and regulations implemented.
- **Impacts of Human Activities:** The main causes of disturbance relating to human activities related to both catchment processes and recreational activities. Recreational activities with a high potential to impact on the estuarine ecology described in Section 7 included dog walking, boating activities, the introduction of weeds, predation by introduced species and disturbance related to the presence of people. In addition to simple loss of habitat, disturbance was found to result in the following impacts: declining water quality, declining vegetation cover, increased availability of mosquito breeding habitat, declining productivity and alterations to the assemblage structure for flora and fauna communities. These types of impacts are thought to be leading to high rates of habitat loss for mangroves, seagrasses and saltmarsh. Climate change associated impacts, including sea level rise and changes to weather patterns (Sections 3.2.9 and 4.5), are also issues for biodiversity conservation.
- **Conservation Planning:** Mangroves, seagrasses and saltmarsh are known to perform a range of important ecological functions. These habitats were also associated with high rates of diversity and abundance of fish and invertebrate fauna. One important aspect of all three habitat types is the structural complexity that they provide, which is associated with higher biodiversities. Therefore, maintenance of the physical / vegetation structure is a very important component of biodiversity conservation. Larval studies described herein (Section 7.3.5) indicate that connectivity between habitats in different parts of the estuary is generally high, although some locations may have more limited connectivity than others. In addition, although 74% of all recorded species can be conserved in only 5 locations (Ettalong, Narara Creek, Koolewong, Woy Woy Bay-Pelican Island and Umina), other factors will need to be taken into account, such as scales of spatio-temporal variation in assemblage structure amongst habitats, staging posts for larvae and habitat structure. Conservation of biodiversity and maintenance of ecological function are also important in commercial terms when considering the fishing, aquaculture and tourism industries (Section 9).

8. CULTURAL HERITAGE

8.1 Overview

A desktop review of cultural heritage was undertaken by HLA Envirosciences (2005). T he full report can be found in Appendix M. Cultural heritage includes consideration of both indigenous and non-indigenous (European) heritage.

Investigations on indigenous heritage included relevant consultation with the interested Aboriginal groups, general history of the area including environmental development and identified sites listed in the Aboriginal Heritage Information Management System (AHIMS) database. It provides some implications likely to be faced when considering management of indigenous heritage of the area.

Non-indigenous heritage is also considered. This section includes consultation with the interested historic societies in the area, general history and identified sites listed on a series of government registers. It also discusses some of the implications likely to be faced when considering management of the historic heritage of the area.

HLA's (2005) report also summarises the relevant legislation and statutory requirements surrounding Aboriginal and European heritage. In addition, the implications discussed in the report are developed and management issues that are likely to occur when heritage is involved are highlighted. Specific recommendations are also given surrounding heritage that has been identified as highly likely to require management directions in the Estuary Processes Study. These aspects of the report are not summarised below but can be found in the full report in Appendix M.

8.2 Indigenous heritage

Consultation

For Aboriginal sites, a search of the NPWS Aboriginal Sites Register and report collection was undertaken to identify known sites and areas of potential. Based on this information general management issues were outlined and relevant Aboriginal communities were consulted advising of the study and asking for their input. However, further consultation was not undertaken at that stage.

Two relevant Aboriginal groups were identified by Victor Zander of the Central Aboriginal Heritage Unit at the Department of Environment and Conservation (DEC; now DECC): the Darkinjung Local Aboriginal Land Council (LALC) and the Gurringa group. HLA liaised with Jodie Cameron of the Darkinjung LALC. However, attempts to contact the Gurringa group were unsuccessful. It is understood that Jodie Cameron has concerns over large areas of Brisbane Water having potential to yield sites but with no evidence having yet been presented.

Site Context

The geology of the Brisbane Water Estuary catchment is composed of sandstone and shales. These large areas of relatively soft sandstone have allowed rapid erosion to form substantial rock shelters along the coast and ideal canvasses for rock engravings (HLA Envirosciences, 2005). In addition, stone resources suitable for tool making occur throughout the region.

Few other Pleistocene deposits are known. Most archaeological sites within the Sydney Basin are dated to the late Holocene, from about the last 2,500 years to present. Many researchers believe that open sites were occupied only in the last 1,500 years before European contact.

The greater Gosford area has traditionally been inhabited by the Kuringai and Darkinjung tribe and it was not until 1788 that Europeans actually visited Brisbane Water (Vinnicombe, 1980; cited HLA Envirosciences, 2005). Shortly after settling Sydney Cove, Sir Arthur Phillips made an exploration of the area, where he observed and interacted with Aboriginal groups on the shoreline of Brisbane Water. Later explorations by Hunter spread small pox throughout the area, decimating Aboriginal populations (Vinnicombe, 1980; cited HLA Envirosciences, 2005).

It was not until 1796 that the Aboriginal population of Brisbane Waters had regular contact with Europeans, but as early as 1804 relations between Aborigines and Europeans had deteriorated (Vinnicombe, 1980; cited HLA Envirosciences, 2005). Conflict arose as land grants in the Gosford area deprived the local Aboriginal population of resources. Land grants were being established in Brisbane Water by 1825, forcing the Aboriginal communities from the area. Intense exploitation of local resources, in association with the high numbers of escaped convicts in the area, led to the exacerbation of this situation. In 1804 only 35 Aborigines were recorded in the Gosford census, declining to 16 in 1841 (Vinnicombe, 1980; cited HLA Envirosciences, 2005). Those Aboriginals that survived colonisation of the area migrated to Sydney and Newcastle.

The Sydney Basin has been inhabited by the Aboriginal people for at least 20,000 years according to available radiocarbon dates. The earliest site in the Gosford region is the Loggers Shelter at Mangrove Creek dating to 11,050 BP (Before Present). Many of the sites identified in various studies were occupied when sea level was about 120 metres below present day and would therefore have been located inland.

A search of AHIMS revealed information with regard to Aboriginal sites in the area as summarised below:

- 274 known sites have been identified in Brisbane Water and the surrounding catchments;
- The vast majority of these sites are rock engravings, middens or shelters with middens indicating the dominant activities of the Aboriginal people in the area in the past;
- 74 of these sites are on or adjacent to Brisbane Water, with the remainder being near the shoreline or on related tributaries;
- Pretty Beach and Daleys Point have the highest concentrations of sites, with areas such as Kariong, Woy Woy and Cockle Broadwater also having high numbers; and
- There is potential for other sites to exist around Brisbane Water, but they have yet to be found.

All Aboriginal sites are protected under the *National Parks and Wildlife Act 1974* and therefore any management considerations that impact upon Aboriginal sites must include this in their design. Known Aboriginal sites should be left undisturbed if possible, however if a management option requires their destruction, a Section 90 “Consent to Destroy” permit must be sought from the DECC. Normally a Section 87 Preliminary Research Permit is required as a precursor to a Section 90. This can be a long process that should factor into management. Under the *National Parks and Wildlife Act 1974* it is a requirement that any development show “due diligence” with regard to Aboriginal heritage in the area.

In addition, it is possible that many more sites may be identified in excess of the 274 identified through AHIMS. The high number and variability of sites around the Brisbane Water estuary means that any development or works will need to seriously consider the likelihood of Aboriginal heritage on the site in question, and develop a budget and timeframe that incorporates this consideration.

8.3 Non-Indigenous heritage

HLA's (2005) report outlined consultation undertaken with the relevant historical societies, the post-1788 history of the area and the known heritage sites identified.

The Brisbane Water Historical Society was contacted to discuss but their interest in the desktop study was limited and did not yield much information. GCC's Environment Officer, Dr Peter Freewater, has identified a series of Oyster Leases in Hardy's Bay that are currently being nominated for the National Heritage List. It is recommended that these leases should be retained until a ruling has been made.

Aside from early explorations described in Section 8.2, the area was free of Europeans until 1823, although there were excursions into the area prior to this time, notably by James Webb, who began shipbuilding on the Hawkesbury in 1797 and was involved in two early conflicts with local Aboriginal groups. Use of the Central Coast and Brisbane Water increased after the establishment of a penal colony in Newcastle in 1804. James Webb later became the first European settler of Brisbane Water in 1823. By the late 1820's farms had been set up along the shores of Brisbane Water, such as the Pickett family at Kincumber. Peter Fagan settled in 1835 in the bay that now bears his name. One of the only first-hand accounts of the area in the early 1800's is provided by the wife of Felton Matthews, who settled in the Narara Bay area in the late 1830's. By 1840, the shores were being intensively settled by Europeans.

8.3.1 Terrestrial Items

A series of online databases were searched to identify historic heritage relating to Brisbane Water and its surrounding area, including:

- State Heritage Register (NSW Heritage Office)
- State Heritage Inventory (NSW Heritage Office)
- Gosford Local Environment Plan (GCC)
- Register of National Estate (Australian Heritage Commission)
- National or Commonwealth Heritage List (DEWR).

A total of some 170 historic sites were listed in the Gosford LGA with 83 in the immediate vicinity of Brisbane Water and its surrounding suburbs. These are summarised in HLA Envirosciences (2005). Of the 83 historic sites recorded in the study area, the majority are wharfs or their remains and it should also be noted that surrounding these wharfs are likely to be other submerged relics. In addition, there are a number of locations around the Estuary which have groupings of historic sites.

Most of the historic sites in question are found within the larger conurbations, specifically Gosford and Woy Woy and are removed from the estuarine areas of Brisbane Water. However, tributaries of the estuary run through these areas. In addition, a large number of sites are distributed across the suburbs, most notably Kincumber, Greenpoint, Empire Bay, East Gosford and Saratoga.

Eleven of the sites registered are associated with the foreshore of the estuary:

1. Mulholland's Farm, 9 Pixie Ave, Green Point.
2. Foreshore land and structures, 9 Pixie Ave, Green Point.
3. Remains of Punt Bridge over Erina Creek, The Entrance Road, East Gosford.
4. Woy Woy public wharf remains, west side of Woy Woy station.
5. Site of public wharf, Blackwall Point, Woy Woy.
6. Site of public wharf, The Entrance Road and Erina Creek, Erina.
7. Site of former public wharf, Lexington Road, Green Point.
8. Site of public wharf, Killuna Road and Kincumber Creek, Kincumber.

