Cardno LawsonTreloar
Shaping the Future

PARRAMATTA RIVER ESTUARY DATA COMPILATION AND REVIEW STUDY

Report Prepared for

Parramatta City Council,
Department of Environment and Climate Change &
Sydney Metropolitan Catchment Management Authority:

On behalf of the
Parramatta River Estuary Management Committee

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EXECUTIVE SUMMARY

The Parramatta River is the largest river entering Port Jackson. The river is tidal to the Charles Street Weir in Parramatta, some 19 km upstream of the commencement of the river at Balmain, or approximately 30 km from Sydney Heads.

Parramatta River Estuary – Gladesville Bridge (DECC, 2008)

For the purpose of the Data Compilation Study, the study area encompasses the whole of the Parramatta River Estuary, which comprises the waterway, bays, foreshores and adjacent lands of the Parramatta River and the tidal creeks, extending from Parramatta Weir to Clarkes Point, Woolwich in the north and Yurilbin Point, Birchgrove in the south (a straight line between the two which does not include the Lane Cove River which already has an Estuary Management Plan). Consideration was also given to the wider areas of the catchment that were considered to influence the estuary.

There are eight local government areas with foreshore frontage in the study area. These are:

- Parramatta City Council LGA;
- Leichhardt Municipal Council LGA;
- Hunters Hill Council LGA;
- City of Ryde Council LGA;
- City of Canada Bay Council LGA;
- Ashfield Municipal Council LGA;
- Strathfield City Council LGA; and
- Auburn Council LGA.

There are a further five local government areas within the catchment. These are:

- Bankstown Council LGA;
- Baulkham Hills Council LGA;
- Blacktown City Council LGA;
- Burwood Council LGA; and
- Holroyd Council.

Complex interactions occur within the estuary. They are governed by a variety of factors including climate, creek morphology and bathymetry, tides, ocean conditions and the impacts of human intervention over time in both the catchment and the estuary.

The diverse nature of estuarine processes results in the division of estuary management responsibilities between a number of government agencies. For example, the ownership and control of estuarine waterfront and submerged lands, is spread across a spectrum of private landholders, local councils, trustees, the Crown and other New South Wales Government authorities. The NSW Estuary Management Process endeavours to provide a process by which estuary management plans are produced such that they are entirely consistent with the tenets of integrated waterway management and ecologically sustainable development.

The Estuary Management Manual recommends an eight step process in order to implement an Estuary Management Plan. In accordance with this policy, the Parramatta River Estuary Management Committee (PREMC) was established in 2006. This Data Compilation Study report represents the second step in the estuary management process, incorporating some preliminary assessment of the compiled data.

This data compilation study identified 672 data sources of which 402 have been directly referenced in this document. A full list of the data sources is provided in **Appendix B**. A summary of the key references is provided in **Appendix C**. The main findings of this Data Compilation Study have been categorised under the following processes headings:

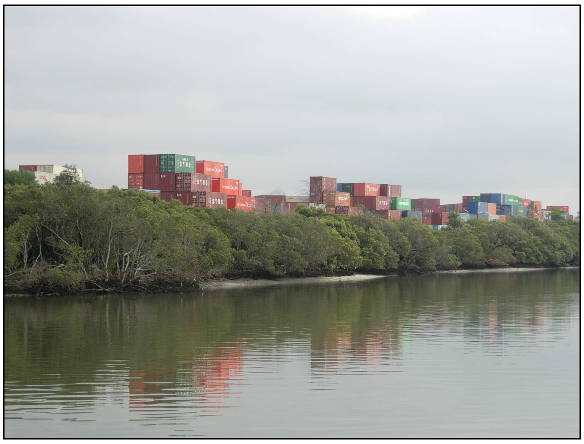
- Catchment Characteristics (including climate and land use)
- Urban Stormwater, Hydrology and Flood Behaviour
- Bathymetry and Estuary Sediments
- Hydrodynamics
- Water Quality
- Ecology
- Human Usage and Recreation
- Cultural Heritage, Values and Significance.

Catchment Characteristics

To understand the estuarine behaviour it is important to understand the impact of the catchment characteristics on the estuary. The catchment characteristics have been summarised in terms of:

- *Climate:* Climate is a dominant factor in the behaviour of the estuary with rainfall, evaporation and solar radiation being significant contributors to the processes occurring within the estuary. The climate of the catchment is summarised in general terms by a range of climatic indicators for two BoM weather gauges located in proximity to the study area: Sydney Olympic Park AWS (1995 – ongoing) and Parramatta (1832 – 1960). The summary indicates that overall, the climate of the area is warm temperate, with wet humid summers and mild, dry winters.
- *Topography:* The principal topographic features of the lower Parramatta River Estuary Catchment are the low relief landscape along the river foreshores (less than 10mAHD in some areas), higher elevated areas along the ridgeline in the Baulkham Hills LGA (up to 120mAHD) and the steeper slopes to the north of the Parramatta River. DECC supplied 10m contour data for the entire catchment, several councils supplied more detailed contours data for individual LGAs.
- *Geology:* The main geological groups underlying the study area are Ashfield Shale, Bringelly Shale and Hawkesbury Sandstone. The Department of Primary Industries (DPI) provided geological mapping for the catchment.
- *Soils:* The prevalent soil landscape in the catchment is the Blacktown landscape which is Residual in character. The erosional soil types Luddenham and Glenorie are the next most prevalent soil landscapes. Fluvial soils are generally found along the line of the valley and river margins. Disturbed soils are also a feature of the study area. The risk of exposing acid sulfate soils (ASS) is common for Australian estuaries. However, this issue has been exacerbated by the history of foreshore reclamations along the Parramatta River Estuary. Soil mapping and ASS mapping was provided for the catchment.
- *Vegetation:* The catchment has a long history of urban development, with the majority of this area having been cleared for industrial and residential land uses. Due to the heavily urbanised nature of the catchment, the extent of native vegetation is limited. Small, isolated pockets of vegetation are scattered throughout the catchment. The majority of the native vegetation is located in the northern part of the catchment, or in association with creeklines.
- *Land Use and Zoning:* The Parramatta River catchment consists of numerous land uses including residential, commercial, environmental protection, education, industrial, open space and recreation and services, transport and communications. Land zoning, management and planning within the Parramatta River Estuary is governed by individual councils and moreover their Local Environmental Plans (LEP).

Recent Residential Development along the Foreshore (Breakfast Point, 28/11/2007)



Heavy Industry – Upper Estuary (2007)

- *Land Ownership:* The New South Wales Government has a documented policy in relation to access to the harbour and river foreshores, including public access to intertidal lands where landowners have absolute waterfronts but where the waterfront is exposed at low tide. Moorings and jetties are the responsibility of NSW Maritime, who is also responsible for the management of the Harbour and river seabed in conjunction with the Department of Lands. Within the study area there is approximately 46.6 km of public foreshore and 24.85 km of private foreshore.

Urban Stormwater, Hydrology and Flood Behaviour

Climate conditions and topographic features dominate the hydrology of the catchment. Water extraction can also have impacts on the catchment hydrology. Water extraction occurs from the groundwater in the catchment and directly from the freshwater sections of the Parramatta River and its tributaries. There are several weirs along the Parramatta River and its tributaries which influence the hydrological behaviour of the estuary.

Flooding has occurred as a result of rainfall events in the catchment on a periodic basis and is a force for significant change to the system over relatively short duration. The flooding behaviour of the Parramatta River Estuary has been extensively documented in numerous flood studies.

The management of urban stormwater falls into two categories – quantity and quality. The quantity aspect of urban stormwater is managed by the provision of pipe networks, overland flow paths and open channels from urban areas to discharge to the estuary. Urban stormwater also delivers loads of litter and debris, nutrients, sediments and a range of contaminants to the estuaries. Controls on the loads take the form of WSUD features spread throughout the catchments. Stormwater quantity and quality within the catchment is generally managed by the various councils and Sydney Water Corporation.

Stormwater Outlets into Iron Cove (4/3/2008)

Bathymetry and Estuary Sediments

Bathymetric data was supplied for the estuary from DECC and NSW Maritime. It is apparent that the deepest sections of the Parramatta River Estuary are in the main channel and that the embayments are much shallower. Upstream of Yaralla Bay the estuary shallows significantly. Also apparent are areas above 0 mAHD that will be exposed over some portions of the tidal cycle. These areas are located primarily in Homebush Bay, but may also be seen at the upstream margins of some of the embayments. A number of very deep areas are also present. These areas are likely to be poorly flushed and subject to poor water quality (e.g. anoxic conditions). These deeper parts of the estuary may also act as sinks for sediments.

In addition to estuarine sediments, there are two sources of sediment delivered to the estuary; fluvial sediments and marine sediments. The movement of marine sand can impact on the navigability of waterways. However, it is thought that marine ingress does not extend as far up Port Jackson as the Parramatta River Estuary. Fluvial sediments are delivered to the estuary via freshwater flows. Sources include catchment creek bed erosion, bank erosion and catchment erosion.

In general, there appears to be a paucity of information relating to the estuary infilling in the Parramatta River Estuary. Where data is available, it is complicated by dredging and reclamation works undertaken over the years.

There have been extensive modifications to the Parramatta River Estuary bed, including both dredging and reclamation works, since the arrival of Europeans in Sydney. It is anticipated that the full extent of historical and ongoing dredging activities is not fully accounted for. Comparison of available sequential bathymetric surveys may provide additional information in this respect.

Numerous studies identify Port Jackson, and the Parramatta River estuary in particular, as being significantly impacted by contaminated sediments. The levels of concentration of some contaminants are some of the highest reported on a global scale.

Several of the available studies report that higher concentrations of contaminants tend to be associated with either particular point sources (e.g. former industrial sites on the eastern shore of Homebush Bay) or the upper reaches of embayments where creeks and stormwater outlets enter the estuary.

The entire study area has been identified as a priority for addressing adverse biological effects associated with sedimentary contamination, particularly Homebush Bay, Iron Cove, Five Dock and the main channel upstream of Hen and Chicken Bay.

Small pockets of foreshore lands throughout the study area are affected by soils identified as having a high probability of occurrence for ASS.

In general, it appears that bank erosion is an issue throughout the study area. This may be due to a range of factors. Bank erosion may have flow-on effects on a number of other features of the estuary and may pose a risk to public safety.

Bank Erosion – Upper Estuary (28/11/2007)

Hydrodynamics

In addition to the system bathymetry, the creek and estuary systems are controlled by three major forcing mechanisms; ocean tides, freshwater inflows and wind and wave driven flows. Less dominant forcing factors that operate on a local and global scale include; density driven flows, global changed in meteorological conditions and sea level rise.

Flood control, transport and water supply systems associated with the early settlement of the area have greatly altered the flow of the Parramatta River. Dredging for ferry access has also changed the natural channels of the river, altering the flow conditions. The Charles Street Weir is the limit of tidal influences on the main arm of the river.

Charles Street Weir (28/11/2007)

Water Quality

In general, estuary water quality processes are dominated by catchment inputs (including point sources and diffuse sources) oceanic inputs and in-estuary processes (including biological interactions and interactions with sediments and the atmosphere, generally strongly affected by climate and hydrodynamic processes).

Existing water quality data was compiled for physical, chemical and biological water quality parameters. In general it was found that the water quality within the estuary was poor with only limited areas of the Parramatta River Estuary considered suitable for secondary contact. Human activities have resulted in elevated levels of nutrients and gross pollutants entering the estuary. Sediment contamination due to urbanisation and industrialisation of the catchment has also had an impact on water quality within the estuary. Extensive alteration of the estuarine foreshore has limited tidal flushing in some areas, further reducing the water quality.

Ecology

The remaining natural vegetation in the catchment is generally associated with creeklines. A number of vegetation assessments have been undertaken in the study area. The key issues raised in these reports include loss of riparian vegetation due to reclamation works and/or clearing and the prevalence of exotic species. Where riparian vegetation is present, it is typically in poor condition and fragmented and therefore has poor habitat value.

NSW DPI – Fisheries, in partnership with the SMCMA, NSW Maritime and the Royal Botanic Gardens have recently mapped aquatic flora for the Parramatta River Estuary. The mapping was undertaken for mangroves, saltmarsh, seagrass and kelp.

Mangroves and Saltmarsh in Iron Cove (4/3/2008)

Fauna species records were compiled for each foreshore LGA based on a search of the NPWS Wildlife Atlas conducted on 13 December 2007. The highest biodiversity with respect to fauna is found in the Auburn and Ryde LGAs. Parramatta and Canada Bay LGAs also have high numbers of species. The lowest diversity of fauna was recorded for Ashfield, which is likely to be a function of the small size of this LGA and its highly urbanised nature. Several site specific fauna studies have also been undertaken within the study area to supplement this information.

A number of introduced (or exotic) aquatic and terrestrial species are present throughout the study area. Exotic species may be introduced to an area via advection on wind or water currents, via animal droppings or via shipping. Many invertebrate and plankton species in particular may survive long sea journeys in the ballast water of ships. Introduced species have the potential to pose significant risks to the natural ecology, human health and economy.

A total of 15 Vulnerable flora species and nine Endangered flora species as listed under the *Threatened Species Conservation Act* have been recorded for the study area. A total of 28 vulnerable fauna species and seven endangered fauna species have also been recorded. There are three ecological communities that are protected under the EPBC Act, including two Endangered and one Critically Endangered communities that occur within the study area. In addition, there are a further three ecological communities listed as Endangered Ecological Communities that are protected under the TSC Act.

Human Usage and Recreation

The Parramatta River Estuary is an important recreational waterway, particularly for the western suburbs of Sydney - designated areas are used for power boating, sailing and sailboarding. It has a long historical association with rowing, evidenced by a number of active, long-term sailing and yachting clubs. There is an increasing amount of waterfront land becoming accessible to the public through the development of walkways and cycleways in foreshore parks and reserves. However, a large proportion of the foreshore is still in the hands of industry and individuals as private residences. There are also regular RiverCat services along the Parramatta River to Circular Quay with a number of wharves at various points along the river.

Numerous foreshore and waterway facilities cater for the recreational demand on the estuary. However, the required facilities do not fulfil the demand in some areas and human usage of the estuary often conflicts with other estuarine processes (such as ecology and water quality).

Dinghy Storage and Boat Access (Iron Cove, 4/3/08)

Cultural Heritage, Values and Significance

The Parramatta River Estuary is considered to be culturally the most significant waterway in Sydney and has been critical in the development of Sydney from the first settlement. The river provided a crucial communication and transport link between Sydney and Parramatta. Initially settlement followed the river and then spread into the surrounding districts. Therefore, the Parramatta River Estuary foreshores contain some of Sydney's earliest European historical monuments and features.

The Parramatta River Estuary lies within some of the most developed and urbanised areas of Australia. As such, the indigenous heritage of the area has been under severe pressure throughout the development of the study area.

Conclusions

Overall, the Parramatta River Estuary is a highly modified system, but it retains a level of functionality despite the wide range of uses and the human impacts throughout the catchment and waterway. The interactions amongst the processes are complex and the ongoing recognition of these interactions through the management phase of the estuary management process will be vital to ensure that the value of the estuary is maintained and enhanced.

A conceptual diagram is shown in **Figure ES1** which provides an overview of the processes within the Parramatta River Estuary.

Table ES1 provides a linkage between the issues identified, the identified knowledge gap and the recommendation for future studies. This table has been prepared to aid the future stages of the estuary management process.

Figure ES1 Parramatta River Conceptual Diagram

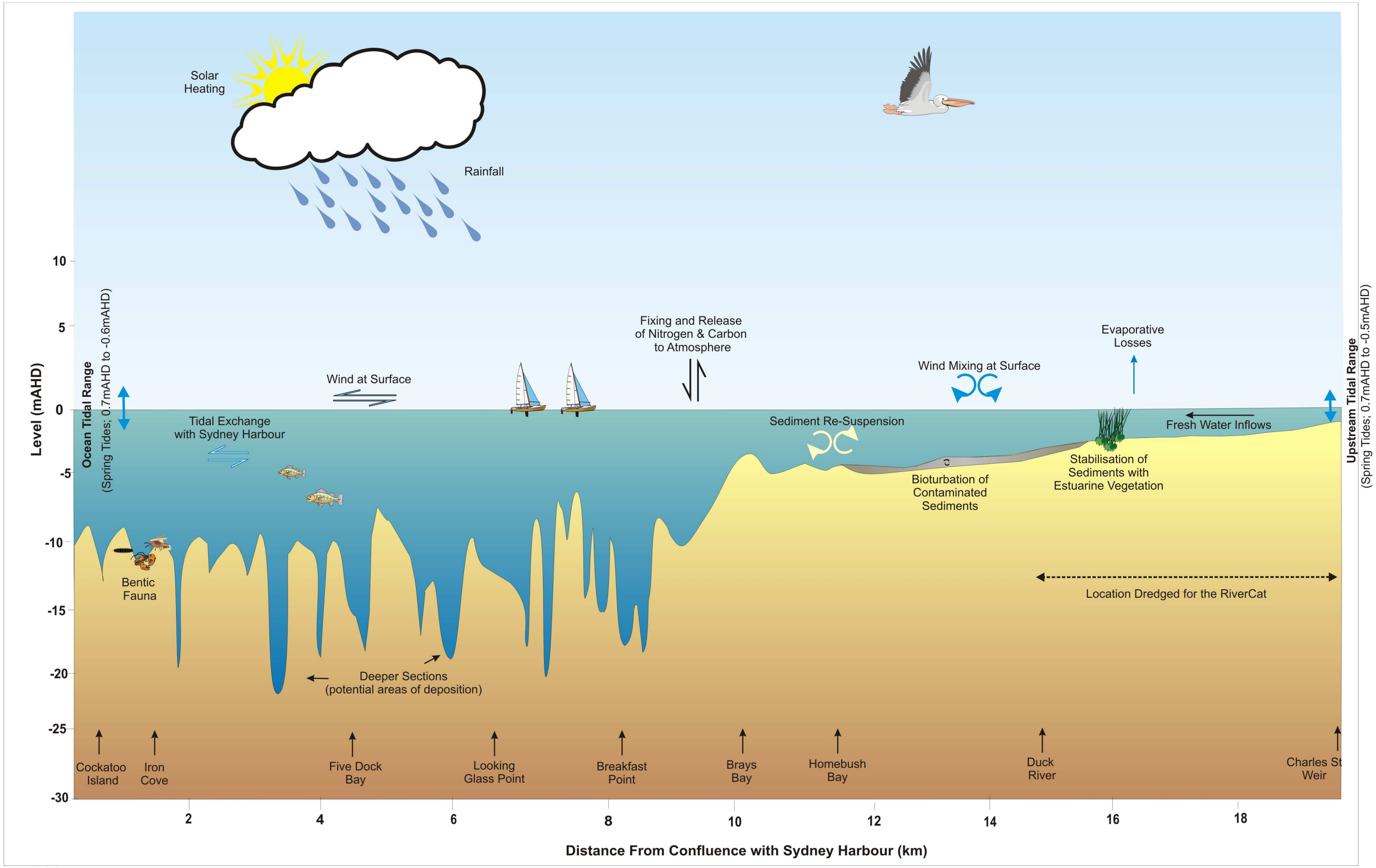


Table ES1 Management Issues, Data Gaps and Further Studies

Management Categories	Management Issues	Priority	Data Gaps	FS ID	Further Studies	Rank
Catchment Processes	Zoning, Planning and development within the Parramatta River catchment needs to address potential environmental impacts (both aquatic and terrestrial).	Medium	LEP boundaries – Information regarding the most up-to-date and predicted LEP mapping has not been made available from all 13 of the councils which make up the Parramatta River Catchment area.	1.03	Update the Local Government LEP boundaries and zoning within the catchment in conformance with changes to State planning policy.	N/A
				1.04	Obtaining the LEP mapping for all councils within the catchment.	15
Catchment Processes	Contaminated lands provide a challenge for future development.	Medium				
Catchment Processes	Contaminated lands are assumed to be very prevalent along the foreshore and thus can significantly contribute to poor water quality if not properly managed.	High				
Catchment Processes	Maintaining the balance between private and public and government land ownership within the catchment poses conflicting management initiatives.	Medium	Land ownership – there is little information available identifying the percentage of private, government and public lands within the area.	1.02	Assess the distribution of public and privately owned land within the catchment, including the associated environmental impacts.	26
Catchment Processes	A large portion of the upper catchment regions are affected by salinity.	Medium				
Catchment Processes	Urbanisation within the catchment has vastly diminished the natural vegetation within the region. Very few areas of natural vegetation still remain within the catchment and particularly along the foreshore. Management needs to focus on the restoration of any remaining pockets of natural vegetation, whilst enhancing and maintaining riparian corridors and environmental recreation/protection areas.	High	Creeks and tributaries – limited information regarding some of the smaller creeks, tributaries and drainage lines throughout the catchment area. Specifically, Powells Creek and Boundary Creek which drain into the Parramatta River estuary via Homebush Bay and Tarban Creek in Hunters Hill LGA.	1.05	Assess the nature and condition of tributaries which flow into Parramatta River Estuary.	29
Catchment Processes	The overall water quality within the Parramatta RiverCatchment has been significantly diminished since European settlement. Industrialisation, land contamination and point sources of pollution have further contributed to poor water quality within Parramatta River Estuary.	High	Sewer overflows and surcharge – little data identifying the known areas of sewer overflow.	1.06	Compile an up to date database of known sewer overflow points within the catchment.	8
Catchment Processes	Variations to the natural landscape, and greenhouse impacts through urbanisation, have altered the prevailing climatic conditions throughout the Parramatta River catchment. Further impacts are likely to occur within increased population and urban sprawl.	Low	Historical land uses – Historical and Current Aerial photographs of the Parramatta RiverCatchment area were not available for the Data Compilation Study.	1.01	Compile a history of land use within the Parramatta River Estuary catchment area using current and historical aerial photography, assessing both local areas which have undergone dramatic changes and the catchment area as a whole.	45
Urban Stormwater, Hydrology and Flood Behaviour	Flooding of ferry wharves.	Low				
Urban Stormwater, Hydrology and Flood Behaviour	Erosion of creek banks and stream channels.	High	There is very limited information on where erosion of creek banks and stream channels is occurring.	2.02	Hydraulic modelling of the catchments to quantify stormwater flow velocities and identify potential erosion "hot spots" based on high velocities.	13

Management Categories	Management Issues	Priority	Data Gaps	FS ID	Further Studies	Rank
				2.03	Where sensitive locations are identified through hydraulic modelling of the catchments (see above), targeted field inspections of the creeks may be undertaken to identify any erosion issues.	30
Urban Stormwater, Hydrology and Flood Behaviour	Marked changes in catchment hydrology due to urbanisation.	High				
Urban Stormwater, Hydrology and Flood Behaviour	Increased local and regional flood problems.	Medium	There is no central coordination for all of the flood studies and floodplain management plans for the study area.	2.06	Compile all flood management actions listed in the relevant Floodplain Risk Management Plans should be compiled and mapped as part of the Estuary Management Study.	28
Urban Stormwater, Hydrology and Flood Behaviour	Inadequate funding for maintenance and creation of stormwater assets.	Medium				
Urban Stormwater, Hydrology and Flood Behaviour	Poor erosion and sediment control on construction sites.	High				
Urban Stormwater, Hydrology and Flood Behaviour	General lack of understanding of catchment issues by multicultural community.	Medium				
Urban Stormwater, Hydrology and Flood Behaviour	The flooding problems in local creeks are not being managed.	Medium	There is no central coordination for all of the flood studies and floodplain management plans for the study area.	2.06	Compile all flood management actions listed in the relevant Floodplain Risk Management Plans should be compiled and mapped as part of the Estuary Management Study.	28
Urban Stormwater, Hydrology and Flood Behaviour	Gross pollutants entering the estuary	High	The locations, types and number of GPTs in the study area.	2.08	Identification of GPTs in the study area (location, type and volume of material collected).	16
			Uncertainty of the pollutant sources and loads.	2.01	Stormwater data compilation or modelling of key catchments and key locations with the aim of determining the likely sources of poor stormwater quality.	11
Urban Stormwater, Hydrology and Flood Behaviour	Poor quality runoff from main roads.	High	Uncertainty of the pollutant sources and loads.	2.01	Stormwater data compilation or modelling of key catchments and key locations with the aim of determining the likely sources of poor stormwater quality.	11
Urban Stormwater, Hydrology and Flood Behaviour	Sever canal contamination (Dobroyd and Hawthorne Canal).	High		2.01	Stormwater data compilation or modelling of key catchments and key locations with the aim of determining the likely sources of poor stormwater quality.	11
Urban Stormwater, Hydrology and Flood Behaviour	Seepage of groundwater from contaminated sites is contributing to poor water quality in the Parramatta River Estuary.	High	Lack of groundwater quality data across the study area.	2.04	Program of groundwater sampling to characterise groundwater quality.	46
			Lack of understanding of groundwater flow and transport of contaminants across the study area as a whole.	2.05	Groundwater modelling to identify transport paths, contaminant plumes and transport rates.	22
Urban Stormwater, Hydrology and Flood Behaviour	Frequent sewer overflows at Bremner Park and in the Hunters Hill area.	High				
Urban Stormwater, Hydrology and Flood Behaviour	Rapid conveyance of stormwater due to piped stormwater system.	Medium				

Management Categories	Management Issues	Priority	Data Gaps	FS ID	Further Studies	Rank
Urban Stormwater, Hydrology and Flood Behaviour	Weirs provide a barrier to fish passage.	Medium				
Urban Stormwater, Hydrology and Flood Behaviour	Water extraction may have an impact on the ecosystem health of the river.	Medium	There is very little information pertaining to water extraction from the river and the water budget for ecosystem health for the river as a whole and for the individual reaches and/or tributaries.	2.07	Information on water access licence titles should be obtained from the Department of Water and Energy (DWE). This information should be assessed against environmental flows for the Parramatta River and it's tributaries to gain an understanding of the impacts of water extraction on ecosystem health.	49
Bathymetry and Estuary Sediments	Sedimentation is thought to have accelerated since European settlement and continues today, affecting the amenity of the waterway.	Medium	It is anticipated that there is other existing data on sediment grain size that has not been identified during this study. However, there is a need for synthesis of this data in order to identify to assess its adequacy.	3.01	Compile a database on existing sediment grain size analyses and assess the need for additional sampling.	50
			Data on sedimentation rates within the estuary are limited but suggest significant historical sedimentation.	3.03	Assess sediment transport throughout the estuary.	36
			There is a need to examine/model sediment transport for the estuary as a whole.	3.03	Assess sediment transport throughout the estuary.	36
Bathymetry and Estuary Sediments	Dredging conducted in relation to various activities has altered the hydrodynamics of the estuary in some locations, and are also likely to have resulted in disturbance of benthic organism, re-suspension of contaminated sediments and turbidity.	Medium	Sediment quality has largely been adequately assessed for the study area, although more detailed studies may be required where estuarine sediments are to be dredged.	3.04	Compile a centralised database, to include geo-referenced data, on historic dredging and reclamation activities.	24
Bathymetry and Estuary Sediments	Reclaimed lands have typically been filled with contaminated material, further compromising water and sediment quality.	High	It is unknown how the fill in reclaimed land is impacting on water quality.	3.05	Quantification of catchment inputs of pollutants including total nitrogen, total phosphorous, heavy metals and total suspended solids (see 2.01).	N/A
Bathymetry and Estuary Sediments	Contamination of estuarine sediments has resulted from the industrialisation and urbanisation of the Parramatta River estuary catchment. This is thought to have significant impacts on both ecological and human health, however, the full impact is not at this time fully understood and the cost of remediation is prohibitive.	High	Inadequate information on the effect of sediment quality on the aquatic biota and the applicability of sediment quality guidelines for Australian conditions.	3.06	Compile a centralised database of all existing studies on sediment quality, to include integration with GIS software.	8
Bathymetry and Estuary Sediments	Bioaccumulation in recreationally fished species is thought to be occurring.	Medium				
Bathymetry and Estuary Sediments	Processes governing partitioning of contaminants, which may lead to mobilisation of contaminants, are not adequately understood.	Medium	Data is insufficient on the partitioning of contaminants between the sediments and the water column in the Parramatta River estuary.	3.07	Assess partitioning of contaminants between estuarine sediments and the overlying water column for a range of environments found within the estuary.	14
			In addition, there is a lack of data on the geochemistry and nutrient flux for estuarine sediments.	3.08	Assess nutrient flux in benthic sediments.	21
Bathymetry and Estuary Sediments	Acid Sulfate Soils occur in some locations throughout the estuary and have the potential to impact on water and sediment quality, infrastructure and the estuarine ecology.	Medium	The mapping of ASS does not provide the level of detail required to assess the impacts of development on ASS.	3.09	More detailed information on the extent of ASS will be required where works that disturb the soils are to be undertaken.	N/A

Management Categories	Management Issues	Priority	Data Gaps	FS ID	Further Studies	Rank
Bathymetry and Estuary Sediments	Foreshore erosion and seawall collapse is occurring at a number of locations throughout the estuary, affecting foreshore amenity, posing a risk to public safety and causing environmental degradation.	High	There is a lack of more recent assessments of bank erosion for both natural and artificial shorelines.	3.1	Bank erosion assessments should be undertaken in high risk areas (i.e. areas with high velocities, erodible soils or previously identified erosion).	27
Bathymetry and Estuary Sediments	Efforts to address foreshore erosion and seawall collapse are hampered by poorly delineated lines of responsibility for maintenance and remediation and a lack of funds.	Medium				
Hydrodynamics	Sediment contamination and transport.	High	Existing modelling does not provide sufficient detail or extent of sediment transport within the estuary.	4.01	Develop a 3D hydrodynamic model of the estuary that may be used to assess water quality and sediment transport in the estuary. As part of the hydrodynamic modelling, tidal limits should be established for Charity Creek, Archer Creek, Clay Cliff Creek and Saltwater Creek	11
Hydrodynamics	Changes in morphology and the related impacts associated with sedimentation and erosion.	Medium				
Hydrodynamics	Extensive alteration to the foreshore, within the Parramatta River and its tributaries has affected reduced tidal movements, extent and the potential mixing of the water column. This can limit biodiversity of aquatic flora and fauna through unnatural variations to pH, salinity and water temperature.	Medium				
Hydrodynamics	Climate change impacts on rainfall and ocean levels.	Low				
Water Quality	Based on data collected under DECC's Harbourwatch program, the waters of the estuary are often unsuitable for primary contact recreation due to high FC counts. Also of concern is the presence of organic chemical and heavy metal contaminants.	High	Faecal coliform data for the lower, middle and upper Parramatta river estuary is limited to a small number of sites and does not adequately characterise the water quality of the estuary.	5.08	The extent and sources of faecal contamination within the Parramatta River estuary needs to be assessed with regards to both primary and secondary contact. Outlining potential hotspots and local catchment areas which may require further attention is a priority. An up to date catalogue of sewer overflow points is also required.	17
			Whilst there have been a number of studies conducted in the Parramatta River Estuary with respect to water quality, these are highly variable in terms of quality and spatiotemporal scales. As a result, a comprehensive, estuary-wide data set on water quality is lacking.	5.07	Characterisation of estuarine water quality for a series of conditions (e.g. dry and wet weather, over a tidal cycle) and on a variety of temporal scales (e.g. seasonal).	5
Water Quality	Overall there are only limited areas of the Parramatta River Estuary which would be considered suitable for secondary contact. There are numerous boat ramps which exist within the Parramatta River Estuary and should provide the basis for monitoring programs and management.	High	As above.			