9. Site of “Brick Wharf”, off Brickwharf Road, Woy Woy.
10. Boatshed, off Sorrento Road, Empire Bay.
11. Site of public wharf, off Victoria St, East Gosford.

Of particular note are Mulholland’s Farm and its associated foreshore structures at Green Point and Rosemount, a house in East Saratoga, each of which are on the NSW State Heritage Register (Figure 8.1; sites numbered as above).

There are also a series of other heritage sites that are immediately adjacent to the Estuary and are an integral part of the cultural landscape of the area (Figure 8.1), and any designs that may impact physically or visually on these areas should be sympathetic to the heritage. These areas include:

- South Mann Street, Gosford;
- Pioneer Park, Point Fredrick;
- Sorrento Road, Empire Bay;
- Humphrey’s Road, Kincumber South; and
- Brisbane Waters Drive, Koolewong.

Seven sites have been listed on the Register of National Estate (Figure 8.2) and are therefore protected under Commonwealth legislation:

- Former Brisbane Waters County Council Building, 50 Mann Street, Gosford;
- Broken Bay Entrance Foreshores, Ettalong (not shown in Figure 8.2);
- Creighton Funeral Parlour, 37 Mann Street, Gosford;
- Old Courthouse, 45 Mann Street, Gosford;
- Showground, Showground Road, Gosford;
- Mulholland’s Farm, 9 Pixie Avenue, Green Point; and
- St Paul’s Anglican Church, Empire Bay Drive, Kincumber.

Of these sites, only St Paul’s Anglican Church and the Old Courthouse are registered sites. The others are indicative listings currently being assessed by the Australian Heritage Commission.

Areas of low, moderate and high sensitivity are delineated by HLA Envirosciences (2005).

8.3.2 Maritime Items

Two online databases were searched to identify shipwrecks in Brisbane Water and its surrounding tributaries:

- National Shipwreck Database (DEWR)
- Maritime Heritage Online (NSW Heritage Office).

These lists produced information on 10 shipwrecks in the Brisbane Water area (Table 8.1).

Table 8.1 Shipwrecks in Brisbane Water Estuary and Surrounding Waters (after HLA Envirosciences, 2005)

Ship Name	Type	Date Lost	Location
Plover	Schooner	1855	Western spit of the bar at Brisbane Water
Power Chief	Launch	1934	Green Point
Traveller	Schooner	1868	Brisbane Water bar
Venus	Schooner	*ca.* 1920	Brisbane Water; Broken Bay, ashore
Violet	Ketch	1878	Brisbane Water bar
Caroline	Ketch	1869	Western spit of bar at Brisbane Water
Midshipman	Ketch	1857	Brisbane Water entrance, Broken Bay
Brothers	Ketch	1876	Half Tide Rocks, Brisbane Water
Leisure Hour	Ketch	1869	Brisbane Water bar
Queen Bee	Steamer	1922	Broken Bay 2 miles NE

Five of the wrecks sunk off the Brisbane Water bar. Two (*Venus* and *Brothers*) were smashed against the shore and are therefore likely to have been completely destroyed. The *Power Chief* ran aground at Green Point, but its condition and location are unknown. The remaining two ships sank in the Broken Bay area, around the entrance to Brisbane Water, and their locations are too vague as to even imply a general area in which they may be located.

None of the shipwrecks above have been re-found to provide exact locations, however most of the comments describing the wrecks show that in general they are concentrated around the Brisbane Water bar, five of the ten sinking in this area. In addition, the Brisbane Water bar's location is also unknown, although consultation with the NSW Heritage Office has suggested it is likely to be in the vicinity of the Brisbane Water entrance. The bed and the bar are also highly mobile and variable in this area.

There are also a number of wrecks in Broken Bay and the Hawkesbury. All shipwrecks are protected under Commonwealth and State legislation, including the *Historic Shipwreck Act 1976* and the *Heritage Act 1977*.

It is understood that a series of Oyster Leases in Hardy's Bay are currently being nominated for the National Heritage List. It is recommended that these leases should be retained until a ruling has been made.

8.4 Summary of Key Findings

The key findings of HLA Envirosciences (2005) assessment of cultural heritage for Brisbane Water Estuary are summarised below:

- **Indigenous Heritage:** The natural resources found in the estuary and catchment made the Brisbane Water Estuary an attractive place for Aboriginal groups to camp and there are a large number of Indigenous places and artefacts associated with the area. The areas of Pretty Beach and Daleys Point have the highest concentration of known sites, and Kariong, Woy Woy and Cockle Broadwater also have high numbers of sites.
- **Indigenous Heritage – Unidentified Sites:** With respect to the indigenous heritage of Brisbane Water Estuary, there are concerns over as yet unidentified sites, for which there is significant potential given the history of known Aboriginal occupation of the area. The high number and variability of sites recorded within the catchment indicates that there is high potential for more sites to be discovered.

- **Non-Indigenous Heritage:** There are 11 items of European heritage significance located on the estuary foreshores. These sites are particularly sensitive, including the general character, aesthetics and views.
- **Maritime Heritage:** There are a number of shipwrecks in the Estuary, however, the exact location of these wrecks is unknown. At least half of these wrecks are thought to be located on the bar near the entrance. This represents a particularly sensitive area.
- **Climate Change:** The implications of global climate change and sea level rise should be considered in the ongoing management and conservation of historic sites and artefacts, both Aboriginal and European. The Foreshore Flooding Study that is currently being undertaken by Cardno Lawson Treloar considers extreme water levels for the Estuary (as discussed in Section 4.5). The outcomes of this study will include hazard definition for the extent of foreshore flooding / inundation for a range of scenarios. This information should be used to inform management of heritage items, particularly for those located in foreshore areas, or partially submerged.

9. RECREATIONAL PROCESSES

Recreational processes were investigated through desktop studies and field inspections to provide an overview of recreational activities and foreshore land use for the Brisbane Water Estuary (KBR, 2005). The full report can be found in Appendix N.

The recreational and aesthetic environment of the Brisbane Water Estuary is highly valued. Human use of the estuary has resulted in conflicts between users in relation to land use and the recreational use and enjoyment of the foreshore and waterways, as well as, degradation of the natural environment (KBR, 2005). High population growth and tourism has further exacerbated these conflicts.

An evaluation of foreshore land ownership, uses and activities, waterway uses and activities, and human use and environmental conflicts is outlined below. An assessment of potential areas for increased tourism is also provided.

9.1 Existing Recreational Activities

There are a variety of human users of the Brisbane Water foreshore, which can be categorised into 'active' users (those who require a vehicle, equipment or watercraft for their activity) and 'passive' users (those users not requiring a watercraft, vessel or specialised equipment). Existing recreational uses of Brisbane Water were also categorised into foreshore and waterway activities.

Foreshore Recreation

Approximately 35% of the Brisbane Water foreshore consists of public reserves, National Parks and Nature Reserves. These areas provide public access to large sections of the foreshore in some locations (Figure 9.1). The most substantial areas at which the public can gain access to the foreshore occur between Ettalong Beach and Woy Woy, within Woy Woy Bay, between Koolewong and Tascott, between Point Clare and West Gosford, and at Yattalunga, Saratoga and Killcare.

Most foreshore reserves are equipped with public facilities, including toilets, rubbish bins, playgrounds, picnic facilities and telephones. Cycle tracks can also be found in some areas, including at the Koolewong Foreshore Reserve and along Fagan's Bay. A number of public boating facilities, such as public wharves, boat launching ramps and marinas in Brisbane Water are located within or adjacent to public reserves.

GCC adopted the Coastal Open Space System (COSS) in 1984, which aims to create a continuous system of open space with significant ecological values. This includes both private land (under voluntary agreements) as well as Council-owned land. The extent of the COSS is shown in Figure 3.5. In addition, two National Parks occur along the foreshore: Brisbane Water National Park and Bouddi National Park. Foreshore Nature Reserves include Riley's Island Nature Reserve, Pelican Island Nature Reserve and Cockle Bay Nature Reserve. These areas also provide an opportunity for public access and recreation.

The majority of foreshore users of reserves and open space areas along the foreshore are passive users and peaks in human use along the foreshore occur on weekends or over the summer period. It is at this time that the most pressure is placed on existing facilities resulting in a high potential for conflict among users. The major foreshore recreational uses are presented in Table 9.1.

Table 9.1 Foreshore-based Recreational and Commercial Activities (after Kellogg Brown and Root, 2005)

Recreational Activities	Commercial Activities
Passive users of reserves and open space	Boat hire
Shoreline recreational fishing	Boat repairs
Picnicking	Boat storage
Bushwalking	Marine operations
Sightseeing	Equipment sales
Bird watching	Food outlets
Walking and jogging	Oyster depuration plants
Cycling	Light industrial activities (manufacturing, general storage)
Dog exercising	Other commercial and light industrial activities
Horse training	
Sports	
Other recreational activities	

Figure 9.2 shows the location of recreational facilities found on the Brisbane Water foreshore. This figure provides an understanding of the spatial distribution of areas used on a recreational basis.

The general level of user satisfaction of park user's was assessed in January-February 2004 by GCC, as part of the Integrated Open Space Services assessment of active and passive parks in the Sydney Region. The findings are reported in Appendix M. Ten parks in the Gosford LGA were assessed by a total of 100 park-user intercept surveys. The predominant activities undertaken by participants were relaxing (17%), walking (15%) or dog walking (12%). This indicates that the majority of activities undertaken in Gosford parks are passive activities.

The survey also assessed the reasons for users visiting parks. These included outdoor / landscape amenity (25%), transient activities (16%), aquatic recreation (13%), exercise (12%), social / family outing (12%), exercising animals (12%), other recreation activities (7%), sport (7%) and outdoor dining (4%). Note that some respondents listed more than one activity, therefore, these percentages sum to a total >100%. These findings indicate that people utilise Gosford parks, including foreshore areas, for a broad range of activities and also highlights the potential for conflict amongst park users. Such conflicts are potentially higher in parks which contain water-based and land-based, recreational and commercial activities.

Waterway Recreational Uses

Major water-based recreational uses are presented in Table 9.2. Figure 9.3 shows the locations in which various waterway activities occur and location of associated facilities.

Boating was one of the most popular activities on Brisbane Water. Boating includes power boating, sailing and paddling / kayaking / rowing. A literature review (KBR, 2005) found that there was an association between the type and size of different water craft and geographic locations within the waterway. The determining factor of vessel size was primarily The Rip Bridge, whereby larger vessels are concentrated on the downstream size and smaller vessels utilise the upstream sections of the waterway.

Table 9.2 Water-based Recreational and Commercial Activities (after Kellogg Brown and Root, 2005)

Recreational Activities	Commercial Activities
Power boating (incl. personal water craft and jet skiing)	Oyster farming
Sailing	Boat tours
Paddling (incl. canoeing / kayaking and rowing)	Boat charters
Swimming (incl. wading and bathing)	Ferry operations
Boat recreational fishing	
Windsurfing	
Diving (incl. both SCUBA diving and snorkelling)	
Fishing	
Kite surfing	

The number of various public boating facilities found in Brisbane Water is shown in Figure 9.3. Of the 43 public wharves location within Brisbane Water Estuary, 13 occur on the western shore, 26 on the eastern shore and 4 on the northern shore. A much larger number of private wharves occur along the foreshore, particularly between Ettalong and Woy Woy, and at Woy Woy Bay. Of the 19 boat ramps, 6 occur on the western shore, 9 on the eastern shore and 3 on the northern shore.

Table 9.3 Boating Facilities (after Kellogg Brown and Root, 2005)

Boating Facility	Number
Public wharves	43
Boat launching ramps	19
Marina / commercial boat shed	5
Fuelling points	5
Public vessel pump-out services	2
Dinghy storage capacity	Unknown
Private moorings	1071
Commercial moorings	462
Casual / visitor moorings	4

Marina's and boat sheds are located at Ettalong Beach, Booker Bay, Gosford, Empire Bay and Hardy's Bay. With the exception of Gosford, all these marinas / boat sheds provide re-fuelling services (two are located in Booker Bay). The Gosford site has a boat pump-out service, as does the Killcare Marina. It is understood that dinghy storage is currently under review by Council and that dinghy storage is currently permissible in any foreshore park with permission from Council. The total number of moorings is controlled by NSW Maritime (both private and commercial) and NSW Maritime also administers the use of private moorings. Commercial moorings are administered by the various commercial operators in Brisbane Water. Of the 1071 private moorings, 982 (92%) are registered to boats with the 89 remaining unregistered.

Activities such as fishing and water skiing require the use of power boats to access various parts of the waterway and, in the case of water skiing, generally require higher powered engines and operation at high speeds. Water skiing is generally permitted throughout the centre of the waterway. However, it is prohibited in Correa Bay and speed restrictions apply in some parts of the estuary. Gosford Water Ski Club runs regular ski races throughout the year. The course is located in the centre of the waterway and overlaps with the sailing course. While water skiing races have been popular in the past, they have been less frequent in recent times due to high insurance costs.

Power boats may also be used in conjunction with other recreational events such as rowing regattas and training. In recent years the number of Personal Water Craft (PWC; or jet skis) has increased in Brisbane Water Estuary due to the banning of their usage in Sydney Harbour.

A number of sailing clubs exist in Brisbane Water and regularly use the waterway for regattas. These clubs and their corresponding activity days are shown in Table 9.4. The race courses for each of these clubs overlap. The courses are located within the centre of the waterway north of Saratoga and into the Broadwater and to Peeks and Rocky Point. Sailing tuition is also provided by the Clubs throughout the year. Racing occurs throughout the year, although the peak season occurs during the summer months.

Table 9.4 Sailing Clubs and Activity Days (after Kellogg Brown and Root, 2005)

Club	Activity Days
Gosford Sailing Club	Wednesdays during daylight savings – yacht twilight 5:30pm Saturday all dinghy classes Yachts each alternate Sunday
Saratoga Sailing Club	Sundays
Woy Woy Sailing Club	Saturdays

With respect to rowing, kayaking and canoeing, there are also a number of races for the various paddling categories. Paddling activities are also more prevalent in the summer months, but guided tours and private kayaking occur throughout the year. The Brisbane Water Rowing Club has been established on the estuary in recent years. Rowing is usually carried out early in the morning, but all day regattas may require large sections of the waterway.

There are thirteen beaches and coves with four tidal swimming pools located around the Brisbane Water Estuary. Popular sites include Ettalong Beach, beaches at Woy Woy Inlet, a beach at Yattalunga and Couche Park in Koolewong. There is typically a range of recreational facilities associated with these sites. Peak periods of usage occur over the weekend and summer periods.

There are also a number of commercial aquaculture operations in Brisbane Water Estuary. The oyster industry (which cultivates Sydney Rock Oysters (*Saccostrea glomerata*)) is an important part of the local economy and historically has contributed approximately $3.3 million to the region on an annual basis (NSW Fisheries, 2002; cited KBR, 2005). Oysters and oyster leases are discussed further in Section 7.3.4.

Other commercial activities include water-based transport. Two ferry services operate within the waterway. The Palm Beach Ferry Service runs a service between Palm Beach and Ettalong and Wagstaffe, which runs almost hourly during the week between 6:30am and 5:40pm and every hour / hour and a half between 8:00am and 6:40pm on Saturdays. In addition, it is understood that a fast ferry service, the Gosford CBD – Circular Quay SuperShuttle Ferry Service, is proposed to commence in mid-2009.

Other commercial waterway based activities include boat hire / charter, sailing / boating tuition, marinas / boat sheds / repairs, moorings, equipment hire / sales and oyster depuration plants (when operational).

The wide spectrum of waterway and foreshore uses outlined in Appendix M identifies the numerous conflicts that are currently present. Careful management of the region's facilities and uses is required in order to achieve equitable outcomes for the various user groups.

Potential conflicts were identified based on conflict with other users and with the foreshore/waterway environment. Existing and potential conflicts were identified during a community meeting (Section 2.3), telephone interviews and consultation with Council. Data derived during this process was used to create a conflicts and impacts matrix. Recreational activities were rated according to the level of potential conflict (low, medium, high, neutral and either positive or negative). The contents of the conflicts and impacts matrix shown in full in Appendix M are discussed below.

Power-boating and Personal Watercraft

The use of power boats and PWC is a concern for both the health of aquatic ecosystems and also the general community. PWC, if not complying with regulations, can cause extreme nuisance to other users of the waterway. The main social conflicts are due to noise, disturbance of the peace, 'chopping-up' water, public safety and disturbance of foreshore activities, such as swimming and fishing. These issues were identified as a concern for a number of community members, particularly fisherman. In addition, Paddy's Channel was identified through community consultation as an area of high boating activity and congestion. Speed and associated wakes from larger vessels are a source of major conflict between different users of the channel and can impact on the waterway itself through erosion and scour.

NSW Maritime controls the use of PWC's and has published a range of rules outlining the distances that PWC are allowed from the foreshore and from other vessels both non-powered and powered. PWC'S must remain 60 metres away from; a person in the water and small non-powered vessels such as surf skis when driving at 10 knots or more (NSW Maritime 2007). PWC's must remain 30 metres away from any power driven vessel and any river bank or shore structures (NSW Maritime 2007). NSW Maritime also provides regulations governing rules for all other water users. They control the speed of watercraft throughout the estuary, including zoning of areas as "No Wash" zones and banning water skiing in certain regions. These measures are designed to minimise the impact of boating activities on the environment and other waterway users. As long as these boating regulations are obeyed, the various boating activities should not conflict with other recreational users or the environment.

However, an awareness of socially or environmentally offensive behaviour, especially with respect to areas of known seagrass and sensitive aquatic habitats / populations is required. The main environmental conflict associated with the use of powerboats and PWC is the degradation of seagrass and other aquatic habitats. There are a number of mangrove communities located within Brisbane Water Estuary, which are important nursery grounds and ecological communities (see Section 7.2.2). Through restrictions of boating activities in these regions, conflicts with environmental values can be minimised. Boating activities also have the potential to impact on coastal processes, specifically foreshore erosion and sediment transport. It is possible that boat wakes may cause erosion in some locations throughout the Brisbane Water Estuary. However, no confirmed instances of boat wake-induced erosion have been recorded to date and, in any case, it is unclear to what extent boat wake is likely to influence shoreline erosion.

In addition, it is difficult to differentiate between erosion caused by wind waves and that caused by boat wakes.

Smaller Watercraft / Dinghies

GCC has previously identified boat launching and storage activities as a potential source of potential conflict, having released a poster titled "*PROTECTING OUR WATERWAY FORESHORES - A Guide for Residents in Foreshore Areas*". A number of small boats, such as dinghies, kayaks, runabout and trailers, are stored, anchored or attached to fixtures along the foreshore reserves. If their purpose is for commuter use, their storage may be contrary to the provisions of the *Crown Land Act 1989* and the *NSW Local*

Government Act 1993. The poster identifies that these boats and other types of vessels damage foreshore vegetation and restrict access to the foreshore.

This conflict may be controlled through the provision of boat-storage facilities and launching ramps. Council has adopted a policy of installing dinghy storage racks in strategic locations and some have been provided in some reserves to accommodate vessels. Council's *Plan of Management – Foreshore Parks* states that any boats / dinghies stored outside of these areas may be removed by Council. However, existing storage facilities do not appear to be adequate, as evidenced by the large number of dinghies which are stored in a variety of foreshore parks and areas around the waterway. The key issue is that the placement of dinghies along the foreshore or at wharf points for extended periods requires management to ensure that services are not jeopardised by congestion, public safety is not compromised and the environment is not degraded.

It is understood that Council has recently reviewed dinghy storage practices. One possible solution, based on the Pittwater Council model, is to identify a number of designated locations which are managed and regulated by Rangers. The aim is that this system would be more efficient that the current situation, with a registration fee charged for dinghy storage which would be used for the upkeep of the various facilities. Rangers would have the authority to remove any unauthorised dinghies in due course following a notice period.

Boat Launching

A number of marinas and boatsheds around the estuary provide slipway services for cleaning and maintenance of larger vessels. These are typically located in areas of intensive boating activity and conflict may arise in these locations between water users due to space requirements and possible pollutants related to slipway activities.