Management Categories	Management Issues	Priority	Data Gaps	FS ID	Further Studies	Rank
Water Quality	Anthropogenic changes within the catchment have significantly altered the nutrient inputs and nutrient flux within the waterbody. It is worth noting that a major shift from diffuse to point sources of nutrient inputs has occurred over the past 50 years.	Medium	Limited data to quantify the influx of organic and inorganic chemicals to the estuary.	5.05	Quantification of organic and inorganic chemical influx into the estuarine system is required. Whilst there is limited information outlining the inputs as a response of sedimentation, such studies need to be expanded upon in order to account for the transition of chemicals and heavy metals into the water column.	7
			In addition, there is little information on how nutrient levels affect the estuarine ecology.	5.06	Calculation of a nutrient budget for the estuary and determination of the potential for eutrophication (see also 3.8).	6
Water Quality	Increased urbanisation and industrialisation of the catchment has increased the diversity and the range of contaminants entering the estuary. Sediment quality in and around the Parramatta River Estuary has a major influence to the overall water quality and aquatic biodiversity. Variations in water temperature and salinity due to human interference can affect the transition of contaminants into the water column (i.e. from a particulate to a dissolved state).	High		5.04	Assess impacts of human activities on water temperatures within the estuary.	41
Water Quality	Extensive alteration to the estuary foreshore and its tributaries has affected some locations, for which the mixing of the water column has been reduced. This can have significant impacts on water quality and the ecological characteristics of the estuary.	Medium	There is little information as to how alterations to the estuary foreshore and its tributaries impact on mixing and other water quality processes in the estuary.	5.01	An analysis of the effects of anthropogenic influences on tidal mixing within the estuary is required.	N/A
Water Quality	The high levels of gross pollutants observed within the estuary indicate that the existing network of GPTs is insufficient. Urbanised catchments produce vast amounts of litter, which can blow directly into the estuary or be entrained in stormwater runoff and make its way to the estuary via creeks. Trapped litter can be unsightly and dangerous to many aquatic species.	High	Limited information available on the location of GPTs and the volume of litter removed.	5.03	The existing quantitative data on gross pollutants within the Parramatta River estuary should be incorporated into a centralized database (where available). This should include the numbers, types and locations of GPTs within the catchment, along with quantity and type of material removed, as well as other incidental litter collection, such as that undertaken by NSW Maritime and on Clean Up Australia Day. This would facilitate a more coordinated approach to the management of catchment-based controls on gross pollutants.	3
Water Quality	Dumping and spills significantly contribute to the total amount of pollution within the Parramatta River Estuary. However, there is little publicly available information on this issue. Catchment monitoring at a local council scale may assist in reducing the amount of illegal pollution entering the Parramatta River Estuary.	High	There is little information available on the extent of water quality issues associated with oils and scums.	5.02	There is limited information addressing the extent of impacts associated with oils and scums within the Parramatta River Estuary. Further assessment is needed to identify the significant sources and the effect of these pollutants on water quality.	1
Ecology	Habitat management for biodiversity conservation needs to be coordinated across the entire study area.	Medium	An up to date assessment of riparian vegetation has not been conducted for the all the key tributaries to the Parramatta River Estuary. Sydney Metro CMA and DECC are currently mapping vegetation across the Sydney Metro Basin with results expected during the second half of 2008.	6.01	Assess the riparian vegetation of the study area as a whole and prioritise stretches of the foreshore for re-vegetation. Considerations of the site constraints and fauna communities present should be incorporated into the prioritisation process.	20

Management Categories	Management Issues	Priority	Data Gaps	FS ID	Further Studies	Rank
Ecology		Medium	Patterns of change in aquatic flora are not adequately characterised for the study area.	6.02	Condition assessment of aquatic vegetation to facilitate prioritisation of rehabilitation works. As mentioned above, key considerations for prioritisation should include site constraints (e.g. relating to human usage and tidal inundation) and fauna communities present.	35
			Little is known about the macroalgal or phytoplankton ecology of the study area.	6.11	Undertake a study of the plankton of the Parramatta River Estuary.	43
			Whilst there is some information available on the fish fauna of the estuary, very few comprehensive assessments covering the entire study area have been conducted.	6.12	Undertake a comprehensive survey of the fish fauna of the estuary.	40
			Whilst there is a great deal of information on the avifauna of the area, data on patterns of change in bird populations is limited.	6.13	Examine the existing data set on avifauna to assess any trends in birds populations associated with the estuary. This may be correlated with any changes in the available habitat or major land use changes.	34
			Very little information was found on the occurrence of mammals, reptiles, amphibians and invertebrates in the study area as a contiguous unit.	6.14	Compile a database of the existing data on terrestrial fauna within the study area and assess the need for further studies.	44
			There is no known data on zooplankton in the estuary.	6.11	Undertake a study of the plankton of the Parramatta River Estuary.	43
			Little is known about the macroalgal or phytoplankton ecology of the study area and how they support estuarine food webs.	6.06	Develop an understanding of primary production in the aquatic environment.	48
Ecology	Management of mangrove expansion is required.	Medium	Methodical approaches for managing mangrove incursion into other estuarine habitats are currently lacking.	6.08	Identify locations in which mangroves are becoming established to the detriment of other estuarine habitats, or in otherwise inappropriate locations, and assess the need for management.	42
Ecology	Whilst efforts are being made to restore natural habitats, these may be counterproductive in the short-term. For example, degraded, weed infested habitat may provide the structural complexity to act as a refuge that is not afforded by recently re-vegetated areas.	Medium	Limited information was available pertaining to the success of habitat restoration programs.	6.04	An assessment of the success of programs to re-establish aquatic vegetation.	47
Ecology	Conflicts between human activities and the ecology are common. This is due to the proximity of the estuary to high density residential and urban areas. Issues include unauthorised removal and/or damage of estuarine vegetation by residents, trampling of off-path vegetative areas and the introduction of pest species.	High	There is no definitive spatial database of the areas negatively impacted by human activities.	6.05	Identification of those natural areas most heavily impacted by human usage. Once identified, the types of impact can be assessed in order to develop methods to reduce these impacts.	18
Ecology	Loss of intertidal habitats through foreshore development and seawalls.	High				

Management Categories	Management Issues	Priority	Data Gaps	FS ID	Further Studies	Rank
Ecology	Introduced species are prevalent throughout the study area. Whilst few targeted studies have investigated their impacts on native species, it is thought that they are having a significant negative impact on native flora and fauna, be it through simple displacement or more complex processes such as competition for resources.	High	The impacts of introduced species on the native flora and fauna have not been characterised.	6.07	Ongoing monitoring of key ecological indicators of both ecological integrity and biodiversity. This monitoring should aim to facilitate identification of patterns and directions of change.	38
Ecology	The impact of poor water and sediment quality on the estuarine ecology is not fully understood.	Low	The effects of pollution on the estuarine ecology are not fully understood. However, in general, it appears that the overall ecological health of the Parramatta River Estuary has improved in recent years.	6.07	Ongoing monitoring of key ecological indicators of both ecological integrity and biodiversity. This monitoring should aim to facilitate identification of patterns and directions of change.	38
Ecology	The bioaccumulation of toxic contaminants in aquatic organisms is known to be an issue for the health of estuarine flora and fauna, as well as human health.	High				
Ecology	Sedimentation and / or smothering of habitats.	Medium				
Ecology	Scouring and erosion associated with stormwater runoff and RiverCat boat wake impacting on estuarine habitats.	Medium	Whilst it can be reasonably concluded that the wake from the RiverCat service is causing bank erosion and undermining of mangroves in the upper estuary, no definitive study has been conducted to date. In addition, there does not appear to have been a targeted assessment of the effects of scour associated with stormwater outlets.	6.09	Identify portions of the river bank affected by scour, recommend appropriate ameliorative actions and prioritise for works based on habitat values.	N/A
				6.10	The undertaking of an assessment of the impacts of RiverCat boat wake on foreshore stability may be included in the Estuary Processes Study. However, this may be considered a low priority given that the existing evidence reasonably implicates the RiverCat boat wake as being the chief cause of bank undermining and mangrove collapse in the upper portion of the estuary, coincident with locations in which the RiverCat is the primary form of boat traffic and private vessels are banned.	23
Ecology	High levels of nutrients in stormwater runoff can promote algal growth.	Medium				
Ecology	Conservation and Management of Threatened Species/Communities appears to be largely uncoordinated throughout the study area and corridors linking important habitats are lacking.	Medium				
Ecology	Climate change has the potential to have a number of largely unknown impacts on the estuarine ecology.	Low	There is very little information on the impacts of climate change on the estuarine flora and fauna.	6.03	Explicit assessment of the potential impacts of climate change and ongoing human usage on the estuarine flora and fauna. To incorporate as a priority an assessment of the potential impacts of sea level rise on estuarine flora.	31
Human Usage and Recreation	The tourism potential of the estuary is not being realised to its full potential.	Low	There is no tourism data relating specifically to the study area or the immediate region.	7.02	Tourism Data Collection: if possible it would be useful to collect data relating to how many people are visiting the estuary, where they are coming from and the purpose for their visit.	2

Management Categories	Management Issues	Priority	Data Gaps	FS ID	Further Studies	Rank
Human Usage and Recreation	Management of the estuary should be in accordance with the community values of the estuary.	High	There is limited information on the community values of the estuary. However, this type of information has been collected in preparing the Draft Parramatta River Foreshore Plan (Environmental Partnership, 2008). An additional survey may be required in order to ensure that the interests of all users of the Estuary are provided with an opportunity to comment.	7.03	It may be useful to undertake an economic assessment of the values of the estuary. That is to undertake an assessment which determines an economic value for the various aspects on the estuary. This is usually done based on how much people are willing to pay to visit the estuary or protect features of the estuary. It may be necessary to conduct a community survey as part of this assessment. This may be done in conjunction with the collection of tourism data.	10
Human Usage and Recreation	No signage on Victoria Road announcing George Kendall Reserve.	Low				
Human Usage and Recreation	Lack of appropriate signage (in some areas) to direct the public to foreshore areas and facilities.	Medium				
Human Usage and Recreation	Problems with graffiti on existing signage.	Medium				
Human Usage and Recreation	Private land use inhibits public access to the foreshore.	Medium				
Human Usage and Recreation	Tall buildings impact on the visual amenity.	Low				
Human Usage and Recreation	Poor orientation of development (i.e. away from the estuary).	Low				
Human Usage and Recreation	Tables and seating should cater for different sized groups.	Medium				
Human Usage and Recreation	The need for informal recreation areas that cater for families and larger groups.	Medium				
Human Usage and Recreation	Mosquitos are a problem around George Kendall Reserve and Meadowbank Park.	Low				
Human Usage and Recreation	The RiverCat bow wave has effects on bank stability and turbidity has increased notably.	High				
Human Usage and Recreation	There is a need to balance the demand for RiverCat services against the environmental capacity or costs.	High				
Human Usage and Recreation	Lack of continuity of walking tracks and open space along the foreshore.	High				
Human Usage and Recreation	Some areas utilise boardwalks, other areas could benefit from this.	Medium				
Human Usage and Recreation	Better pedestrian links are required on the south side of the River across Duck River, connecting Parramatta with Homebush Bay.	Medium				
Human Usage and Recreation	Lack of formalised access points to the waterway, bank erosion and impacts to vegetation due to informal access points being created at multiple locations.	Medium				
Human Usage and Recreation	Lack of appropriate lighting along foreshore areas.	Medium				

Management Categories	Management Issues	Priority	Data Gaps	FS ID	Further Studies	Rank
Human Usage and Recreation	Poor transport is a key constraint to accessing the estuary, made worse by the lower income character of the area.	Medium				
Human Usage and Recreation	Increase in demand for sports by 'second generation immigrants'.	Low				
Human Usage and Recreation	Need to cater for young people, including entertainment facilities and informal recreation for girls.	Medium				
Human Usage and Recreation	Housing developments (medium density) around Homebush Bay will increase demand for public spaces and facilities.	High				
Human Usage and Recreation	Conflict between waterway users, in particular the RiverCat and rowing sculls.	Low				
Human Usage and Recreation	There is a need to rationalise boat ramps and associated facilities (such as car parks).	Medium	No information was available of boat ramp usage and capacity.	7.01	In order to rationalise the boat ramps and associated facilities, it must first be determined which facilities are the most popular and what their capacity is.	3
Human Usage and Recreation	Impacts of car parking on the foreshore.	Medium				
Cultural Heritage, Values and Significance	Integration of data on heritage items is lacking. This a particular issue given the number of agencies that are responsible for management of various parts/aspects of the study area.	Medium	Integration of data on heritage items is lacking.	8.01	Integrate all existing information (including locational details) on a centralised database that may be accessed by all relevant agencies and organisations (as is appropriate).	18
Cultural Heritage, Values and Significance	Loss of heritage items is thought to be a significant issue in the study area. While it is anticipated that a number of items have been lost during the process of urbanisation of the catchment, there are ongoing impacts as well.	Medium	There are a very limited number of studies that explicitly address the visual landscape and landscape character.	8.02	Undertake an Aboriginal cultural heritage assessment for the entire study area, to incorporate consideration of culturally important sites that may not otherwise be accounted for.	31
Cultural Heritage, Values and Significance	Unidentified heritage items.	High	Assessments of heritage in the study area as a whole are generally lacking.	8.03	Undertake a comprehensive survey of European heritage items in the study area in an attempt to identify any previously unrecorded sites. The narrow down the search area, sites considered to have a high potential of containing heritage items may be targeted.	25
				8.04	Undertake targeted maritime heritage surveys in association with locations thought to have a high potential for the occurrence of important archaeological items (e.g. Queens Wharf).	37
			Relatively poor appreciation of the Indigenous heritage of the study area, particularly in the context of the study area as a whole.	8.05	Documentation of Indigenous oral history and personal accounts.	31
				8.02	Undertake an Aboriginal cultural heritage assessment for the entire study area, to incorporate consideration of cultural important sites that may not otherwise be accounted for.	31

Management Categories	Management Issues	Priority	Data Gaps	FS ID	Further Studies	Rank
Cultural Heritage, Values and Significance	The cultural heritage of the Parramatta River Estuary is inadequately promoted, particularly with respect to Aboriginal cultural heritage.	Medium	Much of the information available is from an archaeological perspective, as opposed to an anthropological perspective.	8.02	Undertake an Aboriginal cultural heritage assessment for the entire study area, to incorporate consideration of cultural important sites that may not otherwise be accounted for.	31
			An Aboriginal perspective on the Indigenous heritage sites and their cultural associations with the study area is lacking.			
Cultural Heritage, Values and Significance	Lack of linkages between open space areas and heritage items.	Medium				

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GLOSSARY

AHIMS	Aboriginal Heritage Information Management System
AMC	Ashfield Municipal Council
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.
ARI	Average Recurrence Interval
ASS	Acid Sulfate Soil(s)
Attenuation	A reduction or weakening.
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.
Bed Load	That portion of the total sediment load that flowing water moves along the bed by the rolling or saltating of sediment particles.
BCC	Blacktown City Council
BHSC	Baulkham Hills Shire Council
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.
BOD	Biochemical Oxygen Demand
BoM	Bureau of Meteorology
Breaking Waves	As waves increase in height through the shoaling process, the crest of the wave tends to speed up relative to the rest of the wave. Waves break when the speed of the crest exceeds to speed of advance of the wave as a whole. Waves can break in three modes: spilling, surging and plunging.
Breakwater	Structure protecting a shoreline, harbour, anchorage or basin from ocean waves.
Buffer Zone	An appropriately managed and unalienated zone of unconsolidated land between beach and development, within which coastline fluctuations and hazards can be accommodated in order to minimise damage to the development.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
CCBC	City of Canada Bay Council
CLT	Cardno Lawson Treloar
CMA	Catchment Management Authority
CoR	City of Ryde
CP Act	*Coastal Protection Act, 1979*
Coastal Hazards	Detrimental impacts of coastal processes on the use, capability and amenity of the coastline.
DCP	Development Control Plan
DDD	Dichloro-Diphenyl-Dichloroethane
DDE	Dichloro-Diphenyl-Dichloroethylene
DDT	Dichloro-Diphenyl-Trichloroethane
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 DPI .
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.
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).

Discharge	The rate of flow of water measured in terms of volume per unit time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is flowing.
Dispersive Transport	The transport of dissolved matter through the estuary by vertical, lateral and longitudinal mixing associated with velocity shear.
Diurnal	A daily variation, as in day and night.
DLWC	Department of Land and Water Conservation (Became DNR, now DECC).
DNR	Department of Natural Resources (Now DECC and DWE)
DO	Dissolved Oxygen
DoL	Department of Lands
DoP	Department of Planning (Previously DIPNR)
DPI	Department of Primary Industries
DWE	Department of Water and Energy (previously DEUS and DNR)
Ebb Tide	The outgoing tidal movement of water within an estuary.
Ecosystem	A community of living organisms, together with the environment in which they live and with which they interact.
Eddies	Large, approximately circular, swirling movements of water, often metres or tens of metres across. Eddies are caused by shear between the flow and a boundary or by flow separation from a boundary.
EIA	Environmental Impact Assessment. An assessment of the impact of a proposed development.
EIS	Environmental Impact Statement
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*.
ERH	Effects Range High (under the ISQG).
ERL	Effects Range Low (under the ISQG).
ESD	Ecologically Sustainable Development. Development that does not interfere with the short and long-term well-being, health and viability of ecosystems.
Estuarine Processes	Those processes that affect the physical, chemical and biological behaviour of an estuary, eg. predation, water movement, sediment movement, water quality, etc.
Estuary	An enclosed or semi-enclosed body of water having an open or intermittently open connection to coastal waters and in which water levels vary in a periodic fashion in response to ocean tides.
Fauna	Any mammal, bird, reptile or protected amphibian.
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 state or the context otherwise requires, includes crustacean and oysters and all marine, estuarine and freshwater animal life.
Flocculate	The coalescence, through physical and chemical processes, of individual suspended particles into larger particles ('flocs').
Flood Tide	The incoming tidal movement of water within an estuary.
Fluvial	Relating to non-tidal flows.
Fluvial Processes	The erosive and transport processes that deliver terrestrial sediment to creeks, rivers, estuaries and coastal waters.
Fluvial Sediments	Land-based sediments carried to estuarine waters by rivers.
FM Act	*Fisheries Management Act 1994*
Foreshore	The area of shore between low and high tide marks and land adjacent thereto.
Geomorphology	The study of the origin, characteristics and development of land forms.
Habitat	The places in which an organism lives and grows.
HCC	Holroyd City Council
Hydraulic Regime	The variation of estuarine discharges in response to seasonal freshwater inflows and tides.

Intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, eg. intertidal habitat.
Invertebrate	Animal without a backbone.
IPA	Intertidal Protected Area
IPCC	Intergovernmental Panel on Climate Change
ISQG	Interim Sediment Quality Guidelines
LALC	Local Aboriginal Land Council
LEP	Local Environment Plan
LG Act	*Local Government Act, 1993*
LGA	Local Government Area
Littoral Zone	An area of the coastline in which sediment movement by wave, current and wind action is prevalent.
LMC	Leichhardt Municipal Council
PREMC	Parramatta River Estuary Management Committee
Mangroves	An intertidal plant community dominated by trees.
Marine Sediments	Sediments in sea and estuarine areas that have a marine origin.
Mathematical/ Computer Models	The mathematical representation of the physical processes involved in runoff, stream flow and estuarine/sea flows. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with wave and current processes.
MHL	Manly Hydraulics Laboratory
MSL	Mean Sea Level
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
Neap Tides	Tides with the smallest range in a monthly cycle. Neap tides occur when the sun and moon lie at right angles relative to the earth (the gravitational effects of the moon and sun act in opposition on the ocean).
NESB	Non-English Speaking Background
NLWRA	National Land and Water Resources Audit
NOAA	U.S. National Oceanic and Atmospheric Administration
NPWS	National Parks and Wildlife Services
NSW	New South Wales
NTU	A measure of turbidity.
Numerical Model	A mathematical representation of a physical, chemical or biological process of interest. Computers are often required to solve the underlying equations.
NV Act	*Native Vegetation Act, 2003*
OC	Organochlorine (pesticides)
OP	Organophosphate (pesticide)
PAD	Potential Archaeological Deposit
PAH	Polyaromatic Hydrocarbon
PASS	Potential Acid Sulfate Soils
PCB	Polychlorinated Biphenyls
PCC	Parramatta City Council
PCDF	Polychlorinated dibenzofurans (furans)
PCDP	Polychlorinated Dibenzo-p-dioxins (dioxins)
PoEO Act	*Protection of Environment Operations Act, 1997*
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.
REP	Regional Environment Plan
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.
RFI Act	*Rivers and Foreshores Improvement Act, 1948* (now repealed)
Riparian Vegetation	Vegetation growing along banks of rivers.
RTA	Roads and Traffic Authority
Runoff	That proportion of rainfall that drains off the lands surface.

Salinity	The total mass of dissolved salts per unit mass of water. Seawater has a salinity of about 35g/kg or 35 parts per thousand.
Saltation	The movement of sediment particles along the bed of a water body in a series of 'hops' or 'jumps'. Turbulent fluctuations near the bed lift sediment particles off the bed and into the flow where they are carried a short distance before falling back to the bed.
Sand Dunes	Mounds or hills of sand lying to landward of the beach berm. Sand dunes are usually classified as an incipient dune, a foredune or hind-dune. During storm conditions, incipient and foredunes may be severely eroded by waves. During the intervals between storms, dunes are rebuilt by wave and wind effects. Dune vegetation is essential to prevent sand drift and associated problems.
Seawall	Wall built parallel to the shoreline to limit shoreline recession.
Sediment Load	The quantity of sediment moved past a particular cross-section in a specified time by estuarine flow.
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
SHFT	Sydney Harbour Federation Trust
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 wave length 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 budget.
SMP	Stormwater Management Plan
SOI	Southern Oscillation Index; a value greater than 10 indicates La Nina conditions, whereas a value less than -10 is indicative of El Niño conditions.
SOPA	Sydney Olympic Park Authority
SPM	Suspended Particulate Matter
Spring Tides	Tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean)
Suspended Sediment Load	That portion of the total sediment load held in suspension by turbulent velocity fluctuations and transported by flowing water.
Tidal Amplification	The increase in the tidal range at upstream locations caused by the tidal resonance of the estuarine water body, or by a narrowing of the estuary channel.
Tidal Exchange	The proportion of the tidal prism that is flushed away and replaced with 'fresh' coastal water each tide cycle.
Tidal Lag	The delay between the state of the tide at the estuary mouth (eg. high water slack) and the same state of tide at an upstream location.
Tidal Limit	The most upstream location where a tidal rise and fall of water levels is discernible. The location of the tidal limit changes with freshwater inflows and tidal range.
Tidal Propagation	The movement of the tidal wave into and out of an estuary.
Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides.
Tides	The regular rise and fall of the sea level in response to the gravitational attraction of the sun, moon and planets.
Tributary	Catchment, stream or river which flows into a larger river, lake or water body
TSC Act	*Threatened Species Conservation Act, 1995*
TSS	Total Suspended Solids
Turbidity	A measure of the ability of water to absorb light.
Vertebrate	Animal with a backbone.
WARR Act	*Waste Avoidance and Resource Recovery Act, 2001*
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 to 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 or 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 are referred to as swell or swell waves.
WSROC	Western Sydney Region of Councils

1. INTRODUCTION

This report has been prepared by Cardno Lawson Treloar for Parramatta City Council (PCC), the Department of Environment and Climate Change (DECC) and the Sydney Metro Catchment Management Authority (SMCMA).

The study was conducted from November 2007 to June 2008 and consists of a wide range of quantitative and qualitative assessments, including:

- One water-based field inspection,
- Four land-based field inspections,
- Extensive Consultation and liaison with the relevant Councils and agencies, the Parramatta River Estuary Management Committee and other stakeholder groups, and
- Desktop reviews of existing data and literature.

1.1 Study Area

For the purpose of the Data Compilation Study, the study area encompasses the whole of the Parramatta River Estuary, which comprises the waterway, bays, foreshores and adjacent lands of the Parramatta River and the tidal creeks, extending from Parramatta Weir to Clarkes Point, Woolwich in the north and Yurilbin Point, Birchgrove in the south (a straight line between the two which does not include the Lane Cove River which already has an Estuary Management Plan). Consideration was also given to the wider areas of the catchment that were considered to influence the estuary.

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

To facilitate a comprehensive data reporting system, the study area has been divided into three zones. These zones are referred to in this report as:

- *Upper Parramatta River Estuary*, from the Charles Street weir at Parramatta to Wentworth Point, including Duck River and Bicentennial Parklands,
- *Mid Parramatta River Estuary*, from Wentworth Point to Bedlam Point, including Homebush Bay, Brays Bay, Kissing Point Bay, Yaralla and Majors Bays, Breakfast Point, Morrisons Bay, Glades Bay, Hen and Chicken Bay and Looking Glass Bay,
- *Lower Parramatta River Estuary,* from Bedlam Point to Cockatoo Island, including Abbotsford Bay, Five Dock Bay, Iron Cove, Snapper Island and Spectacle Island.

These three zones are illustrated in **Figure 1.2**.

1.2 Estuary Management Process

The NSW 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 each estuary and its catchment.

The Estuary Management Manual recommends an eight (8) step process in order to implement an Estuary Management Plan, as follows:

1. Form an Estuary Management Committee;
2. **Assemble, compile and interpret existing data;**
3. Undertake an Estuary Processes Study;

4. Undertake an Estuary Management Study;
5. Prepare a draft Estuary Management Plan;
6. Public review of the draft Estuary Management Plan;
7. Adopt and implement the Estuary Management Plan; and
8. Monitor and review the management process as necessary.

In accordance with this policy the Parramatta River Estuary Management Committee (PREMC) was established in 2006. This Data Compilation Study report represents the second step in the estuary management process, incorporating some preliminary assessment of the collected data.

1.3 Study Objectives

The main objectives of the Data Compilation Study are to:

- Identify, collect and collate all existing information on the Parramatta River Estuary;
- Assess the adequacy, relevance and reliability of this information;
- Compile and summarise the relevant information;
- Identify information gaps and therefore research needs;
- Identify threats, conflicts and potentials; and
- Determine the priority issues based on existing information, and in consultation with the Committee.

1.4 Report Outline

This report is divided into a number of sections with four main themes.

Section 2 provides details on the Data Compilation Process.

Section 3 outlines the consultation process carried out for the identification of data.

Sections 4 to 12 compile and review the most relevant data and cover every aspect of information available for the lagoon including:

- Estuary and catchment characteristics,
- Hydrology,
- Estuarine sediments and bathymetry,
- Hydraulics,
- Water quality,
- Ecology,
- Human usage and recreation, and
- Cultural heritage, values and significance.

A preliminary list of management issues is included in **Section 13** based on the information presented in Sections 4 to 12.

Section 14 provides a summary of the key recommendations of this Data Compilation Study.

1.5 Relevant Legislation

The Parramatta River Estuary is a significant feature with respect to numerous aspects of environmental, social and economic processes. As such, the management of the estuary has ramifications for all of these processes, just as the management of these processes has ramifications for the estuary. It is important to view the estuary and the Estuary Management Process within the context of relevant State and Commonwealth legislation.

Key legislation relevant to this study is listed below:

- Aboriginal Land Rights Act 1983
- Contaminated Land Management Act 1997
- (Commonwealth) Environment Protection and Biodiversity Conservation Act 1999
- Crown Lands Act 1999
- Environmental Planning and Assessment Act 1979
- Fisheries Management Act 1994
- Heritage Act 1977
- Local Government Act 1993
- National Parks and Wildlife Act 1974
- Native Title (NSW) Act 1994
- Native Vegetation Act 2003
- Noxious Weeds Act 1993
- Pesticides Act 1999
- Protection of Environment Operations Act 1997
- Threatened Species Conservation Act 1995
- Waste Avoidance and Resource Recovery Act 2001
- Water Management Act 2000.