There are 19 Public boat ramps located around the estuary to facilitate launching of smaller boats. These ramps experience peak usage in the summer months, particularly on weekends. Ramps located in the lower reaches of the waterway have been identified through community consultation as experiencing extreme congestion in these peak periods. The main conflicts appear to arise from a number of inappropriately sized boats attempting to use these facilities for rigging and launching purposes and the number of easily accessible ramps and parking facilities. It is thought that, in some cases, larger vessels may be using these public boats ramps in order to avoid fees and charges associated with the use of marina or boatshed facilities.

It is understood that several ramps located on the eastern shore of the estuary have experienced loss of amenity in recent years due to siltation. This limits the ability of boat owners to effectively launch their vessels as the depth at the end of the ramps is insufficient. This has a flow-on effect whereby users turn to other boat ramps and car parks, causing further congestion at the alternate locations. Congestion and traffic issues at the boat ramps affect both waterway and foreshore users due to time delays, parking availability and local resident access.

It is possible that, due to the congestion and location of formal public boat ramps, the illegal and undesignated launching of boats may occur in Brisbane Water Estuary. These activities may lead to scour and erosion of the foreshore and damage to foreshore and aquatic habitats. In addition, the cumulative effects of undesignated boat launching may cause an increase in sedimentation and loss of foreshore amenity through erosion. Further, jetties and piers used to launch private craft have been observed to have impacts on foreshore vegetation (Section 7.2).

Commercial Ferry Operators

There is a range of potential onshore and offshore impacts that can occur in relation to cargo wharves and commercial ferry operations.

Onshore impacts include:

- Congestion and conflict with other foreshore users in relation to the loading and offloading of supplies and passengers;
- Noise and air quality impacts relating to the idling of large diesel engines for prolonged periods of time; and
- Traffic congestion and lack of parking may inconvenience local residents and the general public.

Offshore impacts include:

- The potential for water quality impacts and disruption of sensitive species located in various parts of the waterway; and
- High boat traffic close to the shoreline may result in scouring and foreshore erosion due to the turbulence and wakes created by the larger vessels.

Commercial and Recreational Fishing

Commercial fishing activities are restricted within the Brisbane Water Estuary by NSW Fisheries (DPI) but allowed in Broken Bay and off-shore. The launching, storage and movement of the generally larger commercial vessels by these commercial fishers may cause conflicts with other waterway users. Several of these commercial vessels are stored in various locations throughout the estuary and also use the fuelling and pump-out facilities.

Recreational fishing is a popular activity engaged in by both locals and visitors to the area. Different types of fishing are popular on the foreshore, which can lead to congestion of local streets and car parking facilities in times of peak usage, typically in summer. Trailer boats may also be used by recreational fishers. Issues associated with trailer boats are discussed above. It is thought that the bag and catch limits (and other regulations) imposed by NSW Fisheries need to more readily available to the public (both locals and visitors). Fishers utilising watercraft must also obey the navigation rules outlined by NSW Maritime.

Sedimentation and Foreshore Erosion

Sedimentation and foreshore erosion is discussed in Section 5.5. Water depth, particularly at mooring and wharf locations, typically reduces amenity and access for the boating public and other waterway users. Sedimentation and mobile sand shoals may also present a hazard to navigation and access. The St Hubert's Island Residents Association and Killcare, Pretty Beach and Wagstaffe Youth and Community Association have identified several sites on the eastern shore of the estuary affected by sedimentation and erosion leading to a loss of public amenity and conflicting with various users.

In addition, uncontrolled access to the foreshore, uncontrolled foreshore development and insufficient protection of open stretches of vulnerable shoreline has led to localised erosion in some section of the waterway. A number of seawalls have been constructed around the foreshore by both Council and residents in an attempt to protect the foreshore. However, these structures may exacerbate erosion at some locations, as discussed in Section 5.5.

Dredging

Dredging has been carried out on a number of occasions at various locations in the estuary in order to improve access and navigation. Areas that have previously been dredged include Wagstaffe, Point Clare, Gosford, Cockle Channel, Paddy's Channel, Saratoga Channel and Woy Woy Channel. Dredging works are regulated under a range of policies and legislation (including *SEPP (Infrastructure)*, the *Protection of Environment Operations Act 1997* and the *Water Management Act 2000*) and unauthorised dredging or reclamation works can attract considerable fines.

At the time of preparation of this report, it is understood that the propagation of the Ettalong Shoals is currently impacting on navigation and safety, and that Council propose to undertake dredging works to ameliorate these issues at this location in the near future.

Impacts on Estuarine Vegetation Communities

The vegetation communities found in the Brisbane Water catchment are discussed in Section 3.2.4. The main impacts on vegetation in the catchment and on the foreshore is associated with walking tracks which are used by mountain bike riders, walkers and bushwalkers, dog exercisers and local residents. Other conflicts identified include vandalism, mowing and the removal of vegetation for views or for the extension of residential gardens. These actions lead to the degradation and loss of the natural habitat and weed invasion. Multiple tracking can also expose the foreshore to further erosion and lead to trampling of seedlings and root systems. These issues are discussed further in Section 7.

It is understood that Council has a policy stating that no development activity is to result in the direct loss of a wetland. Council has provided a number of bicycle and foot paths around the estuary foreshores in an attempt to minimise human impacts relating to recreational activities. This has the effect of concentrating activity on a single formal path and reducing multi-tracking. However, these paths are not available in all foreshore areas and further paths may be required in areas of new and existing development. Alternatively, where the foreshore environment and vegetation communities are considered particularly sensitive, it may be advisable to avoid providing formal pathways in a bid to make these areas less attractive for recreational usage.

Community consultation also highlighted the need for Council to monitor foreshore parks adjacent to residential properties as there is a perceived conflict of interest between preservation of environmental integrity and the value of the surrounding real estate.

Car Parking and Traffic Congestion

Car parking and traffic congestion is a major source of conflict for the various recreational users of the Brisbane Water Estuary. Many ferry and boat facilities do not provide specified parking areas and there is often insufficient parking where it is available. Many reserves and parks surrounding the estuary also have insufficient car parking capacity to meet the demand created during peak periods and in association with major events. This can create conflict between visitors and local residents adjacent to affected areas.

A number of car parks and marinas (Woy Woy Wharf, Booker Bay, Gosford Sailing Club and Empire Bay) become congested on weekends and in peak periods due to the high number of boat users. Parking and traffic often impact on residents with respect to both noise and access. The pressure on parking facilities associated with boat ramps is also an issue. Of the 15 public boat ramps located around the estuary, only 5 are identified as containing "ample parking". The banning of PWC's has probably also increased their usage on Brisbane Water, serving to exacerbate these issues.

The lack of adequate parking leads to spill over to the grounds of clubs, road easements and often across driveways leading to various conflicts. This may also cause safety issues for pedestrians. Additionally, parking on unsealed land can lead to erosion and land degradation.

These issues generally affect all user groups of Brisbane Water Estuary.

Sporting Facilities

Major sporting facilities, such as the Race Course, Golf Course and Showground restrict public access to the foreshore and waterway. Nutrient leaching and associated runoff from large sporting grounds may affect water quality in both tributaries and the estuary. This can promote the growth of weeds and algae.

Light Industry

There are a range of commercial activities undertaken in the catchment, including light industry. The light industry located near the foreshore and tributaries is primarily concentrated in the Fagan's Bay and Narara Creek regions. Light industry has the potential to conflict with other users due to the associated traffic / transport, visual amenity, noise, access and water quality. These issues present a conflict to the natural environment as well.

Dog Exercising Areas

Under the *Companion Animals Act 1998*, local government is responsible for the management of dog exercise in their area. Dog exercising is a popular activity and so Council has specified 200 parks where dogs may be exercised, 44 of which are off-leash exercise areas. However, in general, on-leash dog exercise is permitted on all parks unless specifically sign posted as a dog exclusion area.

The presence of dogs on the foreshore presents both an environmental and human conflict. Environmental conflicts include dog faeces, which can contaminate the water and result in poor water quality. Dog exercise areas near migratory bird habitat (or other sensitive habitats) may impact on bird ecology and other wildlife. The *National Parks and Wildlife Act 1974* stipulates that dogs and other domestic animals may not be taken into the National Parks as they can catch and kill or wound native animals and birds. Human user conflicts can also occur, although typically to a lesser extent and generally relate to complaints of animals on their property. It is understood that behavioural problems and the inability of owners to control their dogs can also be an issue.

9.2 Recreational Fishing

Brisbane Water provides some of the best recreational fishing in Australia, commercial fishing having been banned some time ago. Recreational fishing on Brisbane Water is very popular. Anglers are attracted to the area from Sydney, which has substantially the highest number of recreational fishers in NSW and from the Central Coast. Estimates of annual expenditure by Sydney anglers for day trips and overnight trips to the Gosford region were estimated to be in the order of $2.6 million in 2002, as reported in Kellogg Brown and Root (2005). The popularity of fishing is evident based on the running of a Fishing Expo at Gosford Showground and the existence of a number of fishing clubs in the area.

Fishing is regulated by NSW Fisheries. It is understood that no specific information has been collected on the number of anglers utilising the Estuary and catch sizes. Commonly targeted species include bream, whiting, luderick, flathead, mulloway, mullet, mud crabs and blue swimmer crabs. Popular fishing areas are identified in Figure 9.4 based on stakeholder consultation, and includes:

- The area between Paddy's Channel and The Rip Bridge;
- Lintern Channel;
- Ettalong Beach;
- Fagan's Bay;
- Point Clare;
- Oyster leases (particularly for black bream);

- Washes, rock gutters, holes and kelp beds off rocky headlands;
- Sand and mud flat areas throughout the estuary;
- Channel drop-offs north of Paddy's Channel (particularly for flathead); and
- Coorumbine Creek (particularly for mullet).

The following restrictions on recreational fishing in Brisbane Water have been established by NSW Fisheries (2004; cited by Kellogg Brown and Root, 2005):

- No spears or spear guns permitted;
- All traps are banned (incl. lobster pots and witch's hats);
- All nets are banned (except landing net or prawn dip / scoop net);
- No more than 6 hooks are permitted on any one line; and
- No foul hooking or jagging of fish permitted.

The location of recreational fishing closures is shown in Figure 9.5.