State and Regional Environment Planning Policies relevant to the study area include:

- SEPP (Infrastructure) 2007
- SEPP No. 14 – Coastal Wetlands
- SEPP No. 55 – Remediation of Land
- SREP No. 24 – Homebush Bay Area
- SREP (Sydney Harbour Catchment) 2005.

It is noted that here are also a number of Development Control Plans and Local Environment Plans relevant to the study area, however, these have not been listed here.

2. DATA COMPILATION PROCESS

2.1 Site Visits

A number of site visits were undertaken during the course of the Data Compilation Study, including:

- A water-based site inspection accompanied by representatives of the NSW Maritime and DECC, incorporating all embayments, undertaken on 28 November 2007, and
- A series of land-based site inspections undertaken on 3 and 4 March 2008.

2.2 Literature and Data Review

Data related to the Parramatta River Estuary for the data and literature review was identified from a variety of sources.

2.2.1 Academic Institutions and Research Organisations

A number of libraries were searched for information, including:

- Ashfield Municipal Council (AMC),
- Auburn Council,
- Australian Museum,
- Royal Botanic Gardens, Sydney,
- Bureau of Meteorology (BoM),
- City of Ryde (CoR),
- City of Canada Bay Council (CCBC),
- Commonwealth Scientific and Industrial Research Organisation (CSIRO),
- Department of Environment and Climate Change (including the NPWS library),
- Department of Primary Industries – Fisheries (DPI),
- Department of Water and Energy (DWE),
- Leichhardt Municipal Council (LMC),
- Manly Hydraulics Laboratory (MHL),
- Parramatta City Council (PCC),
- Sydney Water,
- University of New South Wales (including the Water Research Laboratory library),
- University of Sydney, and
- University of Technology, Sydney.

Online databases provided by the universities and Engineers Australia were also reviewed for relevant peer reviewed, academic articles.

Other sources of information included published conference papers. In particular, published materials from the NSW Coastal Conferences and the Australasian Coastal and Ocean Engineering Conferences were targeted.

2.2.2 State and Local Government Agencies

Studies, data and/or mapping (GIS data) was provided by the following organisations:

- Ashfield Municipal Council,
- Auburn Council,
- Baulkham Hills Shire Council (BHSC),
- Blacktown City Council,
- City of Ryde,

- DECC,
- Department of Planning (DoP),
- Department of Primary Industries (DPI) – Fisheries,
- Department of Water and Energy (DWE),
- Leichhardt Municipal Council,
- NSW Maritime,
- NSW Heritage,
- Parramatta City Council,
- Strathfield Council,
- Sydney Harbour Federation Trust (SHFT), and
- Sydney Metropolitan Catchment Management Authority (CMA).

2.2.3 Other Information Sources

Other key stakeholders who provided information for the undertaking of this project, include:

- Shell Refining (Australia) Pty Ltd,
- Sydney Olympic Park Authority (SOPA), and
- Sydney Water Corporation.

A number of newspaper archives were searched, including those for:

- The Australian (1998-current),
- The Glebe / Inner-City News (1998-current),
- The Inner-West Weekly (2004-current),
- The Parramatta Advertiser (1998-current),
- The Sydney Morning Herald (1999-current).

These archives were searched through an online search engine. The dates covered by that search engine are listed in brackets. In addition, Parramatta City Council has provided references from the Parramatta Sun and the Parramatta Advertiser and these are included into the report where relevant.

A search of the World Wide Web was also conducted, using the Google and Altavista search engines. The dates on which websites were accessed is provided where required.

Consultation with key stakeholders and the community, detailed in **Section 3**, was also a key component of the data compilation process.

All data and literature identified has been entered into a database (EndNote X1). All data and literature sourced electronically has been compiled into a separate series of digital files to complement the database. Many hard copy references were also scanned and added to this compilation.

3. CONSULTATION

3.1 The Estuary Management Committee

The Parramatta River Estuary Management Committee (PREMC) comprises of a number of representatives of stakeholder groups, including:

- Auburn Council,
- City of Canada Bay Council,
- City of Ryde,
- Darug Tribal Aboriginal Corporation,
- Department of Environment and Climate Change,
- Deerubbin Local Aboriginal Land Council,
- Department of Primary Industries – Fisheries,
- Friends of Duck River,
- George Kendall Bushcare,
- Hunters Hill Council,
- Mighty Duck River,
- NSW Maritime,
- Parramatta City Council,
- Ryde-Hunters Hill Flora and Fauna Preservation Society,
- Shell Refining (Australia) Pty Ltd,
- Sydney Harbour Foreshore Trust,
- Sydney Metropolitan Catchment Authority ,
- Sydney Olympic Park Authority,
- Sydney Ferries Corporation,
- Sydney Metro CMA, and
- Sydney Water Corporation.

The role of the Committee is to steer the preparation of the Data Compilation and Review Study and also to provide input to the study. Feedback from the committee was used to refine the study limits and ensure that the study met the objectives of the NSW Government's Estuary Management Process.

Cardno Lawson Treloar met with the committee at two key stages of the project:

- Project Inception: presentation of strategic methodology for undertaking the study and findings of preliminary data collation and field inspections (5 December 2007).
- Presentation of the Draft Report: 17 April 2008 a summary of the draft report was presented to the committee, covering the data compilation process, stakeholder consultation, data summary and assessment, identification of data gaps, management issues identification and prioritisation and the conceptual model of the estuary. The community newsletter was also presented at this meeting (see **Appendix D**).

3.2 Stakeholders

Stakeholder consultation was undertaken via telephone contact, as well as separate meetings with representatives of relevant organisations and authorities including:

- DECC (including the Environment Protection Authority (EPA) and National Parks and Wildlife Services (NPWS)),
- Department of Planning,
- Department of Primary Industries – Fisheries,
- NSW Maritime,
- Sydney Water Corporation,

- Department of Lands,
- Sydney Olympic Park Authority,
- Sydney Metro CMA,
- NSW Heritage,
- SHFT, and
- Shell Refining (Australia) Pty Ltd.

A number of other stakeholders were contacted but were unable to provide input to the study.

3.3 Councils

Discussions were held with seven of the eight councils with foreshore frontage, including five of those sitting on the PREMC (as listed in **Section 2.2**):

- Parramatta City Council;
- Leichhardt Municipal Council
- City of Ryde Council
- City of Canada Bay Council;
- Ashfield Municipal Council
- Strathfield City Council; and
- Auburn Council.

These discussions were undertaken to facilitate the data transfer process and to gain some insight into management issues relevant to the respective Local Government Areas (LGAs). Where possible, meetings were conducted face to face. However, some Councils were consulted via telephone.

The additional five councils on the Parramatta River catchment Group were also contacted via telephone. These councils include:

- Bankstown Council,
- Baulkham Hills Council,
- Blacktown City Council,
- Burwood Council, and
- Holroyd Council.

The Local Government Areas are shown on **Figure 3.1**.

Face to face meetings were conducted with PCC, CoR, CCBC, LMC and Auburn Councils. Strathfield Council and AMC were consulted via telephone. The study team was unable to meet with or otherwise discuss the project with Hunters Hill Council. The outcome of these discussions was the provision of GIS data, relevant literature and/or data to the Data Compilation and Review Study. Some councils had greater resources (e.g. for spatial mapping) to draw on than others, resulting in some gaps in the literature and mapping presented in this report.

In addition, staff from these councils also provided information relating to management of the study area. This covered details of past and ongoing monitoring programs, regulatory mechanisms, on-the-ground observations relating to estuarine and catchment processes, data gaps, directions to additional sources of information and advice on key management issues.

Contact was also made with staff at Baulkham Hills, Blacktown and Bankstown Councils to seek their input on catchment processes that they consider to impact on the estuary, including also the provision of data and other resources.

3.4 Community

Consultation with the community was undertaken in May and June 2008. Each of the eight Councils with Parramatta River estuary foreshore lands were supplied with a community newsletter containing a survey, which they were then responsible for disseminating to their local community. A copy of the Newsletter is provided in **Appendix D**.

The purpose of the newsletter was to inform the community of the current study and its purpose. The newsletter also provided background information on the Estuary Management Process and how it applies to the Parramatta River estuary and the current status of the Parramatta River Estuary Management Process. Community consultation is considered to be integral to the Estuary Management Process.

The survey asked the community about their usage of the estuary, how they value the estuary and what type of focus they would like management objectives to have. The findings of the survey were to be incorporated into the Data Compilation and Review Study (this document). However, at the time of issue of this report no responses have been received. It is recommended that any responses received following the issue of this report be utilised for the subsequent phases of the estuary management process.

4. ESTUARY CHARACTERISTICS

4.1 Data Sources

Data sources include:

- Geoscience Australia (2008)
- OzCoasts and OzEstuaries (2005)
- NT (1976);
- Roy (1984)
- Roy, Thom and Wright (1980)
- Roy, Williams*, et al.* (2001).

4.2 Evolution and Classification

Estuarine classifications have been provided by Roy *et al.* (1980) and Roy (1984), who identified three types of estuaries in NSW:

- Drowned River Valley
- Barrier Estuary
- Saline Coastal Lake.

These classifications are illustrated in **Figure 4.1**.

The different stages of maturity within each estuary type reflect the gradual infilling that began about 7,000 years ago, at the end of the last post-glacial marine transgression. Infilling has occurred from the seaward side (marine sand), from the landward side (fluvial sediments) and by the accumulation of suspended fine sediments and calcareous and carbonaceous material produced by biological processes within the estuary itself (e.g. plankton and molluscs).

Roy *et al.* (2001) has since identified five groups of coastal water bodies in eastern Australia, which are summarised below in **Table 4.1**.

The Parramatta River Estuary can be classed as Type II drowned valley estuary. Drowned river valleys have open mouths (semi-enclosed bay environments) and full tidal ranges throughout.

OzCoast and OzEstuaries (2008) provide a good summary of the major features of this system (also illustrated in **Figure 4.1**).

Figure 4.2 presents a schematic diagram of the evolution process for a drowned river valley, showing the formation of a tidal delta at the mouth of the estuary, followed by gradual infilling of the river valley with fluvial sediments. These fluvial sediments may be discharged from the estuary during flood conditions. The Parramatta River Estuary is a mature system and is at the last stage of this process.

Table 4.1 Estuary Classification

Group	Types	Mature Forms
I. Bays	1. Ocean embayments	
II. Tide-dominated estuaries	2. Funnel-shaped macrotidal estuary 3. Drowned valley estuary 4. Tidal basin	Tidal estuaries

Group	Types	Mature Forms
III. Wave-dominated estuaries	5. Barrier estuary 6. Barrier lagoon 7. Interbarrier estuary	Riverine estuaries
IV. Intermittent estuaries	8. Saline coastal lagoon 9. Small coastal creeks 10. Evaporative lagoon	Saline creeks
V. Freshwater bodies	11. Brackish barrier lake 12. Perched dune lake 13. Backswamp	Terrestrial swamps

Another estuarine classification system was developed by Geoscience Australia (2008) who, as part of the National Land and Water Resources Audit (NLWRA), analysed aerial photographs, Landsat TM imagery and scientific literature, as well as data on waves, tides and river power, in order to create an Australia-wide classification of estuaries and coastal waterways (Geoscience Australia, 2008; OzCoast and OzEstuaries, 2008). Seven key types of waterway were identified. These different classifications around the Australian coastline showed a distinct zonation allowing the identification of five major coastal regions.

The south-east coast region is said to predominantly comprise:

- Wave-dominated estuaries (42%)
- Coastal lagoons/strandplain creeks (35%)
- Wave-dominated deltas (10%).

However, Port Jackson, including the Parramatta River estuary, is classified as a tide-dominated estuary (OzCoast and OzEstuaries, 2008). OzCoast and OzEstuaries (2008) provide an overview of the characteristics of these systems, including:

- Geomorphology
- Physical characteristics
- Environment types
- Sedimentary environments and processes of sediment transport
- Positive and negative hydrological processes
- Nitrogen dynamics.

4.3 Management Issues

All estuaries have different characteristics and therefore management of estuaries can not be undertaken using a blanket approach. It is for this reason that the NSW Government developed the Estuary Management Process to allow the management process to be tailored to the different characteristics of each individual estuary.

The Parramatta River estuary is unique when compared to the other estuaries along the NSW coast. This is primarily due to the large size of the estuary and the highly urbanised nature of its foreshores and catchment managed by multiple local councils with a historical legacy dating 220 years.

The management of the estuary therefore must be undertaken within the context of the Parramatta River estuary's unique characteristics.

4.4 Data Gaps and Further Studies

There is a significant amount of information pertaining to the general characteristics of estuaries and the characteristics of the Parramatta River estuary are well documented. It is not considered to be necessary to undertake any further studies to characterise the estuary. Where information is limited pertaining to specific issues, locations or processes within the estuary, these data gaps and recommendations for further studies have been identified in the following chapters.

5. CATCHMENT CHARACTERISTICS

The catchment characteristics of the estuary area are defined here in terms of:

- Climate
- Topography
- Geology
- Soils
- Vegetation
- Land use and zoning
- Land ownership.

5.1 Data Sources

Data sources relating to the general *catchment description* include:

- Bewsher Consulting and WBM Oceanics (2007)
- Cardno Willing (2002)
- Cardno Willing (2004)
- Jones and Frances (1988)
- MHL (2006)
- Robinson GRC Consulting (1999b)
- SKM (2006)
- SOPA (2008h)
- Storm Consulting (2001)
- Vorreiter (1993)
- Water Board (1992)
- Willing & Partners (1990)
- Willing & Partners (1991)
- Mapping from DECC (topography, catchment outlines and drainage lines).

Data sources relating to *climate* include:

- BoM (2008)
- CSIRO (2008)
- NT (1976)

Data sources for *topography* include:

- NT (1976)
- Topographic mapping from DECC

Data sources for *vegetation* include:

- Mapping provided by the NSW NPWS and relevant local councils
- Auburn Council (2008a)
- Benson (2007)
- Biosphere Environmental Consultants (2006)
- CCBC (2008)
- Doig (1997)
- Eco Logical (2006)
- HHC (2008b)
- HHC (2008d)
- James (1997)
- Kubiak (2005)
- LMC (2008b)
- NPWS (2002)
- Oculus (2001)
- PCC (2002b)
- PCC (2002c)
- PCC (2003b)
- PCC (2003c)
- PCC (2008a)

- Robinson GRC Consulting (1999b)
- SMCMA (2008b)
- Urban Bushland Management Consultants Pty Ltd (2006)
- Woodlots and Wetlands, Molino Stewart Environmental Services, *et al.* (1999)

Data sources for *land use, ownership and zoning* include:

- Blaxell (2004)
- DEAP (1986d)
- Hughes, Laginestra and Daffern (2000)
- Jervis (1920)
- Jervis (1935)
- Laginestra and Hughes (2000)
- McLoughlin (2000a)
- PCC (1996b)
- PCC (2002b)
- PCC (2003a)
- Robinson GRC Consulting (1999b)
- Taylor, Birch and Links (2004)
- Webb McKeown & Assoc. (1997)
- Woodlots and Wetlands, Molino Stewart Environmental Services, *et al.* (1999)
- Wikepedia (2008)

5.2 The Catchment

The Parramatta River Estuary dominates the lower portion of the catchment. The minor drainage lines entering the estuary have largely been straightened, narrowed and lined to increase outflow of excess water and to reclaim adjacent lands for development. This straightening and lining means there is a very efficient system for drainage. It also means that contaminants are rapidly conveyed from their source to the receiving waters. This is especially true of the steep short drainage lines that occur in the portions of the catchment underlain by Hawkesbury Sandstone.

The main tributaries to the Parramatta River estuary have been mapped in **Figure 5.1**. A brief description of these tributaries and their catchments is provided below.

5.2.1 Vineyard Creek

Vineyard Creek is located in the Rydalmere area. The main catchment area of the creek is 420 ha. The catchment is predominantly urban, comprising residential, commercial and industrial developments. In its upper reaches, the catchment is steeply graded with narrow valleys spilling out to a wider floodplain downstream of Victoria Rd. It is tidal for a distance of approximately 170m upstream from its junction with the Parramatta River. Vineyard Creek enters the Parramatta River from the north and to the east of the Rydalmere campus of the University of Western Sydney (Robinson GRC Consulting, 1999b).

The tidal limit of Vineyard Creek is located 300m upstream of the Parramatta River. The mangrove limit is located 20 metres upstream of the pipeline crossing (MHL, 2006).

5.2.2 Duck River

The Duck RiverCatchment commences in the Bankstown Local Government Area (LGA), near Bankstown and Condell Park. The area drains north through a system of stormwater pipes and open drains to the Sydney Water Supply Pipeline at Sefton, which is the boundary between Bankstown City and Parramatta City. From here, a more natural watercourse continues through the Parramatta and Auburn LGA's to eventually join the Parramatta River (Bewsher Consulting and WBM Oceanics, 2007).

The tidal limit and the mangrove limit of Duck River is located at the downstream side of the railway culvert (MHL, 2006).

5.2.3 Duck Creek

The catchment area of Duck Creek is relatively flat and consists of mostly medium-high density residential properties. There are some low spots near the main drainage line where storm runoff could pond, and there are also a number of culverts and bridge structures along the drainage channels which cause flow restrictions. The Duck Creek stormwater channel is owned by Sydney Water (Cardno Willing, 2004).

Little Duck Creek is a major tributary of Duck Creek. This drainage system is a mixture of constructed open channel sections and piped sections. There are a number of structures and culverts at road crossings along the drainage line. The Little Duck Creek channel between Colquhoun Park and Duck Creek is a Sydney Water asset (Cardno Willing, 2004).

The tidal limit of Duck Creek is located at the William Street Bridge. The mangrove limit is located on the right bank downstream of the James Ruse Drive Bridge (MHL, 2006).

5.2.4 Powells Creek

Powells Creek consists largely of a concrete lined drainage channel running though Strathfield and Concord, discharging directly into Parramatta River via Homebush Bay (Jones, 1988). The Powells Creek corridor runs adjacent to Bicentennial Park, Sydney Olympic Park incorporating 30ha of foreshore and associated mangrove wetlands. The catchment area consists mainly of residential and recreational land uses and has been highly modified with the development of Sydney Olympic Park. Initiatives to restore the environment within the Powells Creek corridor have been outlined by SOPA (2008h).

The tidal limit of Powells Creek is located 100 metres upstream of the Allen Street Bridge. The mangrove limit is on the left bank opposite Hamilton Street (MHL, 2006).

5.2.5 Haslams Creek

Haslams Creek drains into the Parramatta River at Homebush Bay. The Lower Haslams Creek catchment is located between Homebush Bay and the M4 Freeway. The Upper Haslams Creek catchment covers an area from the M4 Freeway to Rockwood Cemetery and this catchment is highly urbanised. The total area of the catchment is 17 km^2 (Water Board, 1992).

The channel system in the upstream catchment consists of both lined open channels and pipes. The formalised channel in the downstream catchment extends from the M4 Freeway to the Hill Road Bridge. The natural channel downstream of Hill Road extends to Homebush Bay. The formalised channel is owned by the Sydney Water Corporation, while the natural channel is the responsibility of the NSW Maritime.

The tidal limit of Haslams Creek is located 350 metres upstream of the Great Western Highway. The mangrove limit is located 100 metres downstream of the freeway (MHL, 2006).

5.2.6 Boundary Creek

The areas surrounding Boundary Creek are owned by the Sydney Olympic Park Authority and have been highly developed in conjunction with the 2000 Olympic Games. As a result, only a small reach of open water remains (upstream from Lake Belvedere, Bicentennial Park), the remaining sections of the creek runs through underground culverts until discharging in Homebush Bay.

Cardno Willing (2002) has prepared a water management plan for Boundary Creek. It is noted that a Gross Pollutant Trap (GPT) was installed n Boundary Creek during 1999. In, addition a low flow weir downstream from Shirley Strickland Ave was installed to divert flow into the GPT. The areas surrounding Boundary Creek Catchment are mainly used for passive recreation (Cardno Willing, 2002).

5.2.7 Ponds/Subiaco Creek (Bishops Creek)

The catchment area for Subiaco Creek is 840 ha comprising mainly residential land use. There are also some areas of industrial and commercial development and open space in the catchment (SKM, 2006). The major flows in Subiaco Creek originate in Ponds Creek, which joins Subiaco Creek downstream of Victoria Road. Both creeks are overgrown and hence flows are impeded by the heavy vegetative growth. Subiaco Creek enters the Parramatta River from the north and to the east of the Rydalmere Campus of the University of Western Sydney (Robinson GRC Consulting, 1999b).

The tidal limit of Subiaco Creek is located 150 metres upstream of Victoria Road. The mangrove limit is 80 metres downstream of Victoria Road (MHL, 2006).

5.2.8 Archer Creek

The Archer Creek catchment area is 325 ha. The catchment is bounded by Hughes Ave, Fitzgerald Road, Marsden Road, Brush Farm, Brush Road, Bellevue Ave and Adelaide Street. The catchment straddles the boundary between Parramatta and Ryde Councils. The catchment rises along the high ridgeline near Brush Farm Park and passes through a number of incised valleys until it reaches the flatter floodplain areas near the Parramatta River. The catchment is well developed. The upper areas are residential with extensive parklands along the creeklines. The flatter areas below Victoria Road contain several large industrial areas, as well as extensive parklands and the Ryde-Parramatta Golf Course (Robinson GRC Consulting, 1999b).

5.2.9 Smalls Creek/Denistone Catchment

The Denistone Catchment is 218 ha in area. The catchment rises near Second Avenue and Clanalpine Street in the north, is bounded by Adelaide Street and Bellevue Avenue to the west, Blaxland Road and Rydedale Road to the east, and discharges into the Parramatta River to the south. The Main Northern Railway Line crosses the catchment in the top north-east corner. The bulk of the catchment is drained by Smalls Creek. Smalls Creek is jointed by Mariam Creek which drains the north east corner. The catchment is predominantly residential with a large area of clustered commercial premises at the West Ryde Shopping Centre near the intersection of the railway line and Victoria Road. There are also large areas of open spaces in the form of recreational parklands and playing fields; the majority of these areas are in the northern part of the catchment (Willing & Partners, 1991).

5.2.10 Charity Creek

The Charity Creek catchment area is 237 ha. It is bounded by Victoria Road, Devlin Street, Blaxland Road, Marlow Avenue and the Main Northern Railway Line. The catchment boundary crosses the railway line just south of West Ryde Station. The catchment is predominantly residential with some commercial development in the vicinity of Rhodes and Herbert Streets. Most of the drainage system in the Charity Creek catchment consists of concrete pipes or boxed culverts. The creek is culverted down to Meadowbank Boys High School. Below this is a short reach of natural open channel to the railway line. Downstream of the railway line the creek is a concrete lined channel. All the tributaries of Charity Creek are piped (Willings & Partners, 1990).

5.2.11 Hawthorne Canal

Hawthorne Canal is a tidal concrete open channel which begins at Marion Street in Leichhardt and flows into Iron Cove. Flowing into Hawthorne Canal is a mixture of enclosed pipes and open concrete channels which make up the stormwater drainage system. The whole catchment of Iron Cove drains an area of 682 ha and is predominantly residential (71%) in land use, with 6% of the catchment occupied by light industry and 4% used for commercial activities. The remainder of the catchment (19%) is used as open space and special uses such as schools. Water quality within the canal is of concern to the community, local and state government (Vorreiter, 1993).

The tidal limit of Hawthorne Canal is located at the railway bridge (MHL, 2006).

5.2.12 Dobroyd Canal / Iron Cove Creek

Dobroyd Canal (also known as Iron Cove Creek) is a stormwater channel which drains parts of the inner-west suburbs of Ashfield, Burwood, Haberfield, Croydon, Drummoyne and Canterbury. Waters flow from Dobroyd Canal into Iron Cove. The catchment is a well-established urban catchment. Remnant vegetation only exists in very small pockets within the catchment, primarily around the Iron Cove foreshore. The catchment soils are highly erodible and high permeable (Storm Consulting, 2001).

The canal itself consists of approximately 6km of open drain constructed in concrete and masonry, running from 100m upstream of Liverpool Road, Ashfield to the outlet at Timbrell Drive. There are also approximately 2km of tributary sections that are open drains (Storm Consulting, 2001).

The tidal limit of Dobroyd Canal is located 100 metres upstream of Parramatta Road. The mangrove limit is located on the left bank of Iron Cove, 10m from Henley Marine Drive roundabout (MHL, 2006).

5.2.13 Tarban Creek

The tidal limit of Tarban Creek is located 100 metres downstream from Manning Road. The mangrove limit is 80 metres downstream from the old weir (MHL, 2006).

Very little literature was available to provide a description of Tarban Creek. A better understanding of Tarban Creek should be collated as part of the processes study.

5.3 Climate

Climate is a dominant factor in the behaviour of the creeks located within the catchments of the respective lagoons with rainfall, evaporation and solar radiation being significant contributors to the processes occurring within estuaries.

Climate is considered here to be comprised of the following variables:

- Temperature
- Precipitation (including rainfall)
- Evaporation
- Solar radiation (affected by cloud cover)
- Wind speed and direction.

In additional to annual climate patterns, climate is also influenced by long term factors such as:

- El Niño/Southern Oscillation effects (flood/drought cycles)

- Global Climate Change (Greenhouse Effect) (including sea level rise, temperature changes and implications for patterns of rainfall).

There are two BoM weather gauges located in proximity to the study area: Sydney Olympic Park AWS (Gauge No. 066195, Commenced 1995 – ongoing) and Parramatta (Gauge No. 066046, commenced 1832 – 1960). **Tables 5.2** and **5.3** present a data summary (where available) for climatic indicators for both these gauges.

The climate of the Parramatta River Estuary catchment displays all the characteristics of the temperate zone with the unusual feature of a rapid decrease in average annual rainfall from east to west (National Trust, 1976).

Tables 5.2 and **5.3** indicate that, generally, the climate of the study area is warm temperate with wet, humid summers and mild, dry winters. Average monthly rainfall is graphed in **Figure 5.2**. Mean daily maximum temperatures range between 17 – 28.2 ºC and mean daily minimum temperatures range between 4.5 and 19.4 ºC. The mean 3pm wind speed is 13.1 km/h in June and 20.9 km/hr in December. **Figure 5.3** shows annual (9am and 3pm) wind roses for the Sydney Olympic Park AWS. Monthly wind roses are also available from BoM (2008).

In addition, to those weather gauges listed above, there are a number of rainfall gauges located within the Parramatta River Estuary catchment. A list of these gauges is provided in **Table 5.1** and their locations are mapped in **Figure 5.4**. The full details for each of these gauges, including start date, current status and completeness of the record, can be found in **Attachment 1**.

Table 5.1 Additional Rainfall Gauges in the Parramatta River Estuary Catchment

Gauge Name	Gauge No.
Ashfield Bowling Club	066000
Chatswood Bowling Club	066011
Concord Golf Club	066013
Abbotsford (Blackwall Point Rd)	066034
Concord (Brays Rd)	066048
Sydney (Observatory Hill)	066062
Strathfield Golf Club	066070
Parramatta North (Masons Drive)	066124
Riverview Observatory	066131
Granville Shell Refinery	066134
RANAD Newington	066135
Rookwood (Hawthorne Ave)	066164
Sydney Olympic Park AWS	066195
North Parramatta (Burnside Homes)	066111

Table 5.2 Climate Averages for Parramatta (after BoM, 2008)

Statistic Element	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Number of Years
Mean max. temp. (ºC)	28.1	27.7	26.4	23.4	20.3	17.5	17	18.7	21.4	23.7	25.8	27.6	23.1	40
Mean min. temp. (ºC)	16.7	16.6	14.9	11.5	8.2	5.7	4.5	5.4	7.7	10.8	13.3	15.6	10.9	40
Mean 9am air temp. (ºC)	23.2	22.5	20.6	17	13.4	10.5	9.6	11.6	15.2	18.6	21	22.8	17.2	40
Mean 9am wet bulb temp. (ºC)	19	19.1	17.7	14.6	11.5	8.8	7.8	9	11.7	14.4	16.3	18.2	14	40
Mean 9am rel. humidity (%)	66	71	74	75	79	79	77	69	64	60	59	62	70	40
Mean 3pm rel. humidity (%)	53	55	52	53	55	55	54	46	46	45	48	52	51	14
Mean monthly rainfall (mm)	89.4	96.2	99.1	91.3	79.7	82.4	79.6	55	51.4	62.5	62.5	72.3	921.2	100
Median rainfall (mm)	69.7	70	77.5	61.7	39.4	55.7	50.8	39.6	39.6	45.4	54.1	54	888	66
Lowest monthly rainfall (mm)	5.1	0	6.4	0.8	1	0	0	0	0.3	3.6	1	8.7	471.8	100
Highest monthly rainfall (mm)	373.9	449.8	533.1	423	542.3	556.2	312	309.6	224.3	281.2	338.5	349	1856.6	100
Highest daily rainfall (mm)	160.3	180.6	222.8	153.4	125.5	112.8	141.2	132.1	106.7	100.3	128	111.3	222.8	67
Mean no. of raindays	9.4	9.9	9.9	9	8.8	9.1	7.8	7.4	8.4	8.7	8.7	9.2	106.3	66
Mean daily solar exposure (MJ/m^2)	23.8	21.2	17.7	15.1	11.1	8.8	9.5	12.2	15.6	19.2	20.7	23	16.5	13

Table 5.3 Climate Averages for Sydney Olympic Park (after BoM, 2008)

Statistic Element	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Number of Years
Mean max. temp. (ºC)	28.1	28.2	26.4	24.3	20.8	18.4	17.7	19.5	22.4	24.5	25.1	27.5	23.6	12
Highest daily max. temp. (ºC)	44.7	40.8	39.8	33.2	28.4	25.6	24.4	27.9	35.7	38.4	40.4	41.7	44.7	12
Mean min. temp. (ºC)	19	19.4	17.7	14.4	11.4	8.7	7.9	8.8	11.6	13.7	15.5	17.9	13.8	12
Lowest daily min. temp. (ºC)	12.8	12	11.2	6.8	5.4	3.5	1.7	3	6.4	6.8	7.9	11.7	1.7	12
Mean 9am air temp. (ºC)	22.2	22.1	20.3	18.1	14.7	11.9	11.2	12.9	16.3	18.9	19.3	21.5	17.5	12
Mean 9am dew point (ºC)	15.4	16.3	14.8	11.6	8.9	6.2	5.2	5.2	7.4	8.7	11.6	13.8	10.4	12
Mean 9am rel. humidity (%)	67	71	72	67	70	70	68	62	58	55	63	63	65	12
Mean 9am wind speed (km/h)	10.1	9.8	9	9.8	10.8	11.4	11.4	11.9	12.1	11.7	12	10.3	10.9	12
Mean 3pm air temp. (ºC)	26.1	26.2	24.7	22.5	19.5	17.3	16.6	18.1	20.6	22.1	22.9	25.5	21.8	12
Mean 3pm dew point (ºC)	14.9	15.6	14	10.8	8.4	6.2	4.5	4	6.1	7.9	10.9	12.7	9.7	12
Mean 3pm rel. humidity (%)	53	55	54	51	52	51	48	43	43	45	50	49	49	12
Mean 3pm wind speed (km/h)	20.3	18.6	17.2	14.9	13.5	13.1	14	16.5	18.5	19.7	20.5	20.9	17.3	12
Mean monthly rainfall (mm)	101.8	97.3	65.2	84	89.6	75.3	58	69.1	50.5	59.6	78.2	51.8	876.5	12
Median rainfall (mm)	82.7	102.9	52.4	51.4	45.6	50.4	56	50.3	41.4	43.6	61.2	43	815.7	12
Mean no. of raindays	11.3	9.3	11.7	8.3	10.8	9.7	8.6	8.2	8.4	8.2	11.7	8.3	114.5	12
Lowest monthly rainfall (mm)	8.4	7.8	7	2.6	8.8	4.4	12	0.4	5.8	7.4	14.4	1	388.2	12
Highest monthly rainfall (mm)	222.6	206.2	228.4	212.8	311.2	391.2	144.2	297.6	173.4	211	170.4	166.2	1322.4	12
Highest daily rainfall (mm)	113	78	53	115	90	86.2	75	121	79.8	51	46	65	121	12
Mean daily solar exposure (MJ/m^2)	23.7	21.4	17.7	15	11.1	8.8	9.4	12.2	15.6	19.1	20.8	22.9	16.5	13

The closest pan evaporation station is located at Sydney (Observatory Hill). Average evaporation data for this station is shown in **Table 5.4**.