9.3 Public Safety Issues

Public safety issues that may arise due to recreational activities carried out on and around the waterway primarily stem from congestion and space requirements.

Congestion around car parks and boat ramps and unsafe parking are potential hazards to the safety of pedestrians and other motorists. Drivers of vehicles towing trailer boats often suffer from obstructed or limited vision, which when combined with high traffic flows and congestion has the potential to impact on public safety.

Another community concern relates to adequate lighting at boat ramps and car parks. Many fisherman and other boat users launch their craft in times of limited daylight (dawn and dusk) on ramps that lack lighting. One possible solution previously suggested in sensor lighting or focused lighting for the boat ramp areas to limit the risk of accidents.

Public safety is also of concern in areas of the waterway which are utilised by a variety of users. Conflicts and safety issues may arise due to the differing speeds and sizes of vessels using the waterway. These issues are primarily controlled and mitigated by NSW Maritime.

9.4 Foreshore Land Uses

Foreshore Ownership

Brisbane Water foreshore land tenure and zoning is identified in Figure 9.6 and discussed further in Kellogg Brown and Root (2005).

All Brisbane Water foreshore land is owned privately, owned by the Crown or owned by Council. Most Crown land is assigned a specific use through either dedication for a public purpose or reservation from sale, grant of a lease or licence, or for future public requirements or other public purpose. In addition, the same portion of Crown land may serve other purposes, such as open space, wildlife habitat, recreational areas or foreshore access. Land set aside on behalf of the community is known as Crown reserve, and may be used for a range of public uses including environmental and heritage protection, open space, recreation and sport, community halls and special events.

Crown land identified within foreshore areas of Brisbane Waters includes Crown reserve areas and other Crown areas. Crown land also includes the bed of the estuary to the high water mark. GCC is responsible for regulating usage and maintenance of the approximately 140 portions of Crown land identified in the Brisbane Water study area. Council also has ownership of 190 ha of foreshore land. However, this amount of 190 ha does not include crown reserve, of which Council has care, control and management. The Parks and Waterways Division of Council develops management policies and implements maintenance programs for these areas.

In addition, large areas of the Brisbane Water foreshore are owned privately. Protection of land and control of development within sensitive environmental areas (such as foreshore lands) in private ownership or under private lease from the Crown is achieved through zoning. The predominant planning instruments affecting private foreshore lands along Brisbane Water are the LEP, DCPs and the Gosford Planning Scheme Ordinance June 2004.

Foreshore Land Use

Large sections of the foreshore of Brisbane Water are zoned residential. Foreshore residential development occurs on the southern foreshore of Woy Woy Bay, between Tascott and Point Clare, at Gosford and at Green Point. As discussed in Section 3.2.2, it is understood that Council has not identified any new areas of foreshore land for development and intends to accommodate future demand for housing through infill development and re-development. It is understood that, where the DoL is investigating the option for developing foreshore land, the suitability of such a development will be considered.

The major commercial centres are located near Gosford and West Gosford in the north and Woy Woy / Ettalong / Umina in the southwest. Some other smaller commercial centres occur along the eastern foreshores.

The extent of National Parks and COSS areas is discussed in Section 9.1.

Foreshore Access

Approximately 35% of the foreshore land is accessible by the public, being made up of public reserves, National Parks and Nature Reserves. The most substantial areas at which the public can gain access to the foreshore occur between Ettalong Beach and Woy Woy, within Woy Woy Bay, between Koolewong and Tascott, between Point Clare and West Gosford, and at Yattalunga, Saratoga and Killcare (Figure 9.6).

The rest of the foreshore land is either privately owned, Crown land under private lease or Council owned land that is not publicly accessible. Access is limited at some locations due to private property along the foreshore. In other locations access is limited to small reserves or areas of open space at the end of roads or access paths located between residential developments. Public access is generally considered sufficient for local use.

9.5 Summary of Key Findings

The key findings of the report on recreational activities and foreshore land uses are summarised below:

- **Public Safety:** The range and variety of both land-based and waterway activities engaged in by recreational users of Brisbane Water Estuary indicates that there is a high potential for conflict between different user groups. Public safety is also a significant concern, particularly with respect to boating activities. Pedestrian and driver safety may be compromised due to traffic congestion and illegal or improper parking, which can reduce driver vision, pedestrian visibility and, on occasion, force pedestrians off footpaths. As has been previously discussed, hazards to navigation include mobile sand shoals (Section 5.2), erosion and sedimentation (Section 5.5) and strong tidal currents (Section 4.2). The diverse range and size of watercraft and the intensity of boating activity also indicate the potential for safety hazards and conflict between recreational users.

- **Environmental Impacts:** It is understood that recreational fishing and boating activities are in general well regulated by NSW Fisheries and NSW Maritime (respectively) through the imposition of a range of rules and zonings. However, both of these activities have the potential to have environmental impacts and future monitoring should be directed at addressing these concerns. Similarly, foreshore activities have the potential to impact on the environment. These environmental impacts include habitat loss and degradation (both terrestrial and aquatic), declining water and sediment quality, shoreline erosion, sedimentation and siltation and detrimental impacts on the aquaculture industry.
- **Planning and Management:** In order to manage the risk of conflict between users, as well as negative environmental impacts, it may be prudent to consider partitioning of activities. This may include the explicit use of zoning of different parts of the estuary for different user groups and should incorporate consideration of some form of protection for environmentally sensitive areas. It is understood at that this method is already being employed by NSW Maritime and NSW Fisheries (discussed above), but may also be applied to foreshore areas. Where sensitive ecological communities or habitats are identified (see Section 7) these areas could be assessed for exclusion of some activities, or for the implementation of methods by which the intensity of recreational usage is reduced. For example, the provision of facilities and pathways will encourage certain types of recreational activities. This is particularly important given projections of increased intensity of recreational usage of the estuary. Public education is likely to form an important component of any such activities.
- **Foreshore Development & Public Access:** At present 35% of the foreshore of Brisbane Water Estuary is held in public reserves, National Parks and Nature Reserves. The remaining 65% is privately owned / managed. It is understood that regulation of foreshore development has been a challenge and that many un-regulated activities have occurred, with associated impacts on the environment (e.g. Section 5.5). These developments also impact on recreational activities in that they prohibit foreshore access in many locations. The inherent difficulties in management and enforcement of development along such a long extent of foreshore are appreciated. However, it is recommended that, where possible, Council direct resources to enforcement and control, and also review their existing policies on foreshore development. It is understood that both Council and the DoL recognise the high level of pressure on foreshore areas and are not intending to pursue further development in these sensitive areas. As previously discussed (Section 3.2.2), future growth and development in the Gosford region will be focussing on existing medium density residential areas.
- **Climate Change:** Any interactions between projected climate change impacts and recreational usage also needs to be considered. For example, the impacts of various recreational activities and the limited potential for beach recovery after storm attack (see Section 4.4) are likely to have a synergistic effect. The high potential for shoreline recession in Brisbane Water Estuary will need to be incorporated in future planning to ensure that open space and associated recreational infrastructure are retained. This may involve the introduction of mitigation measures or the reservation of additional open space (where possible).

10. INTERACTIONS BETWEEN PROCESSES

10.1 Overview

The previous sections of this report have focused on consideration of each of the broad processes in operation in Brisbane Water Estuary. This section seeks to draw together the findings for each of the processes and to do so in a holistic way, by describing the estuary as a whole. This description is facilitated by the presentation of a series of conceptual models. These conceptual models represent the interactions between the key processes driving the estuary:

- Estuarine hydrodynamics and ecology (Section 10.2.1),
- Geomorphological and ecological processes (Section 10.2.2), and
- Water quality and ecology (Section 10.2.3).

A key finding of the evaluation of the interaction between estuarine processes is the importance of the maintenance of physical processes in maintaining the diversity, distribution and abundance of flora and fauna within the Brisbane Water Estuary. For example, as discussed in Section 7, Gladstone and Shokri (2007) found that spatial patterns in the biodiversity of macroinvertebrates (an indicator for overall diversity) in Brisbane Water Estuary appeared to reflect environmental variation, with distinct species assemblages occurring at the mouth of tributaries entering the estuary, at the seaward boundary of the estuary and in the central section of the estuary. This environmental variation is a function of the combined spatial variation in the hydrodynamic, geomorphological and water quality environments, and will also vary over time. For example, toward the seaward boundary of the Brisbane Water Estuary sediments are more typically composed of mobile marine sands, erosion may be occurring, high energy wave climates prevail and there is a strong marine influence on the tides and water quality parameters. In contrast, further upstream, particularly in proximity to estuarine tributaries, sediments are typically composed of fine silts and mud, sedimentation may be occurring, freshwater inputs significantly influence water quality characteristics and the tides are attenuated.

Based on a complementary approach, up to 74% of the observed biodiversity of Brisbane Water Estuary is conserved over five $1km^2$ grid cells covering Ettalong, Narara Creek, Koolewong, Woy Woy Bay-Pelican Island and Umina (Gladstone and Shokri, 2007). However, underlying these estuary-wide patterns in biodiversity, variation is also likely to occur at much smaller scales, as evidenced by Gladstone and Shokri's (2007) finding that a large area, represented by 69% of the Brisbane Water Estuary, required protection in order to conserve representatives of all species observed in the studies undertaken for this estuary processes study.

It is useful to investigate the influence of different environmental characteristics on the ecology of the estuary and to develop this understanding to assist with identifying sustainable management actions. This is a particularly important consideration in the context of the potential impacts of climate change, such as sea level rise and altered rainfall patterns.

10.2 Conceptual Models

10.2.1 Hydro-Ecology

Figure 10.1 provides an overview of the physical processes operating in Brisbane Water Estuary and Figure 10.2 describes the interactions between hydrodynamics and ecology. The details shown in the figure are described below.

A full description of the hydrodynamics of the Brisbane Water Estuary is provided in Section 4 and a full description of the ecology can be found in Section 7. Key hydrodynamic features influencing ecology are:

- Astronomical tides, which influence mixing and flushing and water levels, and
- Wave climate, which influences bed shear forces and circulation.