Table 5.4 Pan Evaporation Averages for Sydney (Observatory Hill) (after BoM, 2008)

Statistic Element	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Number of Years
Mean Daily Evaporation (mm)	4.6	3.9	3.1	2.6	1.9	1.2	1.5	1.9	2.5	3.3	4.3	4.4	2.9	12

Long period climatic factors are difficult to predict. An indicator for long-period phenomena such as the El Niño/Southern Oscillation (drought-flood) cycle is the Southern Oscillation Index (SOI). The SOI provides information on the past ENSO events, but gives no clear indication of future trends. It is noted that the El Niño/Southern Oscillation is a long term climatic cycle and that short term processes, such as flood events, may occur within these longer term cycles.

A plot of the SOI is shown in **Figure 5.5** as a guide to past drought-flood cycles. El Niño, or drought periods, are indicated by a strongly negative SOI (SOI ≤ -10), while La Nina, or flood periods, are indicated by a strongly positive SOI (SOI ≥ +10). Over the previous 5 years there has been a notable trend towards El Niño conditions and the SOI has fallen below -10 for several years. Particularly notable is the very low SOI in late 2004. This plot demonstrates that El Niño/Southern Oscillation drought conditions have dominated the 2002-2007 period.

In addition, it is understood that the Commonwealth Scientific and Industrial Research Organisation (CSIRO) are currently undertaking modelling of the rainfall climate of parts of eastern Australia (including for the greater Sydney region) incorporating climate change predictions. Preliminary results indicate that, whilst average annual rainfall is likely to decline, more intense and more frequent rainfall events will occur for the east coast of Australia (CSIRO, 2008).

In addition, DECC in partnership with the University of New South Wales are currently modelling regional climate projections for New South Wales (unpublished research).

5.4 Topography

The catchment of the Parramatta River Estuary lies within the larger Sydney Metropolitan CMA. **Figure 5.1** shows the study catchment area. The catchment is bounded by the Hawkesbury RiverCatchment to the north and west, the Cooks and Georges River Catchments to the south and Port Jackson to the east.

The principal topographic features of the lower Parramatta River catchment are:

- Low relief landscape is present along the river foreshores, including Homebush, Silverwater, Camellia, Rydalmere, Parramatta, Clyde and South Granville,
- The lowest lying areas, at less than 10m elevation, are around Homebush Bay and Millennium Parklands, Camellia, Rosehill and further along the Duck River to South Granville. The North Strathfield/Concord West region is also low lying at less than 10m elevation,
- The highest points in the catchment are approximately 120m in elevation and are located along a ridgeline in the Baulkham Hills LGA in the vicinity of North Rocks and West Pennant Hills. There is also an isolated elevated region around Pemulwuy, and

- The landscape to the north of the Parramatta River is generally steeper than that to the south. While the highest points to the north of the river are around 120m elevation, the highest points to the south of the river is approximately 40m in elevation.

Available contour data for the catchment is shown in **Figure 5.6** (after DECC).

In the western region of the catchment the elevation rarely exceeds 75 mAHD and is generally as low as 30m in the southern regions (National Trust, 1976).

There are three basic topographic divisions within the Parramatta River Estuary catchment (National Trust, 1976):

- *The Coastal Plateau* is characterised by the rugged topography of Hawkesbury Sandstone with deep narrow valley dissection and steep hill slopes. A thin capping of Wianamatta Shale overlies the sandstone. The soils produce little runoff.
- *The Alluvial Pattern of Present Stream Courses* is a minor topographic feature of the catchment. The small catchment area of the Parramatta River Estuary results in little siltation and hence alluvial deposits are minimal. Most contributing creeks have delta formations consistent with their size at junctions with the Parramatta River.
- *Undulating Low Hilly Landscape* occupies most of the area known as the Cumberland Basin. It comprises the sag block which remained when surrounding areas were raised to form the present dissection plateau. This mature landscape consists of low shale hills and drain into wide valleys.

5.5 Geology

The main geological groups underlying the study area are:

- Ashfield Shale – shale, siltstone and claystone; part of the Wianamatta Group,
- Bringelly Shale – shale, sandstone; part of the Wianamatta Group, and
- Hawkesbury Sandstone – quartz-rich sandstone (with abundant cross-bedding) with interbedded shale.

Figure 5.7 presents a map showing the extent of each of these geological groups within the catchment. Some of the geological regions shown in **Figure 5.7** are not named in the geological mapping provided by DPI and is a composite of mapping by Clark and Jones (1991) and Herbert (1983). Wherever possible, classifications or names have been applied.

The Wianamatta Group and Hawkesbury Sandstone were laid down during the Triassic period. Since uplift of the Sydney Basin in the Triassic, substantial amounts of sediment have been deposited in some areas. The Cumberland Plain was thought to have formed approximately 80 million years ago as a result of the opening of the Tasmanian Rift off eastern Australia (Australian Museum, 2008). This is thought to have disrupted old stream patterns and led to the development of the current existing geological formations.

Minor igneous activity in the Early Jurassic led to the formation of the Prospect dolerite intrusion near Parramatta (Australian Museum, 2008). This igneous activity also led to the formation of diatremes (volcanic breccia pipes representing the root zones of short-lived volcanoes) composed of varying proportions of volcanic breccia and basalt (Australian Museum, 2008). Dolerite, basalt and volcanic breccia are all represented within the Parramatta River Estuary catchment (**Figure 5.7**).

5.6 Soils

Soil landscapes of the catchment and their properties are shown in **Table 5.5** and **Figure 5.8**. Saline soils are prevalent throughout Western Sydney. Those parts of the catchment affected by saline soils are shown in **Figure 5.9**.

Table 5.5 Soil Landscapes of the Parramatta River Estuary Catchment

Soil Landscape	Description
Blacktown	Moderately reactive highly plastic subsoil, low soil fertility, poor soil drainage.
Luddenham	High soil erosion hazard, localised impermeable highly plastic subsoil, moderately reactive.
Glenorie	High soil erosion hazard, localised impermeable highly plastic subsoil, moderately reactive.
Birrong	Localised flooding, high soil erosion hazard, saline subsoils, seasonal waterlogging, very low soil fertility.
Deep Creek	Flooding, extreme soil erosion hazard, sedimentation hazard, localised very low fertility and permanently high water tables.
Gymea	Localised steep slopes, high soil erosion hazard, rock outcrop, shallow highly permeable soil, very low soil fertility.
Hawkesbury	Extreme soil erosion hazard, mass movement (rock fall) hazard, steep slopes, rock outcrop, shallow, stony, highly permeable soils, low soil fertility.
Lambert	Very high soil erosion hazard, rock outcrop, seasonally perched water tables, shallow, highly permeable soil, very low soil fertility.
Lucas Heights	Sandy soils, low fertility, low available water capacity.
Oxford Falls	Very high soil erosion hazard, perched water tables and swamps, highly permeable soil, very low to low soil fertility, localised rock outcrop.
Picton	High erosion hazard, mass movement (slump) hazard, steep slopes, some impermeable and highly plastic subsoils.
South Creek	Erosion hazard, frequent flooding.
West Pennant Hills	Mass movement hazard, steep slopes, high soil erosion hazard, localised seasonal waterlogging, impermeable plastic shrink-swell subsoil.
Volcanic	Moderately reactive subsoils with low wet strength, erosion and mass movement hazards on steep slopes.
Disturbed Terrain	Limitations dependent on nature of fill material. Mass movement hazard, unconsolidated low wet-strength materials, impermeable oil, poor drainage, localised very low fertility and toxic materials.

*Landscape Groupings
- Residual
- Fluvial
- Erosional
- Colluvial
- Disturbed

The prevalent soil landscape in the catchment is the Blacktown landscape which is Residual in character. Blacktown soils are generally very low in soil fertility. The erosional soil types Luddenham and Glenorie are the next most prevalent soil landscapes and are located predominantly in the north-western sector of the catchment, in the region of the Baulkham Hills LGA. Fluvial soils are generally found along the line of the valley and river margins. These soil are subject to very high to extreme soil erosion hazard and flooding, and are generally highly permeable.

Disturbed soils are also a feature of the study area. This is particularly apparent along the Parramatta River estuary margins, where nearshore areas have been reclaimed for human usage in a number of locations.

The risk of exposing acid sulfate soils (ASS) is common for Australian estuaries. However, this issue has been exacerbated by the history of foreshore reclamations along the Parramatta River Estuary. **Figure 7.5** identifies the areas of the catchment which are potentially affected by ASS. Further discussion regarding the issues associated with ASS can be found in **Section 7.5.**

5.7 Vegetation

The catchment has a long history of urban development, with the majority of this area having been cleared for industrial and residential land uses (**Figure 5.10**; NPWS, 2002). Due to the heavily urbanised nature of the catchment, the extent of native vegetation is limited. Small, isolated pockets of vegetation are scattered throughout the catchment. The majority of the native vegetation is located in the northern part of the catchment, or in association with creeklines.

Figure 5.10 is based on mapping of native vegetation of the Cumberland Plain compiled by NPWS (2002). The vegetation communities have been delineated on the basis of those present at a rate of cover either greater than or less than 10%. This provides a type of index of the integrity of each patch of vegetation, with those at less than 10% cover more likely to be in poorer condition.

Lists of locally occurring native species are available from a number of resources, typically on an LGA-wide basis:

- Auburn LGA – Auburn Council 2008a;
- Canada Bay LGA – CCBC, 2008
- Hunters Hill LGA – Benson, 2007; HHC, 2008b;
- Parramatta LGA – PCC, 2003c; and
- Ryde LGA – Biosphere Environmental Consultants, 2006; Kubiak, 2005.

Lists of exotic species (declared noxious weeds) occurring with an LGA are also available in the following documents:

- Hunters Hill LGA – HHC, 2008d;
- Leichhardt LGA – LMC, 2008b;
- Parramatta LGA – PCC, 2008a; and
- Ryde LGA – Biosphere Environmental Consultants, 2006.

The Sydney Metro CMA has prepared a *Weed Management Strategy* (Eco Logical, 2006) which covers the study area.

Overall, there are a number of studies related to the vegetation found within the Parramatta River estuary catchment. Some of these cover large parts of the wider catchment, whilst others are studies of particular sites. Several of the studies are relatively old, being approximately 10 years old, and may not be representative of the extent and condition of vegetation in the catchment today. These studies are listed below:

- Biosphere Environmental Consultants (2006): Conducted a vegetation assessment for Brush Farm Park and Darvall Park within the Ryde LGA.
- Doig (1997): Lists native plant species of the Parramatta and Hills District.
- James (1997): Appendices to this study includes a description of remnant native vegetation in the region of Auburn, Parramatta, Concord, Bankstown and Strathfield.
- Kubiak (2005): Includes an overview of earlier studies and an assessment of the conservation significance of vegetation communities in the Ryde LGA.

- Oculus (2001): Studied the urban bushland in the Ryde LGA, including an historical overview, existing conditions at the time and conservation assessment.
- Robinson GRC Consulting (1999b): Assessed catchment vegetation as part of a Stormwater Management Plan covering part of the Parramatta River estuary catchment to the north of the river and between the Charles Street weir and Ryde Bridge.
- Urban Bushland Management Consultants Pty Ltd (2006): This study includes an assessment of the wetland on the Shell site, Rosehill, and also includes information on terrestrial vegetation.
- Woodlots and Wetlands, Molino Stewart Environmental Services, *et al.* (1999): The *Lower Parramatta River Stormwater Management Plan* includes a brief description of catchment flora within the Auburn, Burwood, Concord, Drummoyne, Hunters Hill, Leichhardt and Ryde LGAs.

Further information on riparian and estuarine vegetation is provided in **Section 10**.

5.8 Land Use and Zoning

5.8.1 Historical Land Use

Over much of the period from European settlement in 1788, Sydney Harbour including the Parramatta River Estuary was viewed from a utilitarian perspective. However, from the 1970s, as waterfront industries and port activities relocated and shipbuilding declined, changes in land use led to a greater appreciation of the waterways' aesthetic and recreational values. With the introduction of the *Clean Waters Act* in 1970 and early measures to improve the river's water quality, interest in the ecological values of the Parramatta River and its foreshores also emerged. The National Trust of Australia (NSW) published *Parameters for the River* (1976) to stimulate such interest in improving degraded aspects of the river: its foreshores, landscapes, remnant vegetation, habitats and fauna.

Past patterns of land use in the Parramatta River estuary catchment may be determined from analysis of historical aerial photography or analysis of historical records. It is understood that the DECC holds historical aerial photograph records for the Parramatta River catchment area. Photographs have been taken during 1943, 1978, 2000 and 2007. However, these were not available for the study at the time of issue of this report. It is understood that Shell (Refining) Australia Pty Ltd also holds aerial photographs of the Clyde refinery site dating back to the 1920’s. Similarly, these photographs were also unavailable at the time of issue of this report.

The Homebush Bay catchment within the Parramatta River Estuary in particular has been dramatically changed as a result of industrialisation, residential development and more recently the Olympic Games during 2000. The landscape had also been dramatically modified by concreting water channels, reclaiming land and removing native vegetation. Prior to the initiation of remediation works in 1995 for Olympic Games venue provision, aerial photos and monitoring results indicated a highly degraded environment (Laginestra and Hughes, 2000).

Resources outlining historical land use include:

- Blaxell (2004),
- DEAP (1986d),
- Hughes, Laginestra and Daffern (2000),
- Jervis (1920),
- Jervis (1935),
- Laginestra and Hughes (2000),

- McLoughlin (2000a), and
- Taylor, Birch and Links (2004).

The majority of studies which outline land use changes within the Parramatta River Estuary cover only a limited spatial extent, concentrating on a specific land use at a localised scale. There is little to no information which outlines the extent of change across the catchment as a whole.

5.8.2 Current Land Use and Zoning

Land zoning, management and planning within the Parramatta River Estuary is governed by individual councils and is outlined in their Local Environmental Plans (LEP). The state government is currently requiring councils to update their LEPs in line with a state wide template as a result of this process. Therefore, some changes with regards to land use zoning may occur within individual LGAs. At the present time, LEP data and mapping has been provided for this study for four of the 8 councils located on the Parramatta River Estuary foreshore. These are shown in **Figures 5.11 to 5.14**. The remaining LEP mapping should be obtained for the purposes of the remaining stages of the estuary management process.

The Parramatta River catchment consists of numerous land uses as summarized by Robinson GRC Consulting (1999b). Such land uses include:

Residential – medium and high-density (high rise flats) dwelling dominate the area, typically increasing to high density with proximity to transport.
Retail and Commercial – these areas tend to be relatively small and are located mainly in local residential areas
Environmental protection - Areas of environmental significance which cannot be used for development i.e. National parks. Furthermore, some open space areas may also incorporate environmental protection zones such as riparian corridors.
Education – there are numerous schools, colleges, TAFES and universities in the catchment.
Industrial and business – There is a wide range of industries from warehousing to printing shops, carpet sales to electrical goods, and manufacturing of cosmetics. Likewise there are numerous business parks and free standing offices within the catchment area.
Open space and Recreation - The areas allocated for local and regional open space and recreational purposes include reserves, regional parks, golf courses and waterway reserves. These areas are often adjacent to the local waterways.
Services, Transport and Communications - The land used for services, utilities, transport and communications (includes roads and railways). There are a number of major transport links that traverse the catchment. Sydney Water's major sewer which runs from Blacktown to North Head, the NSOOS (Northern Suburbs Ocean Outfall Sewer) also runs through the catchment.

Lands within the lower Parramatta River Estuary, between Ryde Bridge and Drummoyne consist generally of rolling hills, giving way to flat lands at the heads of the inlets such as Hen and Chicken Bay and Abbotsford Bay. In the past much of this flat land has received large amounts of industrial and domestic waste, and has since been capped and used for recreation reserves (Woodlots and Wetlands, 1999). Lands on the Parramatta Peninsula extending into the Parramatta River have gradually been converted from large estates to domestic housing, hospitals or industrial uses. Several older industrial sites have now been developed into medium density housing estates. Heavy industry along the foreshore of the Parramatta River Estuary was originally established in order to take advantage of relatively cheap water transport, with little regard for environmental impacts. Land contamination has since become a major development constraint as it provides the potential to significantly pollute the Parramatta River estuary. Land contamination has been further discussed in **Section 7** of this report.

The Sydney Harbour Catchment REP (NSW Government, 2005b), outlines zones within the waterways of the harbour and its tributaries. The REP extends only to areas within the waterways and therefore does not impede upon any existing land-based zoning under any other environmental planning instruments, i.e. local environmental plans. These comprehensive waterway zones have been specifically tailored to suit the differing environmental characteristics and land uses of the Harbour. This has resulted in a stronger zoning system that provides greater clarity and certainty for applicants and consent authorities in development considerations and applications.

The Harbour REP applies to the hydrological catchment of the harbour. It also defines and contains specific provisions for the 'Foreshores and Waterways Area' (which is generally the area 'one-street back' from the foreshore), strategic foreshore sites, heritage items and wetlands protection areas. **Figure 5.15** defines the zoning and foreshore/waterway boundary which the REP covers.

5.8.3 Point Sources of Pollution

5.8.3.1 EPA Licensed Premises

The NSW EPA, under their load-based licensing program, licences a range of premises in accordance with the *Protection of the Environment Operations Act 1997* (PoEO Act) legislation. Each of these licensed premises represents a potential point source of pollution.

A search of the EPA's *PoEO Act* Public Register of Licensed Premises was conducted on 4 December 2007. The Register was interrogated on an LGA-wide basis for each of the Councils falling within the Parramatta River Estuary catchment. The search returned a total of 461 results. The full list of licensed premises is provided in **Attachment 2**.

The PoEO Public Register also provides information on the type of activities being undertaken on each premises. These details have been grouped according to broader categories and are presented in **Table 5.6**. The major activities undertaken by licensed premises are associated with waste management, followed by manufacturing or construction related activities and chemical storage and/or processing.

Table 5.6 Broad Categories of Activities Undertaken by Premises Licensed under the PoEO Act

Category	Count
Waste Generation, Storage, Transfer, Separating or Processing (incl. recycling)	280
Manufacturing / Construction	72
Chemical Storage and/or Processing	32
Processing of Agricultural Products (incl. abbatoirs, breweries, milk processing, etc.)	14
Pharmaceutical or Veterinary Products Production	11
Extractive Industries	11
Sewage Treatment	7
Landfilling Activities	6
Electricity Generation	5
Bulk Cargo Handling	4
Discharges to Waters	4
Other Activities	4
Contaminated Soil Treatment	3
Mooring and Boat Storage	3
Aircraft (helicopter) Facilities	2
Petroleum Refining*	2*
Railways	1
TOTAL	*461*

** N.B: It is understood that only one (currently operational) Petroleum Refinery exists within the catchment (pers. comm., Environmental Advisor, Shell Refining (Australia) Pty Ltd, 2008) and it is unclear if these two licences actually apply to the same facility.*

5.8.3.2 Contaminated Lands

Contaminated lands are also potential point sources of pollution. Given the industrial history of land use within the study area, particularly with respect to foreshore areas, there are a number of locations within the catchment affected by contamination. Contaminated soils may disperse from these sites to the estuary via aeolian transport, or directly where the contaminated site is located adjacent to a watercourse or via interaction with the groundwater. It is understood that the prevalence of contaminated sites throughout the catchment represents a significant issue for management of the Parramatta River due to the potential for these contaminated sites to impact negatively on the quality of estuarine waters and sediments, as well as posing an environmental and human health risk.

The NSW EPA also maintains a register of notices issued under Section 58 of the *Contaminated Land Management Act 1997* (CLM Act). A search of the register was undertaken on 6 March 2008. The search returned a total of 45 records for individual sites within the catchment, each of which may have more than one former and/or current notice (**Table 5.7**). Only Ashfield Municipal Council and City of Ryde did not have any records of notices issues under the CLM Act. A full list of search results is provided in **Attachment 3**.

Mapping provided by DECC illustrates their records of notices issued under the CLM Act (**Figure 5.16**). This GIS layer is supported by information on the site name, owner, address, accuracy, status and history of notices issued (see **Attachment 3**). It is important to note that the records held under the CLM Act may not represent all contaminated land, they are only areas where contamination is known.

Table 5.7 Records of Notices Issued under the CLM Act for LGAs Falling within the Parramatta River Estuary Catchment

Local Government Area	Total No. of Notices	Suburb	Address	Site Name	Notices
Ashfield	-				
Auburn	12	Auburn	Short and Junction Streets	Ajax Chemical Factory	2 former
		Homebush Bay	Olympic Boulevard	Aquatic Centre Car Park	1 current; 6 former
		Homebush Bay	Bennelong Road	Bicentennial Park	1 current
		Homebush Bay	Hill Road	Haslams Creek South Area 3	2 current
		Homebush Bay	Kevin Coombs Avenue	Haslams Creek South Areas 1 and 2	2 current; 9 former
		Homebush Bay	No specific street	Homebush Bay General Area	2 former
		Homebush Bay	Australia Avenue	State Sports Centre	1 current; 4 former
		Homebush Bay	25 Bennelong Road	Timber Treatment Plant	4 former
		Newington	Bennelong Road	Landfill - North Newington	3 current
		Silverwater	Jamieson Street	Auburn Landfill	2 current
		Silverwater	Jamieson Street	Silverwater Transport Unit	1 former

Local Government Area	Total No. of Notices	Suburb	Address	Site Name	Notices
		Silverwater	Silverwater Road	Wilson Park	4 current; 5 former
Bankstown	6	Chester Hill	127 Orchard Road	Former Orica Factory - Chester Hill	2 current
		Revesby	33 Violet Street	Bituminous Products	2 current; 1 former
		Revesby	21 Marigold Street	Mirotone Pty Ltd	2 current
		Villawood	49-59 Miowera Road	Former Westinghouse Factory	9 former
		Villawood	2 Christina Road	Orica Villawood Plant	2 current
		Yagoona	117-153 Rookwood Road	Galvanising Services	1 current
Baulkham Hills	1	Kenthurst	137 Annangrove Road	Annangrove Climbers	5 former
Blacktown	2	Kings Park	21 Tattersall Road	Former Dow Corning Sealants Factory	1 current
		Seven Hills	27 Powers Road	Ma-Refine Oils Seven Hills	2 current
Burwood	1	Burwood	Parramatta Road	STA Burwood	1 current
Canada Bay	18	Abbotsford	84 Wymston Parade	Former AGL Gasworks	1 current
		Abbotsford	82 Wymston Parade	Former AGL Gasworks	1 current
		Abbotsford	83 Wymston Parade	Former AGL Gasworks	1 current; 1 former
		Abbotsford	37-39 St Albans Street	Former AGL Gasworks	1 current
		Abbotsford	45 St Albans Street	Former AGL Gasworks	1 current
		Abbotsford	43 St Albans Street	Former AGL Gasworks	1 current
		Abbotsford	Adjacent to 80-85 Wymston Parade	Former AGL Gasworks - Nature Strip	1 current
		Cabarita	Cabarita, Medora and Waine Roads	Properties adjacent to the former Dulux, Cabarita	1 former
		Cabarita	33 Phillips Street	Wellcome	1 current; 10 former
		Concord	Nullawarra Avenue	Concord RSL Club	2 current
		Concord	Nullawarra Avenue	Majors Bay Reserve	1 current; 1 former
		Mortlake	Tennyson Road	Mortlake Gasworks	22 former
		Mortlake	Tennyson Road (off)	Sediments adjacent to the former Gasworks	3 current; 1 former
		Rhodes	Walker Street	Allied Feeds	7 former
		Rhodes		Bed of Homebush Bay	1 current
		Rhodes	Alfred Street West	Homebush Bay South Sediments	3 current; 1 former
		Rhodes	Mary Street	Rhodes Waterside	2 former

Local Government Area	Total No. of Notices	Suburb	Address	Site Name	Notices
		Rhodes	Walker Street	Union Carbide Site	1 current; 29 former
City of Ryde	-				
Holroyd	1	Merrylands	Corner Walpole and Peel Streets	Merrylands Substation PCB Storage	3 former
Hunters Hill	2	Hunters Hill	Foreshore land adjacent to 7-11 Nelson Parade	Foreshore Land	1 current
		Hunters Hill	Wybalena Road, Pulpit Point	Mobil Oil Terminal Pulpit Point	4 former
Leichhardt	7	Balmain	Hyam, Foy, Reynolds, Palmer, Booth Streets	Former Unilever Detergent Factory	18 former
		Leichhardt	Corner Moore Street West and Balmain Road	Former SRA Site	3 current
		Rozelle	Reynolds and Buchanan Streets	Ampol Balmain	8 former
		Rozelle	Terry Street	Balmain Power Station	5 former
		Rozelle	35 Terry Street	Former Chemplex Factory	10 former
		Rozelle	Reynolds Street	Former Unilever Sulphonation Plant	4 former
		Rozelle	Robert Street	White Bay Power Station	7 former
Parramatta	12	Camellia	12 Grand Avenue	12 Grand Avenue, Camellia	1 current
		Camellia	6-10 Grand Avenue	Akzo Chemicals	3 current; 4 former
		Camellia	37 Grand Avenue	Collex	1 current
		Camellia	14 Grand Avenue	Hymix	1 current; 2 former
		Camellia	1 Grand Avenue	James Hardie Asbestos Factory	1 former
		Camellia	39 Grand Avenue	Seatons Containers	1 current; 1 former
		Camellia	41 Grand Avenue	Sydney Water	2 current
		Granville	2B Factory Street	Ajax Battery Factory	1 current; 2 former
		Granville	2 Blaxcell Street	Shore Petroleum	4 current
		Rosehill	Devon/Colquhoun Street	James Hardie Landfill	4 current; 6 former
		Rosehill	2 Ritchie Street	Pentecostal Church	1 current; 1 former
		Rydalmere	1 Alan Street	Rheem Rydalmere	2 current
Strathfield	1	Homebush West	22 Mandemar Avenue	Ford Landfill	3 former

= Council with foreshore frontage (light blue)
= Council not located on the foreshore (yellow)

In addition, information provided by Parramatta City Council confirms that a sizeable portion of George Kendall Reserve in Ermington is classed as Unhealthy Building land in relation to the former use of the site as a garbage tip (pers. comm., A. Collins, PCC, 3 June 2008).

5.8.3.3 Sewer Overflows, Surcharges and Dry Weather Leakages

There is little publicly available information which identifies the current known sewer overflow points within the catchment area. Robinson GRC Consulting (1999b) identifies several known overflow sites throughout the upper catchment area (as listed in **Section 9.4.3** of this report).

5.8.4 Future Land Use

As outlined in **Section 5.8**, the DoP is currently reforming planning in NSW such that all local governments will be required to revise their LEPs. Some Council's have already updated their LEPs e.g. Parramatta City Centre LEP.

Industrial land along the Parramatta River Estuary foreshore is rapidly undergoing redevelopment to accommodate the growth in population. One of the latest major developments along the waterfront incorporated the redevelopment of Breakfast Point. Rosecorp has developed the 52 hectare site of the former AGL Gasworks, also on the banks of Parramatta River at Mortlake (Cummins, 2000). Urbanization and redevelopment of the foreshore and within the wider catchment area is likely to continue as the demand for housing within proximity to Sydney city increases.