Astronomical Tides

Possibly the most significant hydrodynamic driver of the ecological attributes of Brisbane Water Estuary are the astronomical tides. The ebb and flow of the tides contributes to mixing and flushing, thereby constituting the primary control on advection and dispersion of pollutants or propagules. The tides are also the primary control of water levels on both a day-to-day basis and over the course of the lunar cycle. In addition, the extent of tidal influence in the estuary corresponds to a distinct ecological gradient from the estuary entrance to the upper reaches, across which a range of water quality parameters vary.

As discussed in Section 4.2, the tides are constrained by the narrow constriction of The Rip, beyond which tidal damping and attenuation occurs. This effect is more pronounced with distance and results in considerable spatial variation in the extent of tidal inundation and mixing and flushing. This is particularly important for mangrove and saltmarsh habitats located at higher elevations and in parts of the estuary significantly affected by tidal attenuation. These locations will be tidally inundated less frequently. The discussion below focuses primarily on saltmarsh locations, however the same principles apply to all intertidal habitats.

Tidal inundation has been identified as an important influence on the distribution, diversity and productivity of intertidal habitats (Section 7.2) such as mangroves and saltmarsh, as well as rock platforms (e.g. Woy Woy Bay and Wagstaffe Point) and sandy beaches. Most marine species, including invertebrates and fish, reproduce by releasing either eggs and sperm or larvae into the water column. In the first instance, for species resident in intertidal habitats, this can only occur when their habitat is inundated. A further complexity to this process is that different species will release their larvae at different stages of the tidal cycle (e.g. Freewater *et al.,* 2006). This type of process typically occurs to ensure that larvae are advected and dispersed away from the spawning ground. Animals resident in those saltmarshes located at higher elevations are likely to have a smaller window of opportunity for spawning and will potentially have fewer opportunities to reproduce and higher rates of larval mortality. Similarly, the frequency of tidal inundation will vary for saltmarshes at the same elevation but located in different parts of the estuary. Consider two saltmarshes, both at the same elevation, one of which is located near the outlet of Erina Creek in the upper estuary and another which is located further downstream on Pelican Island or Riley's Island: Those saltmarshes located on Pelican or Riley's Island will be inundated more frequently than those located near Erina Creek due to the astronomical tide range being greater in the downstream areas. However, while the astronomical tides are a major determinant of water levels within the estuary, wind waves and the associated 'set-up' in water level will also influence water levels. As such, on some occasions, the Erina Creek saltmarshes may be inundated due to a combination of wind waves, water level set-up and the tides.

In addition to controlling water levels, the tides also function as the primary control on mixing and flushing, and consequently the advection and dispersion of larvae. However, tidally induced larval dispersion will be limited by the residence times of larvae in the water column, as well as the timing of release (see above). The residence time of spawned larvae within the water column, larval swimming ability and settlement cues are all species specific.

For example, the larval stages for oysters last approximately 21 days, during which time the larvae are transported throughout the estuary. An 'eyespot' (a simple, light sensitive organ), which is light and gravity sensitive, develops and aids in the selection of a suitable recruitment location. However, a number of other environmental factors are likely to be important cues for spat settlement, including the presence of other oysters. Whilst millions of larvae may be spawned at once, mortality is typically very high due to factors such as predation or the simple inability to find an appropriate place to settle. Hydrodynamic drogue tracking and decaying tracer modelling simulations suggest that while tidal flows are generally sufficient to transport larvae throughout the estuary, the degree of connectivity varies amongst saltmarshes found at different locations (Section 7.3.5). For example, the simulations suggest that larvae spawned from saltmarshes located around Kincumber Broadwater did not appear to be advected as far out into the estuary as larvae spawned from Pelican Island. Therefore, the Kincumber saltmarshes can be said to have a lower degree of ecological connectivity with other saltmarshes throughout the estuary. It is noted that the findings regarding larval transport will also apply to the reproductive propagules of plants, such as floating mangrove propagules.

However, connectivity is not just important within the estuary, but in linking the estuary with adjacent coastal waters. For estuarine species, this relates more to connectivity between estuaries (e.g. between Brisbane Water and Pittwater). Additionally, many coastally spawned fish species also spend part of their life cycle in estuaries and may also form an important food source for estuarine species. Ford *et al.* (2006) suggested that tidal advection into and out of the estuary was an important control on the distribution and abundance of larval and juvenile fish (Section 7.3.5). However, it is thought that larval and juvenile fish may proceed further into the estuary via a staging process, again highlighting the importance of connectivity between habitats.

These findings have important implications with respect to:

- The maintenance of genetic diversity at the population level,
- The ability of disturbed intertidal habitats to recover through re-population from other areas, and
- The maintenance of habitat, community and biological diversity within the Brisbane Water Estuary as a whole.

In a parallel to larval dispersal, tidally induced mixing and flushing can also be considered with reference to the transport and dispersion of nutrients and pollutants associated with freshwater inflows. This is discussed further in Section 10.2.3.

Intertidal habitats are some of the most dynamic and challenging coastal environments. The frequency of tidal inundation is also important for assemblage structure and diversity by, for example, affecting the availability of food/nutrients and refugia. For example, some crab species emerge during low tide to feed on algae and detrital matter associated with the sediment. In contrast, other species may rely on the influx of plankton and nutrients associated with tidal inundation. Some species may rely on the influx of estuarine water to provide not only nutrients, but also oxygen, to flush away pollutants and prevent desiccation. All these factors will influence the diversity, distribution and abundance of intertidal flora and fauna. As discussed in Section 7.2.1, high elevation saltmarshes are less frequently inundated, leading to lower diversity and saltmarsh cover (Roberts and Sainty, 2006). The structure and diversity of assemblages associated with mangrove forests is also found to vary in response to changes in the extent of tidal inundation (Section 7.2.2). Roberts and Sainty (2006) also found that highly flushed channels and islands had a higher number of crab holes (an indicator of crab abundance) thought to be related to increased food availability. These findings are important for assessing the implications of human activities, such as land reclamation, which can affect the tidal prism (i.e. change the range of tidal inundation in some areas).

The extent of tidal influence within an estuary creates a gradient in a number of physical and chemical water quality parameters. Seawater typically has a salinity of 35 ppt and a pH of around 8.2. The salinity of freshwater is <0.5 ppt and the pH will typically range between 6.5 and 8.0, depending on the geology and extent of urbanisation of the catchment (sandstone geology can result in flows with relatively low pH, highly urbanised areas can result in flows with relatively high pH flows). As discussed in Section 6, freshwater inflows are also associated with higher turbidity, total suspended solids and nutrient concentrations. All of these parameters will form a gradient corresponding to the degree of tidal influence. As discussed in Section 7.3.1, Gladstone (2006) showed that spatial patterns of macroinvertebrate assemblages were primarily related to distance from the estuary entrance. In addition, conductivity and pH were important determinants of spatial variation in the biodiversity of macroinvertebrates (Gladstone, 2006). This is also likely to be a function of the extent of tidal influence.

Wave Climate and Bed Shear

Two other hydrodynamic processes, namely the wave climate (swell and sea) and bed friction, are also important influences on the ecological attributes of the Brisbane Water Estuary. Section 4.4 describes the difference between swell and sea waves. Swell waves, from the ocean, contribute to the high energy environment of locations near Ettalong, seaward of Schnapper Road. However, swell waves generally do not propagate past The Rip. Other parts of the estuary are exposed to sea waves (locally generated wind waves), such as The Broadwater. Waves also induce shear forces on the estuary bed (Section 4.4). Parts of the estuary subject to higher bed shear forces include The Broadwater, the eastern St Hubert's Island area (intertidal areas and around oyster beds), Cockle Channel and small parts of Woy Woy Bay. Bed shear forces will also lead to the re-suspension of benthic sediments. This process is considered in Section 10.2.2.

Some species are better adapted to high energy environments than others. The wave climate may influence community structure when storm events uproot or damage plants or animals. Disturbance events such as this have a significant influence on community structure. Connell (1978) showed for both coral reefs and tropical rain forests that, over time, diversity will decline as the community structure moves towards an equilibrium in which some species are able to out-compete others. After a disturbance event, diversity will increase due to differential species-specific survival rates and life history strategies. However, the process is dependent on the frequency with which disturbance events such as storms occur. Therefore, the magnitude and frequency with which larger waves (and associated high bed shear forces) occur will have a significant effect on assemblage structure and diversity. Due to the spatial variability in wave climate around the estuary, this process will be more important in some locations than in others.

As discussed in Section 7.3.1, Gladstone (2006) found that fetch and bottom shear were two of the more important influences on the density and diversity of macrobenthic invertebrates in Brisbane Water Estuary, with higher species diversities associated with Wagstaffe, St Hubert's Island and the lower section of The Broadwater. These areas are all subject to high bed shear forces and/or a high energy wave climate. Overall, the highest species diversity was observed in the Ettalong area (Gladstone and Shokri, 2007). Not only is this area subject to a high energy wave environment, but it is also at the interface of the estuarine and coastal environments.

However, data on distribution, abundance and diversity of species described in this report (and accompanying appendices) effectively represents a 'snap-shot' in time. Section 4.4 (and Appendix C) provides a comparison between modelled 5-years ARI and 100-years ARI wave conditions for both sea and swell waves. Wave heights were found to increase significantly for the 100-years ARI condition in the open expanses of The Broadwater and near the estuary entrance (Section 4.4). It is anticipated that these locations may be subjected to disturbance events over medium to long-term time scales and that variation in the structure of assemblages found at these locations may experience large changes over these time scales. In contrast, the 5-years ARI and 100-years ARI wave heights were not dissimilar for the lower portion of the estuary, south of St Hubert's Island (Section 4.4). As such, fluctuations in assemblage structures would be more likely to occur over shorter time scales. This process is important when considering climate change impacts, such as the potential for storm events to increase in intensity and frequency (Section 3.2.9). It is possible that, as a result of climate change, the frequency of disturbance events will exceed the ability of ecosystems to recover, thereby leading to a complete phase shift from one type of ecosystem to another. This process has been observed for coral reefs in the Caribbean (Hughes, 1994). Although in that case, significantly, natural disturbances represented by hurricanes, also coincided with overfishing and disease outbreaks. Similar coincident events, such as the QX outbreak (Section 7.3.4) and *Caluerpa taxifolia* (Section 7.2.5) invasion, could potentially be observed for Brisbane Water Estuary. This latter point is significant in that it highlights the importance of balancing both ecological function and human usage in the face of uncertainty relating to climate change.

10.2.2 Morphology – Ecology

Figure 10.3 describes the interactions between estuarine morphology and ecology. The details shown in the figure are described below.

The morphology of Brisbane Water Estuary is discussed in Section 5. Estuarine geomorphology varies spatio-temporally in response to a number of factors including catchment geology and sediment source. In particular, geomorphological processes are tightly coupled with catchment runoff and estuarine hydrodynamics, therefore any impacts on hydrology and/or hydraulics are also likely to impact on morphological processes. For example, Gladstone (2006) found that spatial patterns in macroinvertebrate assemblage structure varied to some degree in relation to the silt/clay content of the sediment, which is affected by hydrodynamics (eg silty locations are generally areas where low water velocities are observed).

The key morphological processes interacting with the ecology of Brisbane Water Estuary are sedimentation, re-suspension of benthic sediments and sediment transport. The distribution, abundance and diversity of estuarine flora and fauna are significantly influenced by these factors. Some species live in (or on) fine sediments. However, the suite of animals associated with a particular sedimentary environment will vary depending on whether it is located in the intertidal or subtidal zone, and whether that particular location is subject to a high or low energy environment.

Sedimentation and Sediment Chemistry

Sedimentation is typically associated with catchment derived inputs of fluvial sediments. The particle size of these sediments depends on the catchment geology and topography (see Section 3.2.5), as well as the volume and velocity of freshwater inflows. As discussed in Section 5.2, sediment inputs to Brisbane Water have increased since European settlement in association with development in the catchment. Where the creeks with high sediment loads drain to a low energy environment, sediments will accrete near the creek mouth. This process has historically been associated with infilling of embayments in Brisbane Water over long periods of time, but has accelerated to some extent at some locations in more recent years. The influx of catchment derived sediments has the potential to alter sediment geochemistry due to the presence of nutrients and contaminants bound to fine fluvial sediments.

Sedimentation can lead to the formation of mud flats where there was previously clean sand, as has occurred in Correa Bay near Woy Woy Creek (Section 5.6.4). In some locations, such as Hardy's Bay, it is thought that mangroves have increased in extent due to sedimentation (Section 5.6.2) and that, in some cases, progradation of mangroves has occurred at the expense of saltmarsh habitats (Section 7.2.1). Sedimentation and siltation may also lead to smothering of other habitats such as seagrass or rocky reefs and has also been associated with seagrass die-back, eutrophication and algal blooms.

Increased turbidity associated with freshwater inputs can also impact on ecology. Some species respond negatively to elevated turbidity levels, while others will increase in abundance, which subsequently alters the assemblage structure. While nutrient inputs may stimulate phytoplankton growth, the reduced light penetration associated with turbidity will inhibit phytoplankton photosynthesis further down in the water column (Section 7.2.4). Similarly, high loads of total suspended solids and elevated turbidity may negatively impact on seagrasses not only via smothering, but also by reducing light penetration and increasing epiphytic algal loads, thereby by impacting on seagrass primary productivity (Section 7.2.3).

Catchment derived contaminated sediments can have a significant impact on the ecology. Parts of the Brisbane Water Estuary are subject to significant sedimentary heavy metal contamination, and although the concentrations present were classified as having a low potential for ecological impacts (Section 5.3), there may still be potential for negative impacts on the estuarine ecology. The ISQG Guidelines used for this assessment to identify as to whether impacts may be occurring were developed by the US EPA and are effectively based on a single study (Long, 1995). Whilst it is understood that there are currently a number of studies being undertaken in Australia that address this topic, there are not at this time any comprehensive Australian guidelines for the assessment of the ecological effects of sediment contaminants. Potential effects include impacts on basic biological functions (e.g. growth, survival and reproduction) and bioaccumulation.

Further away from estuarine tributaries sedimentation in the main body of the estuary is less of an issue. Therefore, there is effectively a gradient ranging between parts of the estuary that are under more influence by catchment sedimentary processes, to those areas that more heavily influenced by marine sedimentary processes. This is reflected in the ecology of the estuary. However, where creeks with high sediment loads enter the estuary in a high energy environment, or where sediments are re-suspended, they may be transported further out to be deposited over greater areas in other low energy environments within the estuary. Thus, sedimentation may also occur in parts of the estuary away from creek mouths and depends on whether there is a net export or import of sediments. This process can be observed with the dispersion of contaminated sediments from catchment based sources, to more sheltered parts of the estuary, although it is noted that these contaminants are typically bound to finer sediments (Section 5.3) and therefore the settlement will be driven by the character of these sediments and the hydrodynamics of the estuary.

Bed Shear Forces and Re-Suspension of Sediments

As discussed in Section 10.2.1, the wave climate (or tidal flow in some locations) within the Brisbane Water estuary exerts bed shear forces on the estuary floor. As well as having a direct physical impact on those species living on or near (or recruiting to) the estuary bed, these forces may result in indirect ecological impacts associated with the re-suspension of benthic sediments. As has been mentioned above, other contaminants and materials such as nutrients, microalgae and bacteria are often bound to these sediment particles. By re-introducing these elements into the water column they are more easily available to organisms. In addition, nutrients may also be chemically transformed into biologically available chemical species. For example, speciation of nitrogen is related to temperature, pH and conductivity, with some nitrogen species (such as NH_4^+) being more bioavailable that other forms. Portions of the estuary potentially subject to re-suspension of sediments include large portions of The Broadwater, eastern St Hubert's Island, Cockle Channel and small parts of Woy Woy Bay. This process may occur quite suddenly in response to the onset of favourable wave conditions and the frequency at which these events occur can vary. In contrast, tidal flow induced shear bed forces at The Rip have led to scouring down to the bedrock and there is no further opportunity for additional scour in this portion of the estuary.

The re-introduction of nutrients into the water column stimulates primary productivity and is often linked to rapid increases in algal biomass, on occasion leading to 'bloom' conditions (Section 7.2.4). The concentration of chlorophyll *a* in the water column was shown to be significantly correlated with patterns of species richness and assemblage structure in Brisbane Water Estuary (Gladstone, 2006). Phytoplankton are at the base of an important estuarine food chain and changes in algal biomass may lead to flow-on effects further up the food chain. For example, a sudden increase in phytoplankton biomass may attract a range of planktivores, which in turn can attract larger predators. However, just as quickly, nutrients can be consumed and depleted leading to a mass die-off of plankton. The cycle of algal bloom and die-off can have a significant impact on water quality, whereby concentrations of dissolved oxygen increase significantly, only to be depleted due to bacterial respiration associated with consumption of dead and decaying algae. This process can have a large impact on other species and has previously been associated with fish kills in other estuaries (e.g. Wilson *et al.,* 2002). The pH of water also tends to be elevated during algal blooms.

In Section 7.2.4, specific responses by different plankton species were discussed with reference to upwelled nutrients and bloom dynamics. Similarly, some plant and animal species may be more readily able to take advantage of an increase in the amount of food or nutrients in the water column than others. This results in spatio-temporal variation in species assemblages.

Oyster leases may also be affected by re-suspension of sediments in some locations, for example, eastern St Hubert's Island. Oysters may remediate the effects of sediment re-suspension due to the large amounts of water they filter. They have been referred to as 'biological filters' and it is understood that Sydney Rock Oysters can filter around 20L of water an hour. For this reason, they are also effective indicators of estuarine water quality. However, sediment re-suspension may cause disease outbreaks in oysters such as that caused by the mud worm (Section 7.3.4).

Sediment Transport and Shoreline Recession

The presence of shallow water sediments (e.g. in shoals) can change the bathymetry such that wave dissipation occurs (as occurs at Ettalong due to the presence of marine sands). These effects can influence patterns of erosion and accretion on beaches (eg the wave processes across the Ettalong Shoal are inter-related with the coastal processes occurring at Umina Beach). However, these processes are dependent on the sediment particle size and the inherent energy in the wave climate at a certain location (Section 5.2.3).

The lower part of the estuary may be considered a more dynamic sedimentary environment. Marine sand has been transported into the estuary as far upstream as Pelican Island on the flood tide. Ettalong, Wagstaffe Point, Rocky Point and Booker Bay are high energy sandy environments. Green Point is also sandy, being exposed to local sea waves, but generally unaffected by catchment inflows and swell. While beaches are not obviously inhabited by plants and animals, large numbers of shellfish, beach worms and other animals can be found living in the sand. These animals are adapted to the dynamic nature of these environments, whereby sand erodes during storms and may be slowly replaced by more regular transport processes (Section 5.4.4). In contrast, in Woy Woy Bay is a low energy environment with finer fluvial material mixed with sand. Hardy's Bay has a similar sedimentary environment to Woy Woy Bay. A different assemblage of organisms will be found in these locations. The latter type of geomorphic environment is considered above.

Natural processes of sediment transport and beach evolution may be affected by human activities, through dredging, land reclamation and the construction of shoreline protection works, boat ramps and jetties. St Hubert's Island is an example of a location for which the impact of these activities can be observed (Section 5.6.1). In other locations, seawalls and groynes have been constructed in order to secure the shoreline and prevent erosion. Apart from the immediate impacts of habitat loss, such structures may have longer term, ongoing ecological impacts. These structures have the potential to significantly affect the shoreline geomorphology such that erosion is actually exacerbated due to reflection/refraction and the interruption of sediment transport leading to long-term recession. In this instance, flora and fauna may be permanently lost or affected such that the natural patterns in community dynamics are altered. Other studies have shown that artificial shorelines have significantly different species assemblages to natural shorelines (Chapman, 2003). This is an important issue when considering that Sainty and Roberts (2007) found that only 8km or 9% of the entire Brisbane Water shoreline (an extent of 89km) could be classed as unmodified (Section 7).

In addition, the natural processes of shoreline erosion and sediment transport may also be impacted by projected increases in the frequency and intensity of storm events due to climate change.

10.2.3 Water Quality – Ecology

Figure 10.4 describes the interactions between water quality and ecology. The details shown in the figure are described below.