5.9 Land Ownership

The New South Wales Government has a documented policy in relation to access to the harbour and river foreshores, including public access to intertidal lands where landowners have absolute waterfronts but where the waterfront is exposed at low tide. Moorings and jetties are the responsibility of NSW Maritime, who is also responsible for the management of the Harbour and river seabed in conjunction with the Department of Lands.

Within the study area there is approximately 46.6 km of public foreshore and 24.85 km of private foreshore (Webb McKeown & Assoc, 1997).

Land in the wider catchment area is either freehold, Crown land or land transferred under the Land Rights Act 1983.

5.10 Management Issues

- **Future land use** zoning, planning and development within the Parramatta River catchment need to address potential environmental impacts, both aquatic and terrestrial. Furthermore, contaminated lands provide a challenge for future development as there is limited information regarding the extent and location of contaminated sites within the catchment. These areas are assumed to be prevalent along the foreshore and thus can significantly contribute to poor water quality if not properly managed.
- **Land Ownership** – A focus needs to be placed on maintaining an appropriate balance between private, public and government owned land. Land ownership can be a significant with regards to environmental management.
- **Soils and Geology** – a large portion of the upper catchment regions are affected by salinity. Managing the land and development often conflicts with maintaining water quality within the affected region and throughout the catchment.
- **Vegetation** – Urbanisation within the catchment has significantly impacted the natural vegetation within the region. Very few areas of natural vegetation still remain within the catchment and particularly along the foreshore. Management needs to focus on the rehabilitation of any remaining pockets of natural vegetation,

whilst enhancing and maintaining riparian corridors and other biodiversity corridors, and environmental recreation/protection areas.

- **Water Quality** within the Parramatta River catchment has been significantly diminished since European settlement. Industrialisation, land contamination and point sources of pollution have further contributed to poor water quality within the Parramatta River Estuary.
- **Climate** variations to the natural landscape and greenhouse impacts have altered the prevailing climatic conditions throughout the Parramatta River catchment. Further impacts are likely to occur associated with global climate change (IPCC, 2007).

5.11 Data Gaps

The following data gaps have been identified with respect to catchment processes:

Catchment Descriptions:

- There is very little literature available to provide a description of the catchment characteristics of Tarban Creek Catchment.

LEP boundaries:

- Information regarding the most up-to-date and predicted LEP mapping has not been made available for this study for all 13 councils in the Parramatta River Estuary Catchment.

Historical land use:

- Aerial photographs of the Parramatta River Estuary Catchment area have not been made available from the DECC for this study.

Land ownership:

- There is little information available identifying the percentage of private, government and public lands within the area.

Sewer overflows and surcharges:

- There is little publicly available data identifying the known areas of sewer overflow.

Creeks and tributaries:

- There is limited information on the characteristics of some of the smaller creeks, tributaries and drainage lines throughout the catchment area. Specifically, Powells Creek and Boundary Creek which drain into the Parramatta River estuary via Homebush Bay.

5.12 Further Studies

The following further studies have been identified to address the data gaps listed above:

- A description of the characteristics of Tarban Creek and its catchment should be included in the estuary processes study.
- The history of land use within the Parramatta River catchment area, assessing both local areas which have undergone dramatic changes and the catchment area as a whole.
- Determining the distribution of public and privately owned land within the catchment, coupled with the associated environmental impacts.
- Obtaining the LEP mapping for all councils within the catchment.
- Updating the council LEP boundaries and zoning within the catchment to conform to state wide policy.
- Compile up to date information on known sewer overflow points within the catchment.

6. URBAN STORMWATER, HYDROLOGY AND FLOOD BEHAVIOUR

Despite covering a large potion of the Sydney metro area, the catchment area of the Parramatta River Estuary is relatively small compared with other major rivers of the region (*e.g.* the Hawkesbury Catchment is almost ten times the size). Most streams within the catchment maintain a flow of water throughout the year. However, this base flow is low compared to flood discharges, being generally only a trickle in creek beds. The runoff pattern is directly related to the rainfall pattern for the whole region, and most of the total water resource is derived from storm rainfall. The runoff that continues in the streams beyond the rainfall periods is supplied by interflow in the short term and groundwater in the longer term.

6.1 Data Sources

Data sources related to *water extraction, environmental flows and the estuary* include:

- DECC (2006a)
- MHL (2006)
- NT (1976)
- NSW Government (Undated)

Data sources related to *groundwater and groundwater extraction* include:

- CMJA (2007)
- DLWC (1997b)
- DLWC (1998)
- Johnstone Environmental Technology (1991)
- Mackie Martin & Associates Pty Ltd (1992)
- NT (1976)
- NSW Government (1997)
- NSW Government (2007)
- NSW Maritime (2005a)
- Suh, Birch and Hughes (2004)
- Suh, Birch*, et al.* (2004b)

Data sources related to *catchment flood flows and the estuary* include:

- Ashfield Municipal Council (1995)
- Auburn Council (2003)
- AWCS (1989b)
- Bankstown City Council (2005)
- BHSC (2008)
- Bewsher Consulting (2003)
- Blacktown City Council (2005)
- Burwood Council (Undated)
- Cardno Willing (2004)
- Cardno Willing (2006a)
- CCBC (2006)
- CoR (2006a)
- CoR (2006c)
- Department of Transport (1991)
- DLWC (1997a)
- Environmental Management (2000)
- HCC (Undated)
- Listowski, Phillips and Joliffe (2000)
- NSW Government (2005)
- PCC (2002d)
- PCC (2006e)
- Robinson GRC Consulting (1999b)
- SKM (2002a)
- SKM (2002b)
- SKM (2002c)
- SKM (2005a)
- SKM (2005b)
- SKM (2005c)
- SKM (2006)
- SMEC (2004)
- Willing_&_Partners (1986)
- Willing & Partners (1992a)
- Willing & Partners (1992b)

Data sources related to *stormwater* include:

- AWT (1993)
- AWT (1994a)
- AWT (1994b)
- AWT (1995)
- AWT Science & Environment (1993)
- Barry, Taylor and Birch (1999)
- Barry, Taylor and Birch (2000)
- Birch and Scollen (2003)
- Courtenay, Gladstone and Schreider (2005)
- DECC (2008a)
- Fraser, Timms and Ball (2004)
- Frazer, Timms and Ball (2005)
- Listowski and Phillips (1999)
- Listowski, Phillips and Steele (2000)
- Olympic Co-ordination Authority (1996c)
- SCCG (2002)
- Stormwater Trust and UPRCT (2004)
- Willing & Parnters (1995a)
- Willing & Parnters (1995b)
- Willing & Parnters (1995c)
- Willing & Parnters (1995d)
- Woodlots and Wetlands, Molino Stewart Environmental Services*, et al.* (1999)
- WSROC (2006)

6.2 Water Extraction, Environmental Flows and the Estuary

Water resources of the catchment are virtually unregulated. The major regulating structure in the catchment is the dam retaining Lake Parramatta upstream of the Charles Street Weir. This dam was built to provide Parramatta's water supply, replacing the Marsden Street Weir which had become too polluted for domestic use. Today, this lake is solely for recreational purposes (National Trust, 1976).

Four minor regulating structures are located on the Parramatta River, at Charles Street, Marsden Street, Ross Street (Kiosk Weir) and upstream near the North Parramatta Psychiatric Centre. These weirs are currently being retrofitted with fishways to permit fish migration. A further weir is located on Darling Mills Creek just north of Windsor Road. The gates of these weirs, where existent, are inoperable and cannot be used for regulation. A number of farm dams are located in the extreme west of the catchment, but they have a very limited capacity to regulate flow (National Trust, 1976).

The Department of Lands is the holder of all water access licence title information. However, these can not be searched on a spatial basis and as such the details of the water access licenses could not be provided for the study area. The DoL advised that the Department of Water and Energy (DWE) could provide more detailed information (pers. comm., B Griffiths, DoL, 22 April 2008). However, at the time of writing of this report no information had been obtained. This data should be obtained for the purposes of the processes study.

It is understood that Parramatta City Council and Auburn City Council have licences to extract water from the Parramatta River Estuary for irrigation purposes (pers. comm., A Collins, PCC, 20 June 2008).

Water Sharing Plans that allow for the sharing of water between users and the environment have been developed for most water use in NSW. The NSW Government is now developing a Greater Metropolitan Region Water Sharing Plan under the Water Management Act 2000. This plan will provide the legal framework for the water sharing aspects of the Metropolitan Water Plan. The draft Water Sharing Plan, when completed, will be exhibited for public comment before being published (NSW Government, 2008).

The water sharing plan will define how naturally occurring freshwater will be shared between the environment, agriculture, industry and urban consumers. Water sharing plans dedicate water to meet the environmental needs of river ecosystems and aquifer systems. This environmental water will be given formal, legal protection. In addition, the plan complements many practical actions to protect drinking water quality, improve catchment health and achieve other objectives. These actions are being undertaken by the Sydney Metro CMA, councils and landholders (NSW Government, 2008). The Estuary Management Process should ensure that any estuary management actions do not conflict with the water sharing plans.

The downstream limit of a water source is referred to as the flow reference point. This is the site where daily flow classes are calculated for the purposes of managing water extraction and water sharing. Existing water sharing plans have tended to select the tidal limit as the flow reference point for the water sharing plan (MHL, 2006). This corresponds to the upstream limit of the Parramatta River Estuary.

Freshwater extraction occasionally occurs from below the tidal limit. A body of fresh water usually exists in the region downstream of the tidal limit and upstream of the mangrove limit, however the exact downstream limit is highly variable depending on freshwater inflow. Water extraction from this area will be subject to specific flow rules that aim to protect the environmental health of these unique sections of estuaries (MHL, 2006).

DECC undertook a study to determine river flow objectives for the Parramatta River and Sydney Harbour. The study involved consultation with the community between November 1997 and May 1998. **Table 6.1** outlines the river flow objectives that were determined.

Table 6.1 River Flow Objectives (DECC, 2006)

Objective	Measures	Comments
Protect Pools in Dry Times *Protect natural water levels in pools of creeks and rivers and wetlands during periods of no flows*	• There should be no water extraction from streams or wetlands in periods of no flow.	• The objective has limited application to this catchment. • Along with social and economic considerations, WSPs should define when and how to protect specific pools: - in natural wetlands with licensed pumps - in streams where flow occurs under the sediment surface - where these pools have become deeper or shallower.
Protect Natural Low Flows *Water extraction and storage are high in dry times and impose long artificial droughts that increase the stress on aquatic plants and animals.*	• Share low flows between the environment and water users and fully protect all natural very low flows. These are defined as: • Very low flows: flows below the level naturally exceeded on 95% of all days with flow • Low flows: flows below the level naturally exceeded on 80% of all days with flow • In streams with little water use or important conservation values, minimise risks to ecosystems in low-flow periods.	• The objective has limited application to this catchment. • WSPs need to identify actions to achieve targets for each stream that balance local environmental, social or economic considerations. • In urban streams, the changes made to the natural low-flow regime are generally unknown. Streams may be wetter than natural because of garden watering in the catchment. Alternatively, if inputs to groundwater are reduced, streams could be drier than natural during dry times. Site-specific studies and comparison with undeveloped streams would be needed to determine the amount of change.
Protect Important Rises in Water Levels *Protect or restore a proportion of moderate flows ('freshes') and high flows*	• There is little water harvesting in this catchment, so a target is not needed. • In areas of new development, ensure that stormwater is managed in such a way that there is no increase in the height or flow rate of high flows. • In areas of existing development, explore opportunities for improving stormwater management to mitigate flooding.	• High flows may cause flooding, which is a significant community concern. Mitigation requires both better stormwater management (increased detention and infiltration) and planning to avoid the problem (relocating houses and infrastructure away from flood-prone areas and preventing new development in these areas). • Adequately managing stormwater is more achievable in new developments, and may be costly and difficult to retrofit in existing developed areas. • All councils in this catchment are required to develop stormwater management plans (under the Urban Stormwater Management Program).
Maintain Wetland and Floodplain Inundation *Maintain or restore the natural inundation patterns and*	• Management plans and actions for waterways need to include strategies to maintain, restore or mimic natural patterns of inundation, water movement and drying in natural and semi-natural wetlands, and	• Implementation of this objective will be needed in only a few locations. • Maintaining wetlands and floodplains will improve water quality and reduce downstream flooding.

Objective	Measures	Comments
distribution of floodwaters supporting natural wetland and floodplain ecosystems	remaining native floodplain ecosystems. • Ensure adequate access for native fish to and from floodplain wetlands. • Flooding patterns should not be altered without proper environmental assessment.	
Mimic Natural Drying in Temporary Waterways *Mimic the natural frequency, duration and seasonal nature of drying periods in naturally temporary waterways*	• Identify any streams where unnatural flows have greatly reduced drying periods. Assess potential short- and long-term environmental, economic and social effects of this change and of possible management alternatives. • Decisions on what (if any) action is appropriate to implement this objective in streams should be worked out on a case-by-case basis after giving due consideration to local views.	• The objective has limited application in this catchment. • There are few streams where drying periods differ significantly from natural conditions. In urban streams, the change to the natural low-flow regime is generally unknown. Streams may be wetter than natural because of watering in the catchment; alternatively, if inputs to groundwater are reduced, streams could be drier than natural during dry times. Site-specific studies and comparison with undeveloped streams would be needed to determine the change.
Maintain Natural Flow Variability *Maintain or mimic natural flow variability in all streams*	• Identify streams with unnatural flow variability and develop appropriate actions to mimic natural variability. • Identify streams with potential for flow variability problems and take early action.	• The objective applies mainly to controlled rivers but may apply at some locations or situations on uncontrolled streams, such as in urban streams. In these areas, the objective should be addressed through stormwater management plans. • The objective may also affect water quality.
Maintain Natural Rates of Change in Water Levels *Maintain rates of rise and fall of river heights within natural bounds*	• Identify locations where water levels often rise or fall faster than they would naturally. Identify the reasons (in urban areas, usually the result of increased hard-surfacing) and impacts. Remedial action requires case-by-case assessment. • Identify potential problems and take early action.	• Local information, such as bank erosion, may indicate a need for action. • In urban streams, solutions may require increasing on-site detention or infiltration. • Of all uncontrolled stream categories, this objective applies most to urban streams. • Consideration should be given to prioritising the rehabilitation of channelised streams.
Minimise Effects of Weirs and Other Structures *Minimise the impact of instream structures*	• Implement the NSW Weirs Policy (DLWC, 1997). • Identify, and take action to minimise, the impact on native fauna of other structures that impede movement of water (e.g. floodgates, tidal barriers, culverts).	• The Government's NSW Weirs Policy (DLWC, 1997) and weir review process helps set priorities and assess management options.

6.3 Groundwater and Groundwater Extraction

An interesting feature of the Wianamatta Shale bedrock, forming the majority of the upper catchment area, is the high salt content of underground waters found throughout it. As a result, some tributary creeks and bore holes contain sodium chloride and other solids in concentrations that render the water useless for irrigation for amenity planting or agricultural irrigation (National Trust, 1976).

The upper catchment is characterised by sandstone geology, and therefore, the sandy nature of the soils results in little direct surface runoff. Most of the water seeping through the soils finds its way into rock fractures and across platform shelving into creeks and the river (National Trust, 1976).

In 2006, DECC undertook a study to identify river flow objectives for the Parramatta River Estuary. This study identified the need to maintain groundwater within natural level and variability, critical to surface flows and ecosystems. To achieve this objective the following management actions were identified:

- Implement the State Groundwater Policy (DLWC 1997b, 1998).
- Identify any streams or ecosystems that may depend on high groundwater levels, and assess impacts of reduced recharge or excessive pumping or drainage.
- Identify areas where rising groundwater may threaten ecosystems or surface-water quality.
- Determine appropriate action to keep ground-water level changes within acceptable bounds.

Homebush Bay Area

Groundwater throughout the Homebush Bay precinct occurs within the shales and sandstones predominantly as joint and fracture type (secondary) storage. Minor contributions are also evident from interangular storage within the uppermost weathered sandstones of the Mittagong and Hawkesbury Formations. As is typical in jointed aquifers, storage and transmission or aquifer groundwater is via a complex network of interconnected joints (Mackie Martin & Associates Pty Ltd, 1992).

The aquifers are mostly recharged by rainfall infiltration or base flow from more regional flow systems. The extent of infiltration depends greatly on the permeability of surficial clays and imported materials. Where impermeable clays or pavements exist at the surface, very little infiltration can be expected, but where silty and sandy materials cap shales or where surface ponding is permitted, increased infiltration is expected (Mackie Martin & Associates Pty Ltd, 1992).

Mackie Martin & Associates Pty Ltd undertook groundwater numerical modelling for the Homebush Bay Area. The model identified a main shale aquifer at depth which exhibits regional continuity. Discrete shallow aquifer systems, which include landfills, offer leakage to the shale aquifer. The modelling showed that the hydraulics of the area are influenced by two main components: the brick pit which acts as a sump for regional drainage, and a groundwater mound which suggests a source of recharge (Mackie Martin & Associates Pty Ltd, 1992). It is likely that the outcomes of this study have been significantly impacted by the development of Sydney Olympic Park and the Homebush Bay Area.

Johnstone Environmental Technology (1991) defined the quality of the regional groundwater at Homebush Bay to be neutral to slightly acidic and there was localised evidence of minor organic contamination, possibly resulting from the influence of dumped materials within the surrounding areas.

Suh *et al* (2004a) undertook a study to identify major sources of contaminants and to explain the hydrochemistry of groundwater in relation to past land use and borehole type in the reclaimed lands of the Sydney Olympic site at Homebush. The shores of Homebush Bay were reclaimed using an estimated nine million tonnes of domestic, commercial and industrial waste over several decades (as discussed in **Section 7.3.4**). Suh *et al* (2004a) investigated the impact of this waste on groundwater.

Core samples (n= 4513) collected from the reclaimed lands of Homebush Bay show that, prior to remediation, soil contaminated by heavy metals (Cr, Cu, Pb, Zn) may have posed a threat to groundwater in the area (Suh *et al*, 2004b).

Camellia Peninsula

In 2005, it came to the attention of the Department of Environment and Conservation (now DECC) that a green-yellow substance was oozing from drains around the mangroves and waterways in Camellia along the upper reaches of the Parramatta River. Testing of the substance showed it to be chromium. The origin of the chromium was unknown at the time. However, the area in which the seepage was found was a former industrial site from the 1940s to the 1970s, where industrial production of the metal took place. DEC subsequently undertook sampling of the seepage ahead of any remediation efforts that were to be undertaken. NSW Maritime fenced the perimeter to restrict access and any possible exposure to the chromium (NSW Maritime Authority, 2005).

The Attorney General advised on the 19 October 2006 that the area covered by the plume of chromium and chlorinated hydrocarbons is approximately 6.2 hectares and that (at the time) this area was still a significant distance away from the Parramatta River. Further, he advised that results of off-site groundwater monitoring at the time indicated that the contamination was contained within the site boundary of 6-10 Grand Avenue. The remedial strategy proposed at the time was to ensure the contamination is contained within the site boundary. The Department of Environment and Conservation (now DECC) had reviewed the Draft Remedial Action Plan and had indicated its in-principle support of the proposed new strategy, because it will result in a substantial reduction of the level of contamination in the source areas (NSW Government, 2007).

Discussions with Parramatta City Council (pers. comm., Environmental Health Officer, Parramatta City Council, 14 February 2008) identified that Chromium VI was entering the Parramatta River at the end of Thackeray Street (behind street no's 37 and 39). Further it was noted that a Section 59 notice had been issued under the Contaminated Land Management Act 1997 No 140 (NSW Government, 1997).

CMJA (2007) undertook an investigation into the chromium contamination of groundwater at the Camellia Peninsula, particularly 11B Grand Avenue. This report was not available in its entirety for the purposes of this study. However, Parramatta City Council (PCC) advised that the chromium was known to affect both the soil and the groundwater profile and it is largely isolated to known hot spots associated with waste placement sites. PCC also advised that the Chromium has migrated into the groundwater and is thought to be following established below ground infrastructure (*e.g.* stormwater pipes). It is suspected that it has now leached into the soil from the stormwater pipes and has been noted on the surface after rainfall (pers. comm., Environmental Health Officer, Parramatta City Council, 14 February 2008).

PCC advised that the CMJA report (2007) suggested the implementation of a selective barrier such as chemical treatment that renders the chromium insoluble (pers. comm., Environmental Health Officer, Parramatta City Council, 14 February 2008). It is unclear as to whether a regional remediation strategy has been developed to implement proposed measures. However, it is understood that DECC has targeted land owners in the area based on their ability to pay and proximity to the river (pers. comm., Environmental Health Officer, Parramatta City Council, 14 February 2008). Shell Refinery (Australia) advised that they have submitted a remedial action plan to the DECC for their portion of the contaminated area. Shell are currently awaiting advice from DECC on how to proceed with this issue (pers. comm., Murray Watts, Shell (Refining) Australia Pty Ltd, May 2008).

It is understood that Council-owned land in the area has been determined not to have contamination issues. However a number of other companies have been required to submit voluntary remediation orders and it is understood that others are in negotiation with DECC for appropriate strategies to remediate Chromium on their sites (pers. comm., Environmental Health Officer, Parramatta City Council, 14 February 2008).

Groundwater Extraction

There are 130 licensed groundwater extraction bores in the Parramatta River catchment. Of these, 54 are within the study area (after DECC mapping). **Figure 6.1** shows the locations of groundwater bores in the catchment. There may be other unlicensed bores also within the catchment.

6.4 Catchment Flood Flows and the Estuary

The Parramatta River catchment is shown in **Figure 5.1**. The total catchment area upstream of Ryde Bridge is 212 km^2. The catchment area divides into two sections. The Upper Parramatta River catchment area of 108 km^2 extends from Baulkham Hills to Charles Street Weir and includes Toongabbie Creek and Darling Mills Creek, which joins 3 kilometres upstream of Parramatta and forms the start of the Parramatta River (SKM, 2005a). In 1998, a major detention basin was constructed on Darling Mills Creek in order to reduce the peak floods in Parramatta.

The lower section of the catchment starts at Charles Street Weir and includes Duck Creek, Duck River, Haslams Creek and Powells Creek catchments on the south side and Vineyard and Subiaco Creeks on the north side (SKM, 2005a).

The Parramatta River catchment is highly urbanised with some development extending into the floodplain and consequently some development is prone to flooding with potentially high hazard and damage (SKM, 2005a).

There do not appear to be any widespread flooding problems along the main channel of the Parramatta River because the channel has sufficient capacity to take high flows which are then discharged directly into Port Jackson and then to sea. Specifically, downstream of the Silverwater Bridge, the river has sufficient hydrologic capacity to carry most flows. Nevertheless, there are some low-lying areas which can be inundated during high tides and there are also pockets of flooding along the tributary creeks (Robinson GRC Consulting, 1999b).

Despite the significant urbanisation, the creek systems that drain the various sub-catchments are still very evident. In many of the mid-reaches of the creeks, the flows have been piped which has allowed development to encroach onto the floodplain. Flooding reports maintained by the two Councils indicate that there are local inundation problems distributed right along the old creeklines, especially in those reaches that have been piped. The inundation problems have been exacerbated by the very low hydraulic/hydrologic capacity that the pipes have. In some areas, the capacity is as low as the 1-year Average Recurrence Interval (ARI) event. This is a problem that is expected to worsen as the catchment further develops and the overall imperviousness of the catchment increases, although this impact is being mitigated at least in part by the requirement to have on-site detention incorporated into new and re-developments (Robinson GRC Consulting, 1999b).

The Parramatta River catchment has a number of local flooding problems. These tend to be along the lower reaches of the creeks because of the limited hydraulic capacity of these waterways and the ever increasing floods being generated by a well developed catchment which continues to become more impervious as it is further redeveloped. The waterways are often choked with exotic vegetation which reduces their hydraulic capacity. In addition, the lower reaches of the old creeklines have been piped and filled over. These pipelines tend to have a low hydrological capacity thus causing significant overland flow with associated flooding problems (Robinson GRC Consulting, 1999b).

Historical flooding has occurred in 1898, 1914, 1956, 1961, 1967, 1969, 1974, 1975, 1986, 1988, 1990 and 1991 (SKM, 2005a). Flood level data for these floods is very limited, perhaps due to the relatively few houses and businesses that directly access the river or because the flood rise and fall is too rapid to be recorded effectively.

Catchment flood flows can affect the estuary in several ways including:

- Inundation of the foreshore areas,
- A temporary change in salinity of the estuary due to large freshwater inputs,
- A temporary change in water quality due to catchment runoff, debris and suspended sediments, and/or
- Changes in the morphology of the upper estuary (i.e. the smaller creeks rather than the large open water areas) due to erosion as a result of large flows.
- Increased sedimentation at river/estuary confluences.

These impacts are interconnected with many other aspects of the estuary including impacts on ecosystems due to water quality and salinity changes, impacts on riparian vegetation and foreshore property and infrastructure due to erosion and inundation and short term impacts on the recreational uses of the estuary.

Some of the ferry wharves are inundated in flood events. The wharves at Parramatta and Rydalmere were designed such that they would be inundated in a 100 Year ARI flood event. It was also found that the impact of the wharves on flooding is negligible (Department of Transport, 1991).

The EIS prepared for the dredging of the Parramatta River for the RiverCat service found that the dredging works would reduce flood levels by more than 0.2 metres (Department of Transport, 1991). However, it is likely that sedimentation has occurred since the dredging took place and therefore the dredging works are unlikely to still provide any reduction in flood levels.

Prior to 2005, the principal flood study used for the Lower Parramatta River (the study area for this current study) was the *Lower Parramatta River Flood Study* (Willing & Partners, 1986). Numerous other flood studies for the major tributaries relied on the results of the 1986 study.

In 1999 Parramatta City Council undertook a review of flood information held by Council and the methodology utilised in mapping flood inundation extents. As a result of this investigation PCC initiated the preparation of the Lower Parramatta River Floodplain Risk Management Study (FRMS), which included a complete review of existing flood studies for the Parramatta River and its tributaries.

In 2002 a review of all existing flood studies was undertaken (SKM, 2005c). The aim of the review was to develop a priority list for implementing Revised Flood Studies and Floodplain Risk Management Plans across the Parramatta River catchment.

In 2005 SKM prepared an updated flood study for the Lower Parramatta River (SKM, 2005c). As well as revised flood information, the document also sets out a list of flood data that has been extracted from a number of flood studies and flood reports.

In addition to the Lower Parramatta River study (Willing & Partners, 1986) a number of other studies were reviewed. **Table 6.2** lists the studies that were reviewed and the current status of the review.

Table 6.2 Flood Studies Reviewed in 2002 and Current Status (SKM, 2002c)

Study	**Current Status**
Lower Parramatta River Flood Study (Willing & Partners, 1986)	Superseded by the *Lower Parramatta River Floodplain Risk Management Study – Flood Study Review* (SKM, 2005c)
Clay Cliff Creek Catchment Flood Study, (Dalland & Lucas, 1992)	Superseded by the *Lower Parramatta River Floodplain Risk Management Study – Flood Study Review* (SKM, 2005c)
Addendum No. 1 to Clay Cliff Creek Catchment Management Flood Study (Dalland & Lucas ,1993)	Superseded by the *Lower Parramatta River Floodplain Risk Management Study – Flood Study Review* (SKM, 2005c)
Vineyard Creek Flood Study (Sinclair Knight and Partners, 1992)	Superseded by the *Vineyard Creek Sub-Catchment Management Plan* (SMEC, 2004)
Subiaco Creek Flood Study (Sinclair Knight and Partners, 1991)	Superseded by the *Subiaco Creek Sub Catchment Management Plan* (SKM, 2006).
A'Becketts Creek Catchment Management Study (Bewsher Consulting, 1990)	Superseded by the *Lower Parramatta River Floodplain Risk Management Study – Flood Study Review* (SKM, 2005c)
Duck Creek Catchment Management Study (Sinclair Knight and Partners, 1991)	Superseded by the *Duck Creek Sub Catchment Management Plan* (Cardno Willing, 2004).
Duck River Study, (Brian O'Mara & Associates, 1994)	Superseded by the *Duck River Flood Study* (Cardno Willing, 2006a).
Terry's Creek Catchment Management Study	In May 2006, Ryde City Council engaged Bewsher Consulting undertake a Flood Study for Eastwood and Terry's Creek (CoR, 2006).

In addition to the studies reviewed as part of the above review (SKM, 2002c) the following relevant floodplain and hydraulic studies were identified:

- *Proposed Development of Homebush Bay Haslams Creek Flood Study* (AWACS, 1989b).
- *Haslams Creek Floodplain Risk Management Study and Plan* (Bewsher Consulting, 2003).
- *Potential Flood Losses in the Parramatta Central Business* District (Environmental Management, 2000).
- *Managing Drainage and Flooding at Homebush Bay* (Listowski et al, 2000).
- *Review of the Flooding Effects of Parramatta River Dredging* (Willing & Partners, 1992a).
- *Parramatta CBD Flood Model* (Willing & Partners, 1992b).

As part of the Lower Parramatta River Floodplain Risk Management Study and Plan, SKM (2002a & 2002b) undertook a comprehensive data compilation and review of the available data pertaining to the study and made recommendations for additional data collection. As a result there is now a very comprehensive data set of topographic, bathymetric and flow structures survey. Parramatta City Council holds this data.

In general, Councils in the study area manage flood risk in the floodplain through floodplain policy documents. The relevant policy documents are provided in **Table 6.3**.

Table 6.3 Floodplain Risk Management Policies

Local Government Area	Floodplain Management Policy / Strategy
Parramatta City Council	*Local Floodplain Risk Management Policy* (Parramatta City Council, 2006e)
Leichhardt Municipal Council	Floodplain DCP Currently in Preparation
City of Ryde	*City of Ryde Development Control Plan 2006* (CoR, 2006c)
Auburn Council	*Auburn Development Control Plans 2000 - Stormwater Drainage Development Control Plan* (Auburn Council, 2003)
City of Canada Bay Council	*Specification for the Management of Stormwater* (City of Canada Bay Council, 2006)
Hunters Hill Council	No Floodplain Management DCP
Ashfield Municipal Council	*Stormwater Management Code* (Ashfield Municipal Council, 1995)
Strathfield City Council	*Strathfield Stormwater Management Code* (Strathfield City Council, 1994)
Baulkham Hills Shire Council	*Baulkham Hills Development Control Plan* (Baulkham Hills Shire Council, 2008)
Blacktown City Council	*Engineering Guide for Development* (BCC, 2005)
Burwood Council	*Stormwater Management Code* (Burwood Council, Undated)
Bankstown City Council	*Bankstown Development Control Plan 2005* (Bankstown, City Council)
Holroyd City Council	*Holroyd Development Control Plan 43 – Floodplain Management – DRAFT* (HCC, Undated)

6.5 Stormwater

When urban development occurs, the natural water cycle is altered to the extent that stormwater runoff from individual properties and roads intensify, flows usually increase and potential contaminants from residential and commercial activity and associated vehicle use flow into the streams and watercourses (Stormwater Trust & UPRCT, 2004).

There have been very limited studies undertaken within the Parramatta River Estuary that quantify the impact of stormwater quality and quantity on the estuary. However, investigations were undertaken in 1995 to 1999 of intertidal assemblages on rocky shores as a potential biological indicator to provide a quantitative estimate of the impact of urbanised catchment discharge on the estuaries of Sydney (Courtenay *et al,* 2005). The study found that intertidal rock assemblages in Sydney Harbour and surrounding estuaries appear to be responding to the quality and quantity of discharge from urbanised catchments and, furthermore, that assemblages are more suitable than individual taxa to indicate the difference between natural and estuarine locations disturbed by anthropogenic activities. This information could be used to undertake further investigations within the Parramatta River Estuary with regard to the management of stormwater quality and quantity and quantifying the improvements and impacts.

As part of the Stormwater Extension Officer Program (SEOP) a needs analysis was undertaken in 2002 (SCCG, 2002) for the Sydney Harbour/ Parramatta River catchment. The needs analysis was undertaken to:

1. Determine the stormwater activities undertaken by councils within the region.

2. Identify issues and opportunities / barriers to improve stormwater management in councils and the region.
3. Determine the needs / priorities of local government with a view to the Stormwater Extension Officers providing services and strategies to address them.

The actions proposed as a result of the needs analysis were due for completion in 2003.

There are numerous stormwater management policies, plans and frameworks by which each of the 13 Councils in the study area are attempting to manage the impacts of urban development on stormwater quality and quantity. Various sub region stormwater management plans have also been developed for site specific issues. All of these references have not been listed here. However, a full list of available documents is included in **Appendix B**.

6.5.1 Quality

Stormwater is widely recognised as a significant source of water pollution. It contributes to a range of pollutants found in waterways from sedimentation, heavy metals, debris and eutrophication (see **Section 9**). In urbanised areas, impermeable surfaces make significant contributions to pollution of waterways. In highly urban centres where most of the surface area may be covered by impermeable surfaces, almost all water will drain away as stormwater potentially carrying litter, chemicals, animal faeces and sediment with it.

Waterways in urban areas are susceptible to contamination from stormwater. In 1999 the State Government required all councils to prepare stormwater management plans (SMPs) with a list of identified actions to be undertaken. In March 2002 the EPA conducted an audit of the actions completed to date (WSROC, 2006). A summary of this audit is shown in **Figure 6.2**. Some LGAs have participated in the development of several SMPs, reflecting the position of their governmental boundaries in relation to multiple water catchment areas.

A number of studies have been conducted on stormwater quality and the Parramatta River water, most of which were undertaken by Sydney Water during the early to mid nineties (AWT, 1993, 1994a, 1994b, 1995 and AWT Science & Environment, 1993, cited in Woodlots and Wetlands *et al*, 1999). These studies were summarised and assessed in terms of the water quality implications for the Parramatta River Estuary in the *Lower Parramatta River Stormwater Management Plan* (Woodlots and Wetlands, 1999).

It was found that the types of pollutants entering the Lower Parramatta River depend on land use. In highly urbanised areas, such as along Iron Cove Creek and Hawthorne Canal, large amounts of faecal material and dissolved nutrients were recorded. This suggests inputs from sources such as sewer overflows, sewer leaks, and animal faeces (Woodlots and Wetlands *et al*, 1999). DECC (EPA) Harbourwatch program assesses the level of bacteria at three main locations within the Parramatta River Estuary, and the suitability of the water for primary contact (see **Section 9.3.4**).

In areas with less urbanisation/industrial land use, water quality is better as catchment activities do not generate the same types or loads of pollutants. Areas around Brays Bay and Yallara Bay for example would not be expected to contribute large amounts of faecal coliforms or heavy metals. Sediments and nutrients, however, are probably an issue in such areas (Woodlots and Wetlands *et al*, 1999).

A MUSIC model was established as part of the *Duck River Subcatchment Management Plan* (Cardno Willing, 2004) which assessed the pollutant loads entering the Duck River from the catchment, based on broad land use categories.

The *Lower Parramatta River Stormwater Management Plan* (Woodlots and Wetlands, 1999) provided a detailed discussion for Dobroyd Canal (Iron Cove Creek) and Hawthorne Canal. The study also provide a summary of key catchment issues relating to stormwater quality.

The Water Research Laboratory was commissioned by the upper Parramatta River catchment Trust on behalf of the RTA to investigate potential stormwater pollution hotspots in the catchment (Frazer, 2005). Sampling was undertaken at three hotspots and were analysed for sediments, heavy metal and nutrients. These findings are summarised in the WRL Technical Report 2004/11 (Fraser, 2004). Frazer (2006) outlines the proposed stormwater treatment options for the hotspots. These options primarily target the removal of sediment from the system.

Leichhardt Municipal Council and Sydney University are preparing to undertake a *Water Quality Assessment Study* for the Leichhardt LGA. The study will include:

- Collation of Land Use information,
- MUSIC modelling to identify major pollutant sources,
- Field samples to verify MUSIC modelling, and
- Prioritisation of pollutant sources.

It is expected that this study will start later this year (pers. comm., A. Broome, LMC, 19 March 2008).

Hawthorn Canal and Dobroyd Canal contain high levels of heavy metals, predominantly from cars / roads (Birch & Scollen, 2003; Barry et al, 1999; Barry et al, 2000; see **Section 7.4**). Sydney Water previously proposed a sand filter within Dobroyd Canal to treat the heavy metals. However, the project was never initiated due to public objection. This option may be reassessed as part of the Leichhardt LGA water quality assessment (pers. comm., A. Broome, LMC, 19 March 2008).

DECC funded a stormwater awareness program for the Parramatta River Estuary. The program was run through the eight foreshore Councils along the estuary (DECC, 2008a). The project provided a continuous forum for the eight councils to regularly discuss and integrate stormwater issues, educational strategies and proposed activities. The involvement of each council varied, and reflected resource availability at the time of the project's events and activities. The project focused on three main target groups: non-English speaking background (NESB) communities (Arabic, Chinese and Italian mainstream groups) and council operational staff.

6.5.2 Quantity

In urban areas, the increase in the number and size of impervious areas has reduced the amount of rain that infiltrates the ground or is retained by vegetation. Consequently, increased quantities of stormwater runoff enter the drainage system and the receiving waterways. Urbanisation has also changed the timing for the arrival of the peak flows of stormwater discharged into water environments. Traditionally, stormwater drainage systems have been constructed to remove stormwater from urban areas as quickly as possible in order to minimise the risk of flooding and to prevent water from becoming stagnant. The increased volume entering waterways can cause scouring (in stream erosion) of waterways. In less modified catchments the runoff is released over a longer period of time, which tends to assist with maintaining healthier water environments.

The Parramatta River Estuary is heavily urbanised and the majority of the stormwater enters the Estuary via a series of canals and highly modified urban streams (Woodlots and Wetlands, 1999).

The high velocity of stormwater entering the creeks and estuary can result in erosion of the bank and bed sediments. This may have an impact on riparian and aquatic habitats or on private and public infrastructure. The eroded sediments will be transported downstream and may cause sedimentation issues at downstream locations.

Significant erosion was noted in Vineyard Creek (upstream of the study area) (site visit December 2007). It is likely that this erosion is due to a combination of factors, one of which being the increased urbanisation of the catchment and increased flow volumes and velocities entering Vineyard Creek.

There is very little data or studies available relating to the velocities of frequent rainfall event stormwater flows (*i.e.* not flood flows). Parramatta City Council has commissioned waterways masterplans for four catchments which drain into the Parramatta River Estuary including: Quarry and Branch Creek, Toongabbie Creek, Ponds/Subiaco Creek and Vineyard Creek. These reports identify locations which are particularly subject to erosion and sedimentation and prioritised rehabilitation works (pers. comm., A Collins, PCC, May 2008).

6.5.3 Water Sensitive Urban Design

WSUD is the integration of various Best Planning Practices (BPPs) and Best Management Practices (BMP) for the sustainable management of the urban water cycle. WSUD is concerned with the design of urban environments to be more "sustainable" by limiting the negative impacts of urban development on the total urban water cycle. Therefore WSUD is about:

- trying to more closely match the pre-development stormwater runoff regime, in both quality and quantity;
- reducing the amount of water transported between catchment, both in water supply import and wastewater export; and
- optimising the use of rainwater that falls on the urban areas.

Western Sydney Regional Organisation of Councils (WSROC), Sydney Coastal Council's Group and the Upper Parramatta River catchment Trust received funding in 2002 to develop a metropolitan-wide WSUD capacity building program for Sydney's Metropolitan Council's. The WSUD Technical Guidelines for Western Sydney was prepared in 2004 by WSROC and the Stormwater Trust.

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 Potential Acid Sulfate Soils (PASS), which are thought to occur throughout much of the estuary. PASS can have significant environmental impacts if disturbed often releasing significant quantities of sulphuric acid and heavy metals, contaminating surrounding areas. Furthermore, percolation through the soil profile can lead to groundwater contamination.

Some examples of WSUD programs and infrastructure (as listed on www.wsud.org) within the study area include:

- 2003 Parramatta City Council: Incorporation of WSUD requirement into the site specific Development Control Plan for Parramatta Civic Place.
- 2004 Canada Bay Council: Barnwell Park Golf Course Stormwater Treatment and Reuse.
- 2005 Holroyd Council: Darling St Carpark Filtration System.

- 2004 Blacktown City Council: Better Water Management at the Council Works Depot.
- 2003 Lower Parramatta River Group: Four WSUD Demonstration Sites in the Lower Parramatta River catchment.
- 2003 Strathfield City Council: A Sustainable library for Strathfield.
- 2006 Bankstown City Council: Implementation of On-site Detention and WSUD in the SES Development at Manuka Reserve.
- 2005 Parramatta City Council: Doyle Ground Water Recycling Plant.

Several councils within the study area have WSUD requirements within their DCPs.

Gross Pollutant Traps (GPTs) have been incorporated into the stormwater system at a number of locations to reduce the amount of gross pollutants (*i.e.* litter) entering the estuary. Sydney Water Corporation stormwater quality improvement devices (SQIDs) are shown on **Figure 6.3**. No other information was available as to the locations, number or type of GPTs in the study area.

Homebush Bay

In the mid 1990s a number of studies were undertaken to examine options and identify the most appropriate strategy for the water cycle infrastructure and its management in the Homebush Bay area. This resulted in a number of schemes being developed that aimed to integrate water supply, wastewater, stormwater management and water re-use (Listowski & Phillips, 1999; Listowski *et al*, 2000; Olympic Co-ordination Authority, 1996; Willing & Partners, 1995a; Willing & Partners, 1995b; Willing & Partners, 1995c; Willing & Partners, 1995d).

In 2006, Cardno Willing prepared a stormwater servicing strategy for Sydney Olympic Park (Cardno Willing, 2006b), which built on the existing studies and provides the following aims:

- Maintaining or bettering if possible the performance criteria and targets that were established and adopted when implementing the stormwater infrastructure at Homebush Bay;
- Maintaining or bettering if possible the environmental performance already achieved at Sydney Olympic Park;
- Continued efficient utilisation of resources;
- Minimal capital investment in new trunk infrastructure; and
- Sustainable on-going costs to achieve the environmental performance targets.

6.6 Management Issues

Catchment Flood Flows

The management of flood risk is generally managed through the Floodplain Risk Management Process outlined in the *Floodplain Development Manual* (NSW Govt, 2005). It is vital that the Estuary Management Plan is complementary to the Floodplain Risk Management Process. The status of the existing floodplain management plans at the time of printing this report is outlined below. During the preparation of the Estuary Management Study and the identification of estuary management options, a review should be undertaken of all proposed floodplain risk management actions in the study area.

In 1992, Parramatta City Council prepared a strategy document (*Rivers of Opportunity – Waterways Strategy and Plan*). The aim of the Strategy is to provide the vision and guiding direction for Council and the community in the management of waterways for the next 20 years. The strategy identified flooding as one of the key management issues for the waterways of the Parramatta LGA.

Stormwater

Upper Parramatta River catchment: *Upstream of the Charles Street Weir*

The *Upper Parramatta River Stormwater Management Plan* (Catchment Stormwater Taskforce *et al*, 2002) identifies a range of stormwater management issues for the catchment upstream of the study area. Whilst management issues in the upper catchment will be directly addressed as part of the Estuary Management Plan, it is important to recognise the management issues experienced in the upper catchment may have an impact on the estuary. This will allow a better understanding of the processes present in the estuary.

Mid Parramatta (North) Catchment: *Parramatta River North Bank between Charles Street Weir and Ryde Bridge*

As part of the *Mid Parramatta (North) River Stormwater Management Plan* (Robinson GRC Consulting, 1999b) community and stakeholder consultation was undertaken to identify a range of catchment values and stormwater management objectives. Short-term (3 years) and long-term (25 years) objectives were identified and linked to the catchment values. These management objectives should be integrated into the Parramatta River Estuary Management Study.

A range of catchment management issues and possible causes were identified as part of the *Mid Parramatta (North) River Stormwater Management Plan* (Robinson GRC Consulting, 1999b). These included:

- Erosion of creek banks and stream channels;
- Marked changes in catchment hydrology due to urbanisation;
- Increased local and regional flood problems;
- Inadequate funding for maintenance and creation of stormwater assets;
- Poor erosion and sediment control on construction sites;
- General lack of understanding of catchment issues by multicultural community; and
- The flooding problems in local creeks are not being managed.

Lower Parramatta River catchment: *Ryde Bridge to Port Jackson*

Key stormwater issues were identified in the *Lower Parramatta River Stormwater Management Plan* (Woodlots and Wetlands, 1999). These included:

- Poor quality runoff from main roads;
- Severe canal contamination (Dobroyd and Hawthorne Canal);
- Frequent sewer overflows at Bremner Park and in the Hunters Hill area;
- Rapid conveyance of stormwater due to piped stormwater system.

Duck RiverCatchment

The *Duck River Stormwater Management Plan* (SKM, 1999) identified several stormwater management issues from discussions with Council officers, stakeholders and the community and from existing documentation. The major issues identified were:

- Erosion of watercourses and sediment deposition;
- Litter;
- Elevated nutrient concentration;
- Reduction in areas of urban bushland and riparian vegetation;
- Elevated levels of suspended solids;
- Elevated levels of faecal bacteria;
- Degraded aquatic and riparian habitats;
- Sewer overflows and exfiltration.

Environmental Flows

There is very little water extraction from the system and as such maintaining environmental flows is not a significant issue for the study area. However, the following issues have been identified:

- Weirs provide a barrier to fish passage,
- Variations in discharge and flow velocity due to increasing imperviousness, impacting on ecosystem health and function.

6.6.1 Existing Management Strategies

The management of urban stormwater, hydrology and flood behaviour has generally been addressed in considerable detail in most of the LGAs within the study area and the catchment. As such it is important that the Estuary Management Plan is recognisant of existing management strategies and enhances or is complimentary to these strategies.

The existing management strategies pertaining to urban stormwater, hydrology and flood behaviour have been summarised below. Additional collation of this information may be required as part of the Estuary Management Study.

Floodplain Risk Management

There are several management plans either in effect or currently being prepared to manage the risk of flooding within the study area. It is essential that any management actions developed as part of the Estuary Management Study are complementary to those actions proposed for flood risk management.

River Flow Objectives

The River Flow Objectives are the agreed high-level goals for surface water flow management. They identify the key elements of the flow regime that protect river health and water quality for ecosystems and human uses. It is important that this information is utilised when developing estuary management strategies for the Parramatta River Estuary.

Stormwater Management

Most Councils within the study area and the catchment have several plans, policies and strategies for managing urban stormwater quality and quantity. Where the Estuary Management Study looks at options for managing stormwater, the options should be reconciled against those strategies and plans already in place within each LGA. This would be done as part of the Estuary Management Study.

6.7 Data Gaps

There are very few data gaps with regard to catchment flows and groundwater extraction that would be necessary to understand estuarine processes and to make management decisions with regards to the Parramatta River Estuary. Additional data that would be useful in the estuary management process includes:

- Recent stormwater quality and quantity data (monitored or modelled).
- Stormwater flow velocities during more frequent rainfall events (*i.e.* less than a 2 Year ARI).
- The locations, types and number of GPTs in the study area.
- There have been a significant amount of studies undertaken with regard to groundwater in the Homebush Bay area. However, groundwater contamination may be an issue at a number of locations within the estuary due to land contamination

and industrial activities. Very little information is available with regard to groundwater movement and quality for the majority of the estuary.
- There is very little information pertaining to water extraction from the river and the water budget for ecosystem health for the river as a whole and for the individual reaches and/or tributaries.

6.8 Further Studies

Stormwater data compilation or modelling could be undertaken for key catchments and key locations to determine the likely sources of poor stormwater quality. This modelling could then be used to evaluate the effectiveness of proposed management strategies. It should be noted that MUSIC models exists for the Duck RiverCatchment (Cardno Willing, 2004) and the Vineyard Creek Catchment (SMEC, 2004).

Stormwater flow velocities could be determined through hydraulic modelling of the catchments. Where sensitive areas are identified, field investigations of the creeks could be undertaken to identify erosion issues.

Identification of all GPTs in the study area including details of the type and the volume of material collected.

Groundwater quality sampling would be useful across the study area to gain an understanding of groundwater quality issues and the potential impacts on the estuary. It may also be useful to undertake groundwater modelling to identify transport paths for contaminants, contaminant plumes and transport rates.

No additional studies relating to catchment flood flows have been identified to be undertaken as part of the Estuary Management Process. However, at each stage of the Estuary Management Process the most recent flood studies and Floodplain Risk Management Plan should be integrated into the Estuary Management Study. It is recommended that all flood management actions as a result of Floodplain Risk Management Plans should be compiled and mapped as part of the Estuary Management Study.

Information on water access licence titles should be obtained from the Department of Water and Energy (DWE). This information should be assessed against environmental flows for the Parramatta River and its tributaries to gain an understanding of the impacts of water extraction on ecosystem health. It is understood that the Upper Parramatta River catchment Trust (UPRCT) has several flow gauges in the upper catchment. This information should be obtained for use in the estuary processes study.

7. BATHYMETRY AND ESTUARY SEDIMENTS

7.1 Data Sources

The following data sources on sediments and bathymetry have been identified:

- ANZECC and ARMCANZ (2000)
- AWACS (1989c)
- AWACS (1989e)
- Barry, Taylor and Birch (1999)
- Barry, Taylor and Birch (2000)
- Batley and Hayes (1991)
- Birch and Davies (2003)
- Birch, Eyre and Taylor (1999)
- Birch, Harrington, *et al.* (2007)
- Birch and O'Hea (2007)
- Birch, Robertson, *et al.* (2000)
- Birch and Scollen (2003)
- Birch and Snowdon (2004)
- Birch and Taylor (1999)
- Birch and Taylor (2002a)
- Birch and Taylor (2002c)
- Birch and Taylor (2000)
- Birch and Taylor (2004)
- Birch, Taylor and Matthai (2001)
- Birch (1996a)
- DECC (2008b)
- GHD (1990)
- GHD (1991)
- Hatje, Payne, *et al.* (2003)
- Irvine and Birch (1998)
- Long, MacDonald, *et al.* (1995)
- McCready, Slee, *et al.* (2000)
- McCready, Spyrakis, *et al.* (2004)
- McCready, Greely, *et al.* (2005)
- McCready, Birch, *et al.* (2006a)
- McCready, Birch, *et al.* (2006b)
- McCready, Birch and Long (2006)
- McLoughlin (2000b)
- MPR (1992)
- PCC (2003f)
- PWD (1986)
- Roach and Runcie (1998)
- Robinson GRC Consulting (1999b)
- Rubinstein and Wicklund (1991)
- Short (1996)
- Simpson, Rochford and Birch (2002)
- SKM (1999)
- Snowdon and Birch (2004)
- SPCC (1977)
- Storm Consulting (2001)
- Taylor and Birch (1999)
- Taylor, Birch and Links (2004)
- Webb McKeown & Assoc. (1997)
- Webb McKeown & Assoc. (2007)
- Wicklund and Finney (1987)
- Willing & Parnters (2001)
- Woodroffe (2002)
- WP Geomarine (1998).

7.2 Bathymetry

A number of bathymetric surveys have been undertaken in the Parramatta River estuary. NSW Maritime provided mapping of survey sites and dates as shown in **Figure 7.1**. This information is detailed in **Table 7.1**. It is unclear what the exact spacing between soundings is, however an indication of the resolution of the surveys is provided in **Table 7.1** based on visual interpretation.

Table 7.1 Record of Parramatta River Soundings (after NSW Maritime)

Year of Survey	Approximate Extent	Spatial Resolution of Survey
1951	Cockatoo Island to Spectacle Island	Low
1953	Spectacle Island to Bedlam Point	Low
1955	Hen and Chicken Bay	Low
1956	Bedlam Point to Ryde Bridge	Low
1967	Lower Reaches of Duck River	High
1978	Wentworth Point to George Kendall Riverside Park	High
1989	Main channel between Wentworth Point and George	High

Year of Survey	Approximate Extent	Spatial Resolution of Survey
	Kendall Riverside Park	
1991	Urhs Point to Wentworth Point	High
1992	George Kendall Riverside Park to the confluence with the Duck River	High
1994	Vicinity of Meadowbank Wharf, Three Brothers Rocks and Chiswick Wharf	High
1995	Vicinity of Cabarita Park, Bayview Park Jetty (in Hen and Chicken Bay) and Three Brothers Rocks	High
1996	Main channel between the confluence with Duck River and Wentworth Point, vicinity of Abbotsford Wharf and Balmain West (Elliot Street) Wharf Homebush Bay	High Moderate
1997	Vicinity of Cabarita Wharf	High
1998	Vicinity of the confluence with Duck River	High
1999	Vicinity of Urhs Point	Low
2000	Two locations near the western shore of Homebush Bay, Cabarita Park, Bayview Park Jetty, Huntley's Point and Somerville Point Marina	High
2001	Main channel between Rocky Point and Wentworth Point, Kendall Bay/Breakfast Point and Birkenhead Point, as well as some small isolated locations throughout the estuary	High – Very High
2002	A number of small isolated locations throughout the estuary	Very High
2003	The main channel upstream of the confluence with Duck River, and other isolated locations throughout the estuary	Very High
2004	D'Albora Marinas Cabarita Point and near St Josephs College Rowing Shed in Tarban Creek	Very High
2005	From the confluence with Duck River to the Charles Street Weir, as well as some other isolated locations in the estuary	Very High
2006	Isolated locations along the estuary foreshores	Very High
2007	Cabarita Point to Mortlake Point Vicinity of Kendall Bay Marina and Iron Cove Bridge	Moderate Very High

The bathymetric contours for the Parramatta River estuary are illustrated in **Figure 7.2**. This data was provided by DECC. The depth contours are metres below zero on the Fort Denison tide gauge (at 0, 2, 5, 10 and 20m increments). An interpolation grid of the bathymetry provided by NSW Maritime is presented in **Figure 7.3**.

Figure 7.3 provides a relatively simple representation of bathymetry. It is apparent that the deepest sections of the Parramatta River Estuary are in the main channel and that the embayments are much shallower. Upstream of Yaralla Bay the estuary shallows significantly. Also apparent are areas above 0 mAHD (shading to green) that will be exposed over some portions of the tidal cycle. These areas are located primarily in Homebush Bay, but may also be seen at the upstream margins of some of the embayments. Dark blue spots on **Figure 7.3** represent the deepest areas. A number of deep holes are visible. These areas are likely to be poorly flushed at depth and subject to poor water quality (e.g. anoxic conditions). These deeper parts of the estuary may also act as sinks for sediments.

Bathymetric data may be used as an input to hydrodynamic models of the estuary, as was done by Cardno Lawson Treloar (then Lawson and Treloar), who prepared a Delft-3D hydrodynamic model of Port Jackson and the Parramatta River estuary for tactical assistance to the 2000 Australian Olympic Sailing Team (unpublished data).

7.3 Sediment Transport, Sources and Sinks

In addition to estuarine sediments, there are two sources of sediments delivered to the estuary:

- Fluvial sediments, and
- Marine sediments.

Marine sediments can enter coastal estuaries and embayments due to oceanographic processes such as tidal currents or wave action. The movement of marine sand can impact on the navigability of waterways. However, it is thought that marine ingress does not extend as far up Port Jackson as the Parramatta River Estuary.

Fluvial sediments are delivered to the estuary via freshwater flows from the catchment. Sources include bank or bed erosion within tributaries, or catchment erosion, whereby sediments are mobilised via sheet flow across sparsely vegetated lands.

To some extent, creek erosion and accretion are part of the naturally occurring sedimentary process. A summary of estuary evolutionary processes is provided in **Section 4.2**.

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 velocity of creek flows slow down as they flow into the estuary. As this process occurs, the sediment transport capacity decreases and non-colloidal 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 Parramatta River Estuary. Even quite small wind waves that break at the shoreline can cause sediment re-suspension. 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 (e.g. Iron Cove). These 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.

7.3.1 Sediment Grain Size Analyses

Sediment grain size analyses can be used to infer potential sources and sinks of sediments. Used in conjunction with hydrodynamic data, the patterns of sediment transport throughout the estuary can be investigated.

The literature review undertaken for this study did not lead to the identification of many resources on sediment grain size or sediment transport within the Parramatta River estuary. However, a limited number of studies did provide some information on sediment grain size, sources and sinks. Their findings are outlined below.

Irvine and Birch (1998) analysed sediment grain size for a total of 354 surface samples collected throughout Port Jackson, including the Parramatta River estuary. Fine, muddy sediments (<63µm) dominated at proportions >90% at: Iron Cove, Five Dock Bay, most of Hen & Chicken Bay, Majors Bay, Yaralla Bay, Brays Bay and the western shore of Homebush Bay, as well as much of the mainstream of the estuary between Mortlake Point and the Silverwater Bridge (Irvine and Birch, 1998). Along the mainstream, between Spectacle Island and Looking Glass Point, sediments are coarser with muds representing 10-50% of the sample. These findings demonstrate that fine sediments tend to settle in more sheltered embayments.

At a smaller scale, Taylor and Birch (1999) examined sediment grain size for Iron Cove and determined that at least 90% of surficial sediments were fine muds (<63µm), with higher proportions of fine material found in deeper portions of the cove and/or in proximity to stormwater outlets. That study also determined that tidal re-suspension of sediments is the key mechanism for sediment transport within Iron Cove, although wind waves may also be important at some sites, depending upon wind speed, direction and duration, as well as fetch (Birch and Taylor, 1999).

PWD (1986; cited AWACS, 1989e) conducted a sediment grain size analysis for Homebush Bay and found that the highest fraction (68%) of coarse (>65µm) sediments was found near the mouth of the bay. The relative proportion of coarse to fine material then decreased for samples collected further in the bay, with the lowest fraction of coarse sediments (20%) found in the southern area of Homebush Bay.

However, it is noted that sediment grain size analysis and its relationship with estuarine processes may be confounded by dredging and other extractive activities (if and when permitted).

7.3.2 Estuary Infilling

In general, there appears to be a paucity of information relating to the estuary infilling in the Parramatta River Estuary. Where data is available, it is complicated by dredging and reclamation works undertaken over the years. Those studies relating to estuary infilling (or sedimentation) that were compiled during the literature review are discussed below.

Whilst sedimentation is a natural process in estuaries, it has been greatly increased through the urban development of the catchment since European settlement. A review by McLoughlin (2000b) states that by the mid-1860’s, sedimentation had occurred to such an extent that formerly intertidal areas of Homebush Bay were described as being ‘permanently dry’. Accounts for other locations in Port Jackson describe deposition in the order of over 1m in 3 years (based on a long-term average; McLoughlin, 2000b). However, these rates of sedimentation represent eyewitness accounts and have not been validated during the undertaking of this study.

McLoughlin (2000b) also makes reference to articles published in the *Sydney Morning Herald* in 1861 detailing the blockage (‘again’) of access to the Parramatta River above Homebush Bay (currently a depth of approximately 4m) due to deposition of a large quantity of material by floodwaters. This gives an insight into the extent of sedimentation occurring at that time. However, it is likely that the rate of input has altered over the years in response to changing land use patterns in the catchment.