Water quality processes in Brisbane Water Estuary are discussed in Section 6. They are interlinked with estuarine hydrodynamics and geomorphology. Whilst flushing has already been discussed in relation to larval dispersal and habitat connectivity (Section 10.2.1), in this section it will be elaborated upon in more detail with respect to variations in the influence of catchment and marine inflows (resulting in gradients through the estuary).

Water Quality Gradients and the Extent of Marine Influence

As outlined in Section 6, estuarine water quality can vary spatially along a gradient from the entrance to the upstream reaches where major tributaries (such as Narara Creek) feed into the estuary. Water quality issues relating to elevated turbidity, low concentrations of DO, and high concentrations of nutrients and chlorophyll *a* are more common in the upstream reaches of the estuary upstream of Woy Woy Bay and primarily in relation to inputs from Narara and Erina Creeks (Sections 6.2 and 6.3). These issues are more problematic following wet weather events, although this pattern is less obvious in the lower reaches of the estuary which are under a higher degree of marine/tidal influence (Section 6.3). Recovery after a rainfall event to normal tidal conditions and water quality is also faster in these locations. For upstream areas, such as Fagan's Bay and The Broadwater, the recovery time is much longer. These findings indicate that there is a strong gradient between those areas dominated by marine/tidal influence and those dominated by catchment processes. The effect of nutrient inputs on ecological processes is discussed in Section 7.2.4 in relation to the re-suspension of sediments. This discussion also applies to nutrients introduced by freshwater inflows. Therefore, the effects of nutrient enrichment on seagrasses and algal dynamics can be assumed to be more likely to occur in the upper reaches of the estuary in proximity to Erina and Narara Creeks and/or following wet weather events. In addition, these ecological impacts are likely to be more noticeable after more intense rainfall events.

Being at the interface of the marine and freshwater environments, it is reasonable to assume that while estuaries contain species and habitats representative of both environments, they will occur along a gradient such that marine species are more likely to be found in those areas under a greater degree of tidal influence. Conversely, species less tolerant of saline conditions are more likely to be found in locations under a greater degree of influence from freshwater inflows. Estuarine species that have a wide salinity tolerance may be found throughout the estuary. This pattern was observed by Gladstone (2006), who found that spatial variations in macroinvertebrate assemblages varied at least in part in relation to distance to the entrance, as reported in Section 7.3.1.

Seasonal and Climatic Factors

Research undertaken as part of this estuary processes study only addressed changes over short time scales (weeks - months). However, it can be assumed that the species assemblages may also vary over longer time frames in relation to seasonal or climatic changes (particularly changes in rainfall). Water quality modelling results reported in Section 6.3 found that total nutrient inputs are generally elevated in years with higher than average rainfall. This can lead to the types of changes in primary productivity and community structure described in Section 7.2.4 with respect to sediment re-suspension. Water quality appears to have improved in recent years, thought to be due to the implementation of catchment based controls but more possibly associated with the lower than average annual rainfall (Section 6.2). However, it is unclear whether this has led to an overall improvement in the ecological ‘health’ of the estuary (Section 10.3).

Climate change is predicted to result in lower average annual rainfall (Section 3.2.9). This will lead to a decline in the influence of freshwater inflows. Water quality modelling indicates that freshwater nutrient inputs are lower in drier years (Section 6.3), which is likely to lead to lower productivity estuary-wide. At the same time the extent of tidal penetration is also expected to increase which could result in a shift in the species composition, favouring those species with wider salinity tolerances. However, at the same time that average annual rainfall decreases, it is thought that rainfall will be concentrated into fewer more intense events, rather than spread over the course of the year. It is possible that the combination of these factors could lead to more significant adverse ecological effects associated with rainfall events due to a diminished capacity of species to cope with sporadic pulses of high nutrient inputs.

10.3 Current Ecological Health

The concept of an ‘ecosystem health assessment’ stems from a number of similar assessments undertaken (e.g. those reported in Coates *et al*., 2002).

An assessment has been prepared in tabular form that allows for an overview of ecosystem health ‘at a glance’. Key indicators were chosen from topics covered in this report. Overall, Table 10.1 indicates that those areas that have been urbanised have ‘health’ issues (such as the northern and western foreshores), whilst those areas with little or no urbanisation have good ‘health’. These findings should be translated into appropriate management actions and direct the next phase – the management study.

Table 10.1 Brisbane Water Estuary Ecosystem Health Summary

Indicator	Tributaries	Embayments / Nearshore	Main Estuary Body
Water Quality – Aquatic Ecosystem Health Values	Poor	? Thought to be poor, particularly after rainfall	? Thought to be reasonable
Water Quality – Recreational Water Quality Values	Poor	Reasonable	Reasonable
Erosion	?	Issues associated with foreshore protection structures and for areas exposed to wave activity.	NA
Sedimentation	Urbanised areas are poor	Some areas with high loads from urbanised areas	Minimal
Sediment Quality	Poor for Narara, Erina and Kincumber Creeks	Poor in the northern reaches near Gosford	Generally reasonable
Foreshores	NA	Modified – highly modified in proximity to developed areas	NA
Saltmarsh	NA	Impacted by high levels of anthropogenic disturbance, some decline	NA
Mangroves	NA	Estimated increase of 4%	NA
Seagrass	NA	Estimated increase of 8%, due to an increase in *Zostera capriconi* at the expense of *Posidonia australis*	NA
Phytoplankton	NA	Elevated concentrations Chl *a*	?
Caulerpa taxifolia	NA	Limited in extent, observed near St Hubert's Island, Booker Bay and Ettalong	NA
Macrobenthic Invertebrates	NA	Impacted by pollution (contamination and nutrient enrichment) and physical stressors (dredging, reclamation and recreational activities)	?
Avifauna	?	Decline in 15 species, mostly waterbirds	?
Fish and Prawns	NA	Thought to be impacted by urbanisation	Thought to be impacted by intensive recreational use
Oysters	NA	Occasional algal alerts issued and disease outbreaks	NA

? Indicates not enough data to make a judgement on the indicator.

10.4 Summary of Key Findings

The assessment of interactions between physical and ecological processes in Brisbane Water Estuary identified the following key points:

- **Environmental Interactions:** It is apparent that interactions between estuarine processes are highly complex and vary over a range of spatio-temporal scales. In reality hydrodynamic, geomorphological and water quality processes act synergistically to shape patterns of species diversity, distribution and abundance. The key drivers of ecological variation in Brisbane Water Estuary are the astronomical tides, wave climate, bathymetry, net sediment flux and freshwater inflows.
- **Ecological Health:** The ecological health of the estuary is currently being negatively impacted by the effects of human intervention, namely the alteration of the foreshore (including reclamation in some locations), urbanisation of the catchment (with associated sediments and contaminants) and recreational users displacing aquatic species.
- **Climate Change:** They key concern with relation to climate change is whether species will have sufficient time to adapt to changes in these physical processes and, if not, if they can maintain essential biological functions (e.g. reproductive cycle) under higher rates of environmental change. However, their ability to do so will be further impacted by ongoing human impacts (e.g. disturbance, water quality impacts).

11. RECOMMENDATIONS FOR ESTUARY MANAGEMENT

Overall, based on the available data and the analysis conducted for this study, the Brisbane Water Estuary is considered to be functioning reasonably well given the level of development that has occurred within the catchment and along the foreshores. The preservation of estuarine function is largely related to the wide entrance, good tidal flushing and the preservation of the National Parks and Reserves in the western and south-eastern portions of the catchment.

11.1 Recommendations for the Next Phase – the Estuary Management Study

Key issues and management actions required to address major issues identified within the study include:

- Comprehensive review of land use zoning of foreshore areas to determine compatibility with ecological requirements.
- Catchment management for urbanised tributaries (including the need for stringent development controls and retrofitting existing developed areas) in order to control inputs of sediments and pollutants. The Narara and Erina Creek catchments should be addressed as a priority and targets for nutrient and sediment control should be set.
- Collection of performance data for gross pollutant traps, particularly sediment traps, to better determine sedimentation and gross pollutant loads delivered to the estuary.
- Survey of tributary foreshore areas to identify erosion issues to reduce catchment sources of sediment to the estuary.
- Management of existing foreshore erosion issues, tighter controls on further development (including requirements for foreshore restoration in development controls) and more comprehensive preservation of foreshore areas for ecological conservation and public access (at nominated locations which are consistent with ecological processes). Targets for rectification and restoration works should be set in terms of length of foreshore (e.g. an increase from 9 to 20% of foreshore length to be restored in a 10 year timeframe).
- Ongoing sedimentation issues at Hardy's Bay, Fagan's Bay and Correa Bay are likely to cause minor localised navigation difficulties if sources and sinks are not addressed in the future.
- Further consideration of zoning of recreational activities within the estuary may aid in reducing ecological impacts as well as user conflicts.

It is noted that management of the estuary is complex, made further so by the wide range of agencies and organisations involved, each with specific interests. Additionally, there are a large number of community interest groups that, due to the large nature of the estuary, have site specific concerns. However, managing the estuary to achieve a balance between human uses and ecological processes requires an estuary-wide approach to ensure that localised issues are addressed in the context of the entire estuary. This approach seeks to ensure that inter-linked processes are not inadvertently affected in the endeavour to manage specific issues.

11.2 Recommendations for Data Collection

Despite the comprehensive nature of the assessments for this study, the complex nature of the estuary, coupled with its sheer magnitude mean that some data gaps remain. As such, recommendations to address this issue include:

- The establishment and on-going maintenance of a common database for all data.

- The implementation of a comprehensive water quality monitoring program to consider long-term ecological health. The program should incorporate event sampling and include additional sites that are located away from tributary mouths.
- Compilation and ongoing collection of data on phytoplankton and zooplankton dynamics.
- Collection of further information to quantify nutrient exchange in the sediments.
- Collection of further information to identify rates of infilling in embayments and identify sediment sources.
- Ongoing monitoring of saltmarsh, mangrove and seagrass areas.
- Ongoing monitoring to detect any further outbreaks of *Caulerpa taxifolia* and preparation of a plan to control the spread of this aquatic weed.
- Collection of further data on larval sources and sinks. This data will aid both habitat management and fisheries management.
- Compilation of data on species records, habitat use and behaviour of avifauna frequenting the estuary.

12. REFERENCES

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