More contemporary estimates of infilling or sedimentation are provided for Homebush Bay in Irvine and Birch (1998), who infer rates of sedimentation in Port Jackson (including the Parramatta River estuary) by analysing sediment cores. Based on the assumption that sedimentation has increased markedly since European settlement (i.e. over the last 150-200 years) the authors of that study estimated an average rate of sedimentation between 1.5-3.5 mm/yr. This is quite significant when considering the size of Port Jackson as a whole. However, it is noted that this estimate was developed from analysis of a total of 38 cores collected throughout Port Jackson.

In their study of sedimentation rates for Iron Cove, Hen and Chicken Bay and Homebush Bay, Taylor and Birch (1999) found that sedimentation rates were four times higher in the summer months, which was primarily attributed to re-suspension of sediments within these embayments by wind waves or tidal exchange.

Based on bathymetric survey conducted in 1978 and 1985, AWACS (1989e) provided an analysis that indicates that accretion has occurred between the two parallel shores near the mouth of Homebush Bay at an approximate rate of >30mm/year. This may be the result of infilling of a known dredge hole at this location (**Section 7.3.3**). Accretion of that magnitude also appears to have occurred in the southwest corner of the bay and along the top end of the bay (AWACS, 1989e), whereas scattered patches affected by erosion at a rate of >30mm/yr are located near the mouth of Homebush Bay and slightly north-west of the mouth of Haslam's Creek.

The general trend within Homebush Bay is for accretion of sediments, although AWACS (1989e) note this conclusion is limited by the extent of the bathymetric survey, which did not extend right up to the mouths of Powells and Haslams Creeks. AWACS (1989e) determined that, while delta formation has occurred to a limited extent in association with Haslam's Creek, delta formation is not the primary mechanism for sedimentation within Homebush Bay. Instead, the authors attribute the observed accretion to:

- The introduction of suspended sediments in tidal inflows, and/or
- Re-suspension of fine material within the bay as a result of wave action.

With respect to Iron Cove, Barry, Taylor and Birch (1999; 2000) make reference to sedimentation occurring around the outlet of both Dobroyd and Hawthorne Canals as they enter Iron Cove. This is reportedly due to deposition of sediments entrained in stormwater inflows.

Overall, there appears to be inadequate information on the existing and potential rate of sedimentation within the estuary and its tributaries. This is an important consideration as it relates not only to the potential impacts on estuarine flora and fauna, but also on the amenity of the waterways and sedimentary geochemistry (e.g. nutrient cycling, contamination status).

7.3.3 Human Extraction / Dredging

There have been extensive modifications to the Parramatta River Estuary bed, including both dredging and reclamation works, since the arrival of Europeans in Sydney. McLoughlin (2000b) provides an excellent history of dredging works (compiled from a number of sources) in Sydney Harbour, including the Lower Parramatta River and embayments, ranging from 1788 to the 1990's.

The history of dredging is said to have begun in 1842 due to rapid acceleration of sedimentation in Port Jackson in association with vegetation clearing undertaken by Europeans, and from this time onwards, the bed and foreshores of Port Jackson have been modified to mitigate sedimentation, enable access by watercraft and improve foreshore amenity (McLoughlin, 2000b). This has included extensive dredging and reclamation works in the Parramatta River, particularly in Homebush Bay. In general these works have been undertaken at the expense of mangrove and wetland areas, which were deemed to be unsightly and unhealthy.

Table 7.2 provides a history of dredging activities in the Parramatta River Estuary up to 1993 (after McLoughlin, 2000b). The reliability of the dredge volumes presented in **Table 7.2** has not been checked. However, it is noted that they appear to be unrealistically precise and it has been assumed that this is the result of being converted from the empirical measurement.

Table 7.2 History of Dredging in the Parramatta River Estuary 1875-1993 (after McLoughlin, 2000b)

Location	Year(s)	Tonnes
Iron Cove		
Callan Park	1893-94	731,804
Leichhardt Park	1901	3,901
Long Cove (Hawthorne Canal)	1902-07	139,670
	1911	3,028
	1914	2,987
Leichhardt (Hawthorne) Canal	1916-20	99,985
Timbrell Park, Iron Cove Creek	to 1941	?
Dobroyd Point	to 1945	?
Western Shores	1972-77	?
TOTAL		981,375
Homebush Bay		
	1893	275,844
	1905	?
	1906-14	4,052,626
	1916-17	276,281
	1927-28	?
	1948-61	?
TOTAL		4,604,751
Parramatta River		
	1890	108,976
incl. Ryde Bridge to Duck River	1902-06	558,963
	1908	2,012
incl. Ryde to Ermington	1911-20	2,077,425
Ryde to Silverwater	1925-26	106,064
	1928-32	?
	1949-54	?
Homebush Bay to Duck River*	1993	?
TOTAL		2,853,440
Other Embayments in the Parramatta River		
Hen and Chicken Bay	1914	9,307
	1920	8,778
Kendall Bay	1918-20	190,754
Canada Bay	1968-74	128,016
Brays Bay	1974	23,368

**Dredging activities do not account for works undertaken to facilitate extension of the Parramatta Ferry service.*

AWACS (1989e) note that there has been dredging undertaken adjacent to the western foreshore of Homebush Bay for use by the industries formerly located there. AWACS (1989e) also record anecdotal evidence that there had been no dredging between 1978 and the publication of that study. However, no further details are provided.

It is understood that, more recently, dredging was undertaken between the Old Shell Barge Wharf, upstream of Duck River, to the Charles Street weir at Parramatta in order to facilitate the extension of ferry services to Parramatta (GHD, 1990 and 1991).

However, despite the abovementioned studies, it is anticipated that the full extent of historical and ongoing dredging activities is not fully accounted for. Comparison of available sequential bathymetric surveys may provide additional information in this respect.

7.3.4 Land Reclamation

Land reclamation has also occurred along the Parramatta River Estuary, either through placement of dredge spoils or via dumping of landfill or other material. Reclamation of foreshore lands can be interpreted from historical aerial photography. A list of the available aerial photography of the study area (after Webb McKeown & Associates, 2007) is shown in **Table 7.3**. In addition, as noted by Webb, McKeown and Associates, 2007), historic parish maps may also be used to gain an indication of changes to the estuary foreshore over time, although these are likely to be of a lower quality than aerial photographs.

Table 7.3 Available Historical Aerial Photography (after Webb McKeown & Assoc., 2007)

Year	Scale	Format
2002	1:25,000	Colour
1998	1:50,000	Colour
1996	1:50,000	Colour
1994	1:25,000	Colour
1991	1:25,000	Colour
1989	1:40,000	Black & White
1986	1:16,000	Colour
1984	1:40,000	Black & White
1983	1:40,000	Black & White
1982	1:73,000	Black & White
1982	1:16,000	Colour
1979	1:40,000	Black & White
1978	1:16,000	Black & White
1975	1:40,000	Black & White
1974	1:73,000	Black & White
1972	1:40,000	Black & White
1971	1:40,000	Black & White
1970	1:14,400	Black & White
1966	1:35,000	Black & White
1965	1:39,500	Black & White
1965	1:22,000	Black & White
1961	1:13,000	Black & White
1955	1:15,360	Black & White
1951	1:12,000	Black & White
1930	1:22,000	Black & White

It is understood that PCC also holds aerial photographs for the years 1943, 1978, 2000 and 2007.

McLoughlin (2000b) also provides an overview of reclamation works in the Parramatta River and the wider Port Jackson from 1842 to the 1970's. Those locations situated within the study area are detailed in **Table 7.4**. This review provides more specific details of reclamation works and covers the period prior to the advent of aerial photography.

It is understood that significant reclamation works have also been undertaken in George Kendall Reserve, Ermington (pers. comm., A. Collins, PCC, 3 June 2008).

Table 7.4 History of Reclamation Works in the Parramatta River Estuary 1842-1970s (after McLoughlin, 200b)

Years	Location	Area	
		Acres	Hectares
1890-1907	Long Cove (head of Iron Cove) / Hawthorne Canal	81	32.8
1893-94	Callan Park, Iron Cove	5.5	2.3
by 1897	Sewerage Farm, Parramatta (partly complete)	41	16.6
1898	Tarban Creek	NS	NS
by 1944	Timbrell Park, Iron Cove Creek (plus strip on south side of channel)	24 + 2	10.5
by 1945	Frontage to Robson Park, Dobroyd Point, Iron Cove	6.5	2.6
1893, 1904-17, 1948-62	Homebush Bay, western side	300	122
1948-62	Homebush Bay, eastern side	NS	NS
1968-74	Canada Bay (incl. other material)	16	6.5
1974	MacIlwaine Park, Brays Bay	3	1.2

*NS – Not Specified

7.4 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 and ARMCANZ, 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,
- Dioxins (polychlorinated dibenzo-p-dioxins or PCDDs) and furans (polychlorinated dibenzonfurans or PCDFs),
- Polycyclic aromatic hydrocarbons (PAHs) associated with heavy industry/combustion,
- Organochlorine (OC) pesticides (such as DDD, DDE and DDT) and organophosphate (OP) pesticides,
- Phenols used in chemical synthesis, and
- 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. Sediments record and time-integrate the environmental status of an aquatic ecosystem. 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. Due to their chemical characteristics these types of pollutants tend to be persistent in the environment because they are typically quite stable.

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, Macdonald *et al.* (1995), as advised by ANZECC and ARMCANZ (2000), are commonly used in Australia. Two guideline values are provided for each analyte:

- ISQG-L (effects range low or ERL; 10%ile of in-fauna affected), and
- ISQG-H (effects range high or ERH; 50%ile of in-fauna affected).

7.4.1 Enrichment, Sources and Dispersion

Contamination Status

There are a number of studies on sedimentary contamination for the Parramatta River estuary. Several of these studies cover the larger Port Jackson area and incorporate the study area, whilst others target specific locations within the estuary. In general, the quality of sediments within the estuary has been highly compromised due to point sources associated with industrial activities, as well as diffuse sources such as residential areas and roadways.

A large number of studies on the quality of sediment within the wider Port Jackson estuary have been conducted and these typically include the Parramatta River estuary. These studies have targeted a range of contaminants, including:

- *Heavy metals* (Birch, 1996; Birch and Davies, 2003; Birch and O'Hea, 2007; Birch and Taylor, 1999; Birch and Taylor, 2000; Birch and Taylor, 2002a, b and c; Birch and Taylor, 2004; Birch, Taylor and Mattai, 2001; Birch, Robertson et al., 2000; GHD, 1990; GHD, 1991; Hatje, Payne *et al.,* 2003; Irvine and Birch, 1998; McCready, Birch and Taylor, 2003; McCready, Birch *et al.,* 2006a; SPCC, 1977),
- *OCs* (Birch and Taylor, 2002a, b and c; Birch and Taylor, 2004; Birch, Robertson *et al.,* 2000),
- *PAHs* (Birch and Taylor, 2002a, b and c; Birch and Taylor, 2004; Birch, Robertson *et al.,* 2000; McCready, Slee, *et al.,* 2000),
- *PCBs* (Birch and Taylor, 2002a, b and c; Birch, Robertson *et al.,* 2000), and
- *Nutrients* (Birch, Eyre and Taylor, 1999; Birch and Taylor, 2004).

These studies identify Port Jackson, and the Parramatta River estuary in particular, as being significantly impacted by contaminated sediments. The levels of concentration of some contaminants are some of the highest reported on a global scale (Birch and Taylor, 2004). Enrichment of background heavy metal concentrations due to anthropogenic activities has also been assessed by analysing sediment cores (Birch, 1996; Birch and Davies, 2003; Taylor, Birch and Links, 2004). Taylor, Birch and Links (2004) provide a more detailed chronology of contamination, linking the contamination profile with specific activities/land uses conducted around Iron Cove, Hen and Chicken Bay and Homebush Bay. In addition, Birch, Harrington, *et al.* (2007) established background concentrations and enrichment of dioxins and furans for the study area.

Birch and Taylor (2004) provide a synthesis of much of the literature relating to sedimentary contamination in Port Jackson. Their literature review provides information on sampling and analytical methodology, types of contaminants, sources and sinks, ecological effects and toxicity. Prioritisation of specific locations within Port Jackson for remedial works was also undertaken, with the following locations listed as being of the highest priority: Duck River, the eastern shore of Homebush Bay, Fairmile Cove and the upper reaches of Hen and Chicken Bay, Five Dock Bay and Iron Cove (Birch and Taylor, 2004).

Several of the resources on sedimentary contamination in the Parramatta River estuary relate to specific locations within the study area. These have been considered below. This section has been divided into sub-sections representing the upper, middle and lower sections of the Parramatta River estuary (as delineated in **Section 1.1**).

Upper Parramatta River Estuary

GHD (1990 and 1991) reported concentrations of heavy metals, OCs and PAHs for the upper estuary, including Duck River, as part of an EIS for the extension of ferry services to Parramatta and the associated dredging works. However, information regarding the analytical methods and quality assurance is not provided.

The *Duck River Stormwater Management Plan* prepared by SKM (1999) reported sediment quality results for Duck River and Duck Creek (above the weir), stating that sediment quality was affected by pollution with heavy metals, OCs, PCBs and PAHs, thought to be derived from diffuse sources in the catchment. Several of these contaminants (including iron, chromium, lead, mercury, zinc, chlordane, dieldrin, PCBs, DDT and oils and grease) were present in relatively high concentrations in Duck River.

Mid Parramatta River Estuary

MPR (1992) monitored concentrations of lead in sediments at four locations near Camellia before and after the refurbishment of a water main and bridge structure crossing the river. These structures were originally painted with lead-based paint, which was being removed and replaced with an epoxy based paint. They concluded that the concentration of lead did not change after undertaking the works (MPR, 1992).

Homebush Bay

Birch, Harrington *et al.* (2007) examined the extent of contamination relating to dioxins and furans, primarily in relation to Homebush Bay and the Rhodes Peninsula. Concentrations were found to be the highest in Australia, as well as being among the highest reported concentrations of dioxins and furans for any location in the world (Birch, Harrington, *et al.* 2007). Further, that study found that the sediments of Homebush Bay have a distinct congener signature related to chemicals produced on the eastern shore of the Bay and known to have been manufactured by industry on the peninsula. Birch, Harrington *et al.* (2007) used this distinct chemical signature to determine that sediments immediately upstream and downstream of Homebush Bay are also affected by contamination due to sediment transport.

Concentrations of polyorganosiloxanes (silicones) in sediments are also reported for Homebush and Brays Bays in the range 0.07-0.54 µg Si/g, concentrations that are typical of locations that are affected by residential and industrial land uses (Batley and Hayes, 1991).

Homebush Bay, Hen and Chicken Bay and Iron Cove

Taylor and Birch (1999) and Taylor, Birch and Links (2004) analysed concentrations of heavy metals (copper, lead, zinc and cadmium) and OCs in these three embayments. The sediments in these embayments were found to be highly contaminated by heavy metals, with the stormwater canals entering the bays the primary source of heavy metals, the exception being cadmium for which Iron Cove Creek was determined to be the most significant source for Iron Cove (Taylor and Birch, 1999).

Lower Parramatta River Estuary

Iron Cove

Heavy metal concentrations were found to be highest near the stormwater outlets and declined towards to the middle of the cove, said to reflect both direction of input and the settling characteristics of the sediments with which the metals are associated (Simpson, Rochford and Birch, 2002). The presence of fly ash in sediments also contributed to higher concentrations of heavy metals in the coarser fraction (>63µm) in some locations due to the binding of metals to fine fly ash, which then attached to larger sediment particles (Simpson, Rochford and Birch, 2002). It is understood that coal ash from the Balmain Power Station, which was in operation from the 1930s to the 1960's was used as infill to reclaim an area of former mud flats.

In addition, Storm Consulting (2001) provides a review of the published literature on the level of contamination of sediments in Iron Cove and Dobroyd Canal. Advice from Ashfield Council indicates that sediments located behind Hawthorne Parade are contaminated with fly ash from the former coal stations in Balmain (pers. comm, J. Harris, AMC, 26 February 2008

Sources

Potential sources of contaminants are considered in many of the studies listed above. Several studies report on more detailed investigations into source identification, be they diffuse or point sources. Several of the abovementioned studies (such as Birch and Taylor, 2004) report that higher concentrations of contaminants tend to be associated with either particular point sources (e.g. former industrial sites on the eastern shore of Homebush Bay) or the upper reaches of embayments where creeks and stormwater outlets enter the estuary (such as Storm Consulting, 2001).

Heavy metal inputs from roads, cars and traffic have also been analysed based on analysis of soils and/or dust in the Iron Cove catchment. It is understood that students and staff of the Environmental Geology Group at Sydney University also have several forthcoming papers of this nature for the Parramatta River catchment.

Birch and Scollen (2003) and Birch and Snowdon (2004) examined heavy metal concentrations in soils within the Iron Cove catchment. Birch and Scollen (2003) found that higher concentrations of heavy metals were associated with higher traffic volumes in the local contributory catchment. These contaminated soils are then entrained in stormwater runoff and thereafter make their way into the estuary. This indicates traffic and roadways may be significant sources of heavy metals found in estuarine sediments. However, it is understood that there is some conjecture over the relationship between traffic volume and pollutants exported.

Birch, Robertson *et al*. (2002) undertook an analysis of the effect of land use practices on sediment quality. Whilst their study area was the Upper Parramatta River catchment, it is considered that the results are also applicable to the Parramatta River estuary due to similarities in land use patterns and the potential for impacts further downstream in the estuarine portion of the river.

McCready, Slee, *et al.* (2000) concluded that the relatively consistent level of contamination of Sydney Harbour sediments with PAHs indicated that high temperature combustion processes (and the subsequent atmospheric fallout), e.g. from the burning of coal to extract gas at the Balmain Gasworks, were the primary contributor of PAHs.

Point sources of contamination include foreshore lands that are known to be affected by contamination due to industrial activities. This includes a large number of reclaimed areas along the foreshore, for which contaminated fill materials were commonly used (see **Section 7.3.4**). An example from the literature is provided below.

Wicklund and Finnecy (1987) reviewed a report by Longworth and McKenzie Pty Ltd on the contamination status of the former Union Carbide site, Rhodes. The Longworth McKenzie Pty Ltd report made an attempt to assess the affect of groundwater from contaminated reclaimed lands on the water and sediment quality of Homebush Bay. Wicklund and Finnecy (1987) acknowledge that, while Longworth McKenzie's assessment was of insufficient extent to make a firm conclusion, the contaminated soils of the Union Carbide site may impact the sediment quality of Homebush Bay via direct transfer of solid soil (e.g.

aeolian transport) or via contaminated groundwater seepage through the sea wall, the latter method considered to be undoubtedly occurring. It is understood that these leachates were to be monitored and that there are approximately 25 piezometers in place to monitor groundwater levels and contaminant concentrations (Short, 1996).

This process, whereby point sources directly impact sediment quality, is likely to be affecting several locations within the study area due to the large extent of reclaimed land and industrial history of many parts of the foreshore.

It is important to note that substantial efforts have since been expended to remediate these areas, with work in progress occurring during the course of this study. **Figure 7.4** shows an example of some contamination remediation works observed on the day of the site visit (28 November 2007).

7.4.2 Transition between the Water Column and the Sediments

Partitioning of contaminants between benthic sediments or the water column is influenced by geochemical processes. Variables such as the salinity and pH of the water column, or the total organic content of sediments, will determine whether contaminants such as heavy metals remain bound to sediments or are mobilised into the water column.

Barry, Taylor and Birch (1999; 2000) describe heavy metal partitioning, between the water column and the sediments, in both Hawthorne and Dobroyd Canals and Iron Cove. They determined that heavy metals (Cu, Zn and Pb) present in stormwater inflow to Iron Cove tended to bind to the sediments due to mixing with estuarine waters, associated with the increased salinity in particular. The implications of this finding are that any heavy metal contaminants delivered to the estuary via stormwater will tend to attach to sediments and thereafter be subject to sedimentary transport processes.

The effects of sediment geochemistry on heavy metal partitioning in Iron Cove were considered by Simpson, Rochford and Birch (2002). They found that there was typically sufficient reactive sulfide to keep metals bound to sediments and for this reason, the flux of metals between sediments and the water column was generally low. This is an important consideration given the extent of occurrence of ASS in the study area. However, zinc was the most easily mobilised metal due to sediment re-suspension, especially if the pH of waters decreases (Simpson, Rochford and Birch, 2002). These findings highlight the importance of maintaining natural tidal flows with a view to ensuring that appropriate flushing occurs to maintain the pH at higher levels.

In addition, bioturbation or re-suspension of sediments may also lead to the transport of contaminated sediments to other areas. Birch and O'Hea (2007) found that wind-induced re-suspension contributed the greatest mass of heavy metals to the water column, which may subsequently pose a risk to filter-feeding aquatic organisms.

SPCC (1977) examined partitioning of pollutants in the Parramatta River estuary and the potential for these pollutants to be released into the water column. With respect to oils, even in the heavily contaminated sediments of Duck River, the sediments were unlikely to act as a significant source of oils in the water column (SPCC, 1977), although under low flow conditions, the sediments of Duck River may contribute slightly higher concentrations of oils to the water column. SPCC (1977) also found that the mobilisation of heavy metals from the sediments was unlikely, except where bioturbation is a contributing factor. Metals are also associated with organic material. However, since most of the sediments in the estuary can be characterised as being organically stable, the release of heavy metals to the water column in association with organic sediment is unlikely to be a significant source of water pollution.

These studies highlight the relationship between sedimentary geochemistry (including also biological processes) and hydrodynamics, where the hydrodynamics and physiochemical character of the estuary mediate the partitioning of pollutants between the sediments and overlying water column. This is particularly important given the high level of contamination in the Parramatta River estuary and the prohibitive cost of remediating all affected sediments.

Whilst it is appreciated that the literature review may not have uncovered all existing studies on this topic, it is considered that further attention should be directed to understanding the key processes that affect partitioning of both contaminants and nutrients between the sediments and the water column.

7.4.3 Bioaccumulation and Ecotoxicology

As discussed in **Section 7.4**, contaminants bound to estuarine sediments may negatively impact the ecology of the estuary. The potential for contaminants to directly or indirectly (i.e. through bioaccumulation) impact on estuarine biota, and subsequently (potentially) humans, is typically assessed through application of the relevant ANZECC and ARMCANZ (2000) guidelines, which are derived from Long, MacDonald, et al. (1995).

Many of the studies discussed above compared the recorded concentrations of contaminants against guidelines (Birch, Harrington, *et al.,* 2007; Birch and Taylor, 1999; Birch and Taylor, 2000; Birch and Taylor, 2002a, b and c; Birch, Taylor, *et al.* 2000; McCready, Birch and Long, 2006; McCready, Slee, *et al.,* 2000; McCready, Spyrakis, *et al.,* 2004). In their synthesis of the literature relating to possible biological effects of contamination, Birch and Taylor (2004) state that the spatial extent of the study area in which adverse biological effects may be anticipated are highly variable depending on which particular contaminant is under consideration, be it a heavy metal or organic contaminant. However, it is notable that Birch and Taylor (2004) state that almost all of Sydney Harbour, including the Parramatta River estuary, exceeds the ISQG-L concentrations for at least one metal.

Below is a summary of those locations identified in Birch and Taylor (2002c; 2004) as being of concern with respect to adverse biological effects:

- The entire Parramatta River estuary, with the exception of the stretch between Spectacle Island and Wrights Point, has concentrations of total chlordane in excess of the ISQG-H value,
- Homebush Bay, parts of Iron Cove and parts of the main waterway between Homebush Bay and Cockatoo Island have PCB concentrations above the ISQG-H value,
- Concentrations of DDT in Iron Cove exceed the ISQG-H value,
- Concentrations of PAHs in excess of the ISQG-H values found in Iron Cove, Duck River and the main waterbody upstream of Hen and Chicken Bay,
- Sediments in upper-Iron Cove exceed the guideline values for more than 10 contaminants, and
- Sediments in the study area have at least one OC compound in excess of the ISQG-H value.

In summary, those locations that are of most concern in terms of total exceedences for heavy metals, OCs and PAHs combined are Homebush Bay, Hen and Chicken Bay and Iron Cove, with benthic communities in these locations being in the highest risk category and, more generally, sediments upstream of Majors Bay have an 80% chance of being toxic to estuarine biota (Birch and Taylor, 2002c), as shown in **Figure 7.5**.

The entire study area has been identified as a priority for addressing adverse biological effects associated with sedimentary contamination, particularly Homebush Bay, Iron Cove, Five Dock and the main channel upstream of Hen and Chicken Bay (Birch and Taylor, 2004).

Roach and Runcie (1998) investigated the bioaccumulation of PCBs and OCs in the tissues of edible fish species (Yellowfin Bream *Acanthopagrus australis*, Silver Biddy *Gerres subfasciatus* and Pink-eye Mullet *Trachystoma petardi*) fished from waters within the study area. They found that concentrations of these contaminants were higher than the National Maritime Authorities Maximum Residue Limit at some of these locations, raising the possibility of detrimental health effects for people consuming these fish species (Roach and Runcie, 1998). These findings indicate that the bioavailability of these sedimentary contaminants is sufficient to lead to bioaccumulation in estuarine biota and therefore has the potential to pose a risk to human health.

Webb, McKeown and Associates (2007) make reference to a series of studies undertaken by David Booth of the University of Technology, Sydney, on heavy metal accumulation in an unspecified species of fish. However, these references were not available at the time of preparation of this report. Further information on the presence of heavy metals and other contaminants in fish tissues can be found in **Section 10.3.1**.

There are also a number of studies investigating the potential for biological impacts associated with sedimentary contamination for discrete locations within the Parramatta River estuary. These have been discussed below.

Mid-Parramatta River Estuary

<u>Homebush Bay</u>

Rubenstein and Wicklund (1991) provide data on dioxin concentrations in Homebush Bay based on a review of the relevant, available studies. They determined that residues of dioxin in a range of estuarine biota (including fish species and invertebrate species) indicated that dioxin was bioavailable and was present in sufficiently high concentrations to trigger the need for remediation of contaminated sediments with a view to mitigating risk to human and ecological health.

The Ecotoxicology Guidelines

It is noted that the original Long, MacDonald, *et al.* (1995) study from which the ANZECC and ARMCANZ (2000) guidelines were developed was conducted in the United States by the National Oceanographic and Atmospheric Administration (NOAA). However, recently some supporting research has been published on these topics. McCready, Birch, *et al.* (2006a) have undertaken an assessment of toxicity and chemical concentrations for Sydney Harbour and evaluated these against the ISQGs. A suite of toxicity tests were used, including amphipod survival (using the locally indigenous species *Corophium colo* and *Heliocidaris tuberculata),* sea urchin fertilisation/larval development and pore water tests. Toxicity was tested for heavy metals, PAHs and OCs. They determined that none of the relationships between toxic responses and concentrations of contaminants resulted in a strong correlation. For example, in some instances, high chemical concentrations exceeding the ERM guidelines were not highly toxic, despite being predicted to be highly toxic (McCready, Birch, *et al*., 2006a). However, of all contaminants, copper, lead and zinc appeared to be most closely related to sediment toxicity. In addition, it was acknowledged that the findings might be different if different experimental organisms were chosen. Further, samples used in that study not infrequently contained multiple contaminants present in concentrations higher than the ERH (McCready, Birch, *et al.*, 2006a), which may have led to confounding of the results.

McCready, Birch, et al. (2006b and c) determined that the predictive abilities of the ISQGs for sediments from Sydney Harbour were generally accurate and protective of non-toxic conditions and that these guideline values are appropriate for compliance testing under a range of conditions. As expected, ISQG-High guidelines were more predictive of adverse effects than ISQG-Low guidelines. However, it is noted that amphipod survival tests conducted by McCready, Birch, *et al.* (2006b) and McCready, Greely, *et al.* (2005) indicated that the predictive abilities of ISQGs was influenced by the sensitivity of test species and/or bioavailability of contaminants.

7.5 Acid Sulfate Soils

Acid Sulfate Soils (ASS) 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.

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, 2008b). 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, 2008b). 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.

The probability of the occurrence of ASS within the Parramatta River Estuary catchment has been mapped by DECC, as shown in **Figure 7.6**. Small pockets of foreshore lands throughout the study area are affected by soils identified as having a high probability of occurrence for ASS. Locations potentially affected to a larger extent include:

- The estuary bed upstream of the confluence of the Parramatta River and Duck River and some of the foreshore lands there,
- The northern foreshores between Duck River and Meadowbank Wharf,
- Parts of the foreshores of the Millennium Parklands, and
- Soils around Haslam's and Powells Creeks.

A finger of land projecting inland from the uppermost section of Majors Bay is identified as having a low probability of occurrence for ASS.

Robinson GRC Consulting (1999b) and SKM (1999) also provide an overview of ASS in parts of the study area based on mapping by the Department of Land and Water Conservation (now DECC).

Figure 7.6 also shows locations at which soils are classified as 'disturbed'. This category typically describes lands that have been subject to historic landfill or reclamation works. The large extent of these areas supports the review of historic reclamation works provided by McLoughlin 2000b (refer to **Section 7.3.4**).

7.6 Bank Erosion

On the day of the boat-based inspection of the estuary (28 November 2007) foreshore erosion was evident in a number of locations. These observations are recorded below. In addition, several reports that discuss bank erosion were identified during the literature review.

In general, it appears that bank erosion is an issue throughout the study area. This may be due to a range of factors, including:

- Undermining due to boat wash,
- Ageing infrastructure, the sandstone seawalls in particular,
- High rates of usage of foreshore open space,
- Erosion adjacent to stormwater outlets,
- Coastal processes (such as wind waves), or
- Dredging of navigation channels.

Bank erosion may have flow-on effects on a number of other features of the estuary and may pose a risk to public safety. As noted by PCC (2003f), the key issues relating to the declining condition of seawalls along the Parramatta River estuary are public safety risk, loss of foreshore amenity, property impacts, the loss of significant heritage items and environmental degradation.

The failure to undertake works to mitigate and remediate foreshore erosion stems primarily from a lack of funding, although it is noted that some Councils indicated that they were unsure as to which agency was responsible for maintaining seawalls (e.g. PCC, 2003f). It is understood that generally Councils are responsible for public infrastructure above the MHWM, while infrastructure below the MHWM is owned by the Crown.

Further information relating to specific locations along the estuary is provided below.

WP Geomarine (1998) prepared an appraisal of damage to seawalls along the Parramatta River and determined that damage to seawalls has been the result of undercutting of the banks as the channel has deepened (or been deepened) and moved closer to the shoreline and/or the wave climate has been altered due to the presence and operations of the RiverCat. This was said to have affected both natural and artificial shorelines. A key issue raised in the WP Geomarine (1998) report is that the audits conducted up to that date have only assessed visible damage and that the extent of damage may in fact be greater than indicated (i.e. below low tide level).

Webb, McKeown and Associates (1997) conducted an audit of seawalls along the Parramatta River estuary, with the exception of those contained within the Leichhardt LGA. That study identified a number of foreshore treatments, including natural beaches or rocky shores and vegetated shores. The foreshore was divided into zones and a condition ranking (very good to very poor) was applied to each zone. Mangroves and beaches were also ranked by condition relating to the impacts of erosion. The audit also identified the type, cause and implications of each type of defect or failure and different zones were allocated a priority for repair, for which a remediation option was recommended.

Webb, McKeown and Associates (1997) key findings were as follows:

- Seawalls in exposed locations were subject to boat waves and were in significantly poorer conditions than seawalls elsewhere in the estuary.
- The movement of tides also resulted in the loss of seawall backfill, although primarily in embayments or where stormwater pipes pass through the seawall.
- Mangroves were beneficial in preventing foreshore erosion via dissipation of wave energy and by encouraging siltation.

- Sections of river bank not protected by a seawall were subject to slumping, primarily due to boat wakes, but also due to tidal cycles (wetting and drying) and wave attack. This was particularly problematic adjacent to seawalls or where mangroves are absent.

However, it is noted that this report was prepared over 10 years ago and may not represent an accurate record of the condition of the estuary foreshores at the present time. For example, during the course of consultation with the foreshore councils, a number of locations affected by seawall collapse were identified:

- Portion of the seawall along the Silverwater stretch of Duck River recently collapsed and was replaced (pers. comm., G. Stamatakos, AMC, 2 April 2008).
- There is currently seawall construction being undertaken in Sheppards Bay, along Parsonage Street near the Ryde Bridge (pers. comm., J. Pucci, CoR, 3 March 2008).
- Seawall collapses have occurred at Werrell Reserve in Abbotsford and near the wharf at Chiswick. These areas were repaired in 2007.

It is understood that NSW Maritime currently has in place a program to monitor the condition of foreshore infrastructure, including seawalls, which led to the development of the *Parramatta River Long-term Shoreline Monitoring Study*. However, this study was not complete at the time of preparation. It is understood that boat wash from the RiverCat and harbour ferries has been implicated in shoreline erosion along the estuary (Webb, McKeown and Associates, 2007).

An example of seawall collapse observed on the day of the site visit (28 November 2007) is provided in **Figure 7.7**. **Figure 7.8** shows examples of bank erosion at locations not protected by seawalls.

Upper Parramatta River Estuary

Undermining of the river banks due to wash from the RiverCat is particularly evident along the stretch of the main estuary upstream of Duck River. The subsequent collapse of the banks is leading to the undermining of mangroves in this location. **Figure 7.9** shows photographs taken on the day of the site visit (28 November 2008).

Although observed throughout the study area, it is particularly noted that the Upper Parramatta River Estuary was primarily affected by erosion where the banks have previously been inadequately stabilised with ad hoc materials. On the day of the site visit, a number of such locations were recorded and bank protection material was seen to be falling into the estuary from the banks (see **Figure 7.10**).

PCC (2003f) provide a list of previous seawall audits for the Parramatta River. However, one of the reports referenced, the 1998 *Parramatta River Seawall Damage Appraisal and Addendum* was not available at the time of preparation of this report. The highest risk area within the Parramatta LGA was identified as being a 150m stretch of seawall at Queens Park Wharf (PCC, 2003f). Willing and Partners (2001) had previously determined that remediation works valued at $1.5M were required at this site as a priority due to the apparent level of risk to public safety and both public and private property.

AWACS (1989c) undertook an assessment of foreshore conditions on both sides of the river for the stretch of estuary between Silverwater Bridge and Homebush Bay, also including Homebush Bay. Several sections were identified as being seawalls subject to slumping (AWACS, 1989c). However, it is anticipated that these findings may now be dated and that more up to date information is required.

It is understood that SOPA has also prepared seawall audits and management plans for the stretch of foreshore adjacent to Millennium Parklands (Webb, McKeown and

Associates, 2007). However, this material was not available at the time of preparation of this report.

Mid Parramatta River Estuary

It is understood that CCBC holds an extensive photo archive from 1984 of the foreshore from Hen and Chicken Bay to the western boundary of that LGA. This archive is held in both hard copy and electronic formats, and the photographs have been annotated and are referenced to a map. This material was prepared by the former Concord Council (now amalgamated into the City of Canada Bay).

In addition, anecdotal evidence suggests that there have been no significant changes in the seawalls along the CCBC foreshore since audit undertaken in 1999. The results of that audit were not available at the time of preparation of this report.

7.7 Management Issues

Based on the data compilation and review provided in **Section 7**, a preliminary list of management issues relating to estuary sediments and bathymetry has been compiled:

- **Sedimentation** is thought to have accelerated since European settlement and continues today, affecting the amenity of the waterway.
- **Dredging and land reclamation works** have had a significant impact on the estuary. Dredging conducted in relation to various activities has altered the hydrodynamics of the estuary in some locations, and are also likely to have resulted in disturbance of benthic organism, re-suspension of contaminated sediments and turbidity. Reclamation works have also occurred throughout the study area. Reclaimed lands have typically been filled with contaminated material, further compromising water and sediment quality. As a result, significant areas of wetland vegetation i.e. salt marsh and mangroves have been lost within the estuary.
- **Contamination of estuarine sediments** has resulted from the industrialisation and urbanisation of the Parramatta River Estuary catchment. This is thought to have significant impacts on both ecological and human health, however, the full impact is not at this time fully understood and the cost of remediation is likely to be prohibitive. In addition, processes governing partitioning of contaminants, which may lead to mobilisation of contaminants, are not adequately understood. At present, indications are that bioaccumulation in some recreationally fished species is thought to be occurring.
- **Acid Sulfate Soils** occur in some locations throughout the estuary and have the potential to impact on water and sediment quality, infrastructure and the estuarine ecology.
- **Foreshore erosion and seawall collapse** is occurring at a number of locations throughout the estuary, affecting foreshore amenity, posing a risk to public safety and causing environmental degradation. Efforts to address this issue are hampered by poorly delineated lines of responsibility for maintenance and remediation and a lack of funds.

7.8 Data Gaps

The following data gaps have been identified:

Bathymetry:

- Bathymetric data is available for the whole study area and is considered to be adequate for usage as inputs for understanding of estuary processes, such as hydrodynamics, mixing and flushing. As such, there is no identified data gap within the available information.

Sediment Transport, Sources and Sinks:

- It is anticipated that there is other existing data on sediment grain size that has not been identified during this study. However, there is a need for synthesis of this data in order to assess its adequacy.
- Data on sedimentation rates within the estuary are limited but suggest significant historical sedimentation.
- There is a need to examine/model sediment transport for the estuary as a whole.

Sediment Quality:

- Sediment quality has largely been adequately assessed for the study area, although more detailed studies may be required where estuarine sediments are to be dredged.
- Data is insufficient on the partitioning of contaminants between the sediments and the water column in the Parramatta River Estuary.
- In addition, there is a lack of data on the geochemistry and nutrient flux for estuarine sediments.
- Inadequate information on the effect of sediment quality on the aquatic biota and the applicability of sediment quality guidelines for Australian conditions.

Acid Sulfate Soils:

- More detailed information on the extent of ASS will be required where works that disturb the soils are to be undertaken.

Bank Erosion:

- There is a lack of more recent assessments of bank erosion for both natural and artificial shorelines.

7.9 Further Studies

Below is a list of recommended further studies:

- Compile a database on existing sediment grain size analyses and assess the need for additional sampling.
- Characterise estuarine sediments in terms of grain size, geochemistry and susceptibility to bioturbation.
- Assess sediment transport throughout the estuary.
- Compile a centralised database, to include geo-referenced data, on historic dredging and reclamation activities.
- Quantification of catchment inputs of pollutants including total nitrogen, total phosphorous, heavy metals and total suspended solids.
- Compile a centralised database of all existing studies on sediment quality, to include integration with GIS software.
- Assess partitioning of contaminants between estuarine sediments and the overlying water column for a range of environments found within the estuary.
- Assess nutrient flux in benthic sediments.
- More detailed information on the extent of ASS will be required where works that disturb the soils are to be undertaken.
- Bank erosion assessments should be undertaken in high risk areas (i.e. areas with high velocities, erodible soils or previously identified erosion).

8. HYDRODYNAMICS

In addition to the system bathymetry (**Section 7.2**) the creek and estuary systems are controlled by three major forcing mechanisms:

- Ocean tides,
- Freshwater inflows, and
- Wind and wave driven flows.

Less dominant forcing factors that operate on a local and global scale include:

- Density driven flows,
- Global changes in meteorological conditions, and
- Sea level rise.

Flood control, transport and water supply systems associated with the early settlement to the area have greatly altered the flow of the Parramatta River. Dredging for ferry access has also changed the natural channels of the river, altering the flow conditions. The Charles Street Weir is the limit of tidal influences on the main arm of the river.

8.1 Data Sources

Data sources on the hydrodynamics for the Parramatta River Estuary include:

- AWACS (1993)
- AWACS (1994)
- BoM (2008)
- Cardno Lawson Treloar (2007)
- CSIRO/BoM/AGO (2007)
- DECC (2007c)
- DECC (2008c)
- DNR (2008)
- Forbes and Church (1983)
- IPCC (2007)
- Lawson &Treloar (2000)
- MHL (2004a)
- MHL (2004b)
- MHL (2004c)
- MHL (2004d)
- MHL (2008)
- Olympic Co-ordination Authority (2000b)
- Ranasinghe, Lord*, et al.* (2007)
- SKM (2005c)
- Wolanski (1977)

8.2 Inflows and Outflows

The Parramatta River estuary is constantly open to the ocean and as such the water level within the estuary is primarily driven by the ocean level and the tidal prism. During large catchment flow events water levels within the estuary would temporarily be elevated.

Inflows to the system take the form of:

- Exchange with the ocean (tides),
- Catchment runoff (via stormwater drainage system as well as overland flows),
- Direct rainfall to the surface,
- Sewer overflows, and
- Groundwater.

The primary outflow from the system that balances the inflows is the exchange with the ocean. However, minor outflows are also through evaporation from the surface of the water body.

8.2.1 Exchange with Ocean (Tides)

Tides in the Parramatta River Estuary are semi-diurnal, that is, there are two high and two low tides each day, normally. On rare occasions there may be only one high or low tide because the lunar tidal constituents have a period of about 25 hours. There may also be a significant diurnal difference, that is, a significant difference between successive high tides and successive low tides (Cardno Lawson Treloar, 2007).

The Tidal Limit is defined as the maximum upstream location that a tidal variation in water level is observed. The tidal limits once extended to near Marsden Street at Parramatta, until the construction of the Charles Street weir restricted the tidal influence. In Duck River and Duck Creek, the tidal range has also been limited by weirs at the Clyde Railway Bridge and Martha Street respectively (National Trust, 1976).

In spite of the intrusions to stream courses, the predominant characteristics of Port Jackson tides have not altered through urbanisation. Consequently, present tidal conditions reflect those operating within the estuary before European settlement, both in time and in magnitude. All tidal extremes for the Parramatta River tidal limits are approximately 10 minutes later than at Fort Denison, and their magnitude is virtually the same. Thus there is no tidal wave to speak of, the motion being practically uniform lifting of the water surface (NT, 1976).

MHL (2006) provides a summary of the tidal limits in the Parramatta River estuary. The tidal limits were determined using water level recorders. The tidal limit was determined for a predicted ocean tide high water greater than 1.8m ISLW and no significant fresh water inflow into the estuary. Only waterways with a tidal extent greater than 2km were surveyed.

A summary of the tidal limits is provided in **Table 8.1** and the tidal limits of the estuary are shown on **Figure 8.1**.

Table 8.1 Tidal Limits (MHL, 2006)

BRANCH	DATE RECORDED
Tarban Creek	14/01/02
1.0m rise in creek at old weir, 100m downstream from Manning Road	
Subiaco Creek	20/07/00
Rise in creek, 150m upstream from Victoria Road	
Vineyard Creek	20/07/00
Large rise in creek, 300m upstream from Parramatta River	
Parramatta River	22-23/7/98
Weir at Parramatta	
Duck Creek	22-23/7/98
Tide would get to William Street bridge	
Duck River	22-23/7/98
Large rise on upstream side of railway culvert	
Haslams Creek	7-8/5/00
Tide would get to 350m upstream from Great Western Highway	
Powells Creek	22-23/7/98
100m upstream from Allen Street bridge	
Canada Bay – Unnamed Creek	11/07/02
Tide would get to 20m downstream from Great Western Highway	
Dobroyd Canal / Iron Cove Creek	06/10/00
Tide would get at least to 100m upstream from Parramatta Road	
Hawthorne Canal	06/10/00
Tide would get at least to under railway bridge	

The tidal limits have not been identified for the following tributaries:

- Charity Creek;
- Archer Creek;
- Clay Cliff Creek (assumed to be tidal up to River Road West); and
- Saltwater Creek (assumed to be tidal for its entire length, based on tidal limit of unnamed creek in Canada Bay).

However, all of these creeks (with the exception of Archer Creek) are completely comprised of a concrete lined channel.

It should be noted that as part of the work undertaken by SOPA at Homebush Bay, sections of seawall have been removed allowing natural tidal flushing of wetland areas for the first time in over 100 years (Olympic Co-ordination Authority, 2000b).

The *Estuaries NSW* website (DECC, 2008c) also provides a summary of tidal data for the Parramatta River estuary that has been collected under the Estuary Management Program and its predecessors, in conjunction with Manly Hydraulics Laboratory (MHL, 2004d).

The tidal prism is the volume of water that flows into (flood) and out of (ebb) the estuary during a tide cycle. **Table 8.2** shows the measured tidal prism and local tidal range at the location closest to the entrance of the system (Manns Points to Long Nose Point), along with the tidal range at Fort Denison, Sydney Harbour (DECC, 2008c).

Table 8.2 Tidal Prism Measurements 19 March 1992 (DECC, 2008c)

Tide State	Flow (10^6 m^3)	Local Tidal Range (m)	Fort Denison Tidal Range (m)
Flood Flow	23.77	1.57	1.55
Ebb Flow	27.65	1.62	1.56

A tidal survey is a measurement program run over at least one full tidal period, that is, approximately 12.5 hours. Over this time, tidal characteristics are measured at a number of locations in the estuary consecutively. The tidal characteristics measured include tidal flow and velocity, water levels and physical water quality characteristics such as salinity, temperature, dissolved oxygen, pH and turbidity.

Table 8.3 outlines the tidal surveys that have been undertaken by MHL and the Water Board (now Sydney Water Corporation) for the Parramatta River Estuary. **Figure 8.2** shows the location and plots of the flows and water levels measured within Port Jackson and the Parramatta River Estuary on the 19 March 1992 (MHL, 2004d).

Table 8.3 Tidal Prism Measurements (DNR, 2008c)

Date	Data Collected
1980-01-17	Parramatta River - current metering on 1 line and 3 tideboards.
1980-05-14	Majors Bay - current metering and float tracking.
1980-05-15	Yaralla Bay - current metering and float tracking.
1980-08-22	Hen and Chicken Bay - current metering and float tracking.
1983-02-02	Parramatta River (Silverwater) - tidal discharge and temp/salinity.
1986-01-29	Homebush Bay - drogue tracking, spot velocity readings, suspended sediment samples, bed sediment samples and core samples.

Date	Data Collected
1992-03-19	Port Jackson current metering - tidal discharge monitored at 11 locations (8 with ADCP), water levels at 6 locations plus water quality profiles.
1999-03-02	Tidal gauging on an unnamed left bank side creek of Powells Creek - velocities, water level and an S4 current meter deployed
2002-03-01	Parramatta River water levels at 6 sites from Long Nose Point to Parramatta Weir
2001-01-01	North Newington Wetlands water level monitoring

8.2.2 Elevated Ocean Levels

In the downstream reaches of the Parramatta River Estuary, the peak flood levels are controlled by extreme ocean flood levels and not flood flow levels (SKM, 2005c). The 100 Year ARI ocean level was determined to be 1.42 mAHD (SKM, 2005c).

An estuarine planning level study was undertaken for the Leichhardt Foreshore, which is located at the downstream end of the Parramatta River Estuary (Cardno Lawson Treloar, 2007). The study has produced information on water levels (designated as a still water level) and wave impacts (a short term process) as may be generated by a range of storm events, including the 5, 10, 20, 50, 100 and 200-years average recurrence interval (ARI) design conditions. Nevertheless, in some cases it is possible that the largest waves likely to occur with an elevated still water level are boat waves.

Table 8.4 presents extreme water levels for typical Average Recurrence Intervals (ARI), also derived from the Fort Denison water level records derived by MHL (reported in Cardno Lawson Treloar, 2007). These levels exclude wave setup and relate to locations seaward of the breaker zone.

Table 8.4 Extreme Water Levels in Port Jackson – Fort Denison

Average Recurrence Interval (years)	Water Level M AHD
5	1.24
10	1.29
20	1.34
50	1.43
100	1.45
200	1.50

8.2.3 Outflows

Outflows from the systems take the form of:

- Evaporation from the surface of the water body, and
- Exchange with the ocean (tides).

The tidal behaviour of the estuary has been discussed in some detail in the previous sections.

The closest pan evaporation station is located at Sydney (Observatory Hill) (BoM, 2008). Average evaporation data for this station is shown in **Table 5.4**.

8.3 Water Levels

Water level variations in the Parramatta River Estuary result from one or more of the following natural causes:

- Eustatic and Tectonic Changes
- Tides
- Wind Set-up and the Inverse Barometer Effect
- Wave Set-up
- Wave Run-up
- Fresh Water Flow
- Tsunamis
- Sea level rise
- Global Changes in Meteorological Conditions.

MHL have recorded water level data at four locations within the study area (the locations of the gauges are shown on **Figure 8.3**):

- Powells Creek (May 2001 – Ongoing) (DNR, 2008 & MHL, 2004a),
- Nuwi Wetland (December 2002 – Unknown) (MHL, 2004c),
- Haslams Creek (Jan 1992 – Oct 1995) (MHL, 2008 & AWACS, 1993 & 1994), and
- Wanngal Wetlands (August 2002 – Unknown) (MHL, 2004b).

Limited water level data is available for the following sites in the following documents:

- Powells Creek: July 2003 till 30 June 2004 (MHL, 2004a),
- Nuwi Wetland: December 2002 till 30 June 2004 (MHL, 2004c),
- Haslams Creek: January 1992 till December 1993 (AWACS, 1993 and 1994), and
- Wanngal Wetlands: August 2002 till 30 June 2004 (MHL, 2004b).

All gauges are managed by MHL on behalf of DECC, as such it is expected that additional water level data from these sites can be obtained from MHL upon request.

8.4 Climate Change and Sea Level Rise

Predicted changes associated with climate change include:

- Sea level rise (DECC, 2007)
- Increase in intensity of regular and rare catchment flood events (DECC, 2007)
- Increase in the number of ocean wave storm events (IPCC, 2007)
- Increase in oceanic inundation associated with ocean wave events (Ransinghe et al, 2007)
- Decreases in annual average rainfall (CSIRO/BoM/AGO, 2007, 2007)
- Increases in temperature and solar radiation (CSIRO/BoM/AGO, 2007)
- Increase in sea surface temperature (CSIRO/BoM/AGO, 2007)
- Increases in evapotranspiration (CSIRO/BoM/AGO, 2007), and
- Increases in wind speeds (CSIRO/BoM/AGO, 2007).

The associated effects of sea level rise in the coastal zone may manifest as responses including (for example):

- Coastal groundwater level rise
- Changes to coastal groundwater chemistry (increased salinity)
- Increased tidal dominance of estuaries (and associated marinisation of estuaries).
- Inundation of low lying stormwater drainage infrastructure.

8.5 Hydrodynamics

As early as 1977, hydrodynamic modelling has been undertaken in some form for the Parramatta River Estuary. In 1977, a simple 2 layer box model was developed for the section of the Parramatta River Estuary between the Charles Street weir and the Silverwater Bridge which looked at the fate of stormwater and its effects on the water quality of the estuary (Wolanski, 1977).

As part of preparation of the Australian Sailing Team for the Year 2000 Olympic Games, Lawson and Treloar (2000) undertook numerical modelling of Port Jackson for the Australian Yachting Federation. This model also included the Parramatta River Estuary. However, the bathymetric data used in the model for the majority of the estuary is fairly limited and does not provide a detailed understanding of the currents within the estuary. This portion of the model could be updated with recent bathymetric data for utilisation in the processes study.

UTS have developed a preliminary model based on available bathymetric data for Sydney Harbour and were hoping to integrate this model with a model developed by Sydney Water for the Parramatta River in the 1990's as part of the Governments Clean Waterways Program. However, UTS and Sydney Water are not able to locate this model. As such, the further development of the UTS model will be undertaken as a student research project (Pers. comm. J. Kandasamy, UTS & A. Collins, Parramatta City Council, 17 April 2008).

As part of the development of the UTS model, water and sediment samples were collected from 15 sites within the estuary. At each of these sites, flow velocity and vertical profiles of temperature and salinity were also recorded (Pers. comm. J. Kandasamy, UTS & A. Collins, Parramatta City Council, 17 April 2008).

8.5.1 Tidal Flushing

The mixing of fresh and saline waters through wave action, turbulence or the salt wedge phenomenon that accompanies tidal action within all estuaries is an essential characteristic of these unique environments.

To better understand the fragility of an estuary, the mechanics of tidal action affecting the flushing out, or alternatively the concentration of nutrients, should be noted. A river can be divided into a series of tidal compartments. During a tidal cycle, each compartment receives and transmits a certain volume of water from and to its adjacent tidal compartments. Thus a molecule of water which enters the system at Duck Creek will flow seawards down the creek by tidal exchange and through the freshwater flow forces but will flow upstream on the incoming tide. It continually oscillates backwards and forwards achieving a very gradual gain towards the ocean (National Trust, 1976).

Bays off the main channel play a slightly different role in tidal flushing. Since water enters and leaves the bays at only one point through the rise and the fall of the tide, the tidal mixing tends to be less effective as compared to the main channel. Accordingly, in some bays a particle may just oscillate around a mean position. The convoluted nature of the Parramatta River Estuary provides many opportunities for this occurrence (National Trust, 1976).

8.5.2 Currents

Currents within the Parramatta River Estuary are caused by a range of phenomena, including (Cardno Lawson Treloar, 2007):

- Astronomical Tides
- Winds

- River Discharges
- Coastal Trapped Waves and Other Tasman Sea Processes
- Nearshore Wave Processes
- Density Flows.

The astronomical tides are caused by the relative motions of the Earth, Moon and Sun. 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 to the estuary and mixed oceanic and oceanic/river water from the estuary to the sea. 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; which parameter varies due to the inequality between tidal ranges. The tidal prism is affected by changes in inter-tidal areas, such as reclamations, but not by dredged areas below low tide, such as navigation channels and trenches (Cardno Lawson Treloar, 2007). Additional information on tidal behaviour within the estuary is provided in **Section 8.2.1**.

Wind forcing is applied to the water surface and momentum from the wind is gradually transferred down through the water column. At the surface, wind generated currents are in the direction of the wind, but in the southern hemisphere they gradually turn to the left of the wind direction until they flow in the opposite direction. The Parramatta River Estuary is too shallow for this condition to develop fully and wind driven currents are affected by the estuary bed. Wind driven currents diminish with depth and are greater in more shallow areas (Cardno Lawson Treloar, 2007). Additional information on wind direction and speed is provided in **Section 5.2.13**.

Density currents may be caused by freshwater inflows, for example, when the Parramatta River is in flood. The freshwater is more buoyant and tends to spread across the surface until mixing with the ambient seawater occurs (Cardno Lawson Treloar, 2007).

Coastal Trapped Waves (CTW) are long period wave phenomena that propagate northward along the continental shelf (Forbes et al, 1983). Their origin is not fully understood, but they are believed to originate from the passage of successive high and low pressure meteorological systems across southern Australia. These systems have inter-arrival times varying from 3 to 7 days, typically, and these are the periods of the observed CTW. These waves are irregular and cause approximate coast parallel currents and variations in water levels. They are trapped on the continental shelf by refraction and the Coriolis force. CTW are known to occur on the continental shelf of NSW and will affect observed water levels in the lower reaches of Parramatta River Estuary (Cardno Lawson Treloar, 2007).

8.5.3 Waves

Waves act as an erosive river element and also as an agent in mixing the salt and fresh waters. The most common waves experienced within the Parramatta River Estuary are wind waves. The size depends on the fetch, the velocity and duration of a particular wind. The wave energy generated on the Parramatta River Estuary is reported to be relatively small (National Trust, 1976).

Waves have a dominant direction of wave propagation, directional spread and a wave grouping tendency. 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 the estuary bed contours. Numerical modelling undertaken for Leichhardt LGA foreshore included directional spreading in its simulations (Cardno Lawson Treloar, 2007).

Waves propagating into shallow water may undergo changes caused by refraction, shoaling, bed friction, wave breaking and, to some extent, diffraction. Waves propagating shoreward develop reduced speeds in shallow water. In order to maintain constancy of wave energy flux their heights must increase. This phenomenon is termed shoaling and leads to a significant increase in wave height near the shoreline. Wave breaking occurs in shallow water when the wave crest speed becomes greater than the wave phase speed (Cardno Lawson Treloar, 2007).

Waves propagating through an area affected by a current field are caused to turn in the direction of the current. Wave height is also changed. Opposing currents cause wave lengths to shorten and wave heights to increase and may lead to wave breaking. Within the Parramatta River Estuary, flood and ebb tidal currents will move wave energy focal points. However, strong winds may also occur on flood and ebb currents (Cardno Lawson Treloar, 2007).

Wave modelling was undertaken by Cardno Lawson Treloar (2007) as part of the *Estuarine Planning Levels Study Foreshore Region of Leichhardt*. The modelling found that in some cases, the shoreline of the study area would be sheltered from local sea waves during the severe ocean storms that cause elevated water levels in the Leichhardt LGA. In those circumstances, however, it might still be possible for boat waves to cause significant wave run-up. General wave conditions for large pleasure craft and RiverCat ferries of wave height = 0.5m with a wave period of 5 seconds were adopted where wind wave conditions consistent with ocean storm tide levels were lower.

8.5.4 Winds

Wind affects both the wave and current climates in the Parramatta Estuary. Available wind data is summarised in **Section 5.2.13**.

8.6 Management Issues

The management issues resulting from the hydrodynamics of the estuary are related to the different aspects of each of the section of this report:

- Sediment contamination and transport;
- Flood inundation;
- Stormwater quality impacts on the estuary;
- Water quality impacts on ecology;
- Public safety and health risks; and
- Changes in morphology and the related impacts associated with sedimentation and erosion.

8.7 Data Gaps

Current and wave modelling within the study area is fairly limited. It is understood that UTS is currently undertaking a 2D hydrodynamic model for the estuary and Cardno Lawson Treloar have a 3D hydrodynamic model for the lower portions of the estuary that is currently assisting Sydney University with research projects. However, neither of these models provide enough detail for the entire study area. The UTS model is unlikely to provide sufficient detail to undertake the processes study and the Cardno Lawson Treloar model would need to be extended upstream to provide a higher level of detail for the entire estuary.

The tidal limits are not known for Archer Creek.

8.8 Further Studies

It is recommended that as part of the Parramatta River Estuary Processes Study a hydrodynamic model should be developed which can assess the water quality and sedimentary processes within the estuary. It is expected that this would require the use of a three dimensional (3D) hydrodynamic model. A 3D model is able to look at density differences in the water column. As such, the model can not only assess sediment inputs into the estuary but can also analyse the distribution of the sediments within the freshwater stratification, the mixing and the settlement of sediments. This would be of particular interest in locations where contaminated sediments may be entering or moving around the estuary (e.g. Hawthorne Canal). Due to the variations in depths throughout the estuary and the significantly deep sections (up to -22mAHD) the processes occurring at different depths will be quite different. Deeper sections have the ability for anoxic conditions to develop and large flows can distribute the water from these deeper sections around the estuary. A hydrodynamic model needs to be able to incorporate density variations throughout the water column to be able to assess these issues.

The hydrodynamic model should also assess the impact of climate change on estuarine dynamics, ecosystems and flooding.

As part of the hydrodynamic modelling or through site inspections the tidal limit should be determined for Archer Creek.

9. WATER QUALITY

In general, estuarine water quality processes are dominated by:

- Catchment inputs,
- Oceanic inputs, and
- In-estuary processes.

Catchment inputs include point and diffuse sources. As discussed in **Section 5.8.3**, point sources of pollution may consist of licensed or scheduled premises, sewer overflows or stormwater outlets. Diffuse sources of pollution include urban areas, agricultural areas or leachate from landfills. Contaminated lands may be either point or diffuse sources of pollution, depending upon the manner in which the contaminants are transported off-site and into the estuary.

Inflows from the ocean are likely to be of a good quality and assist with flushing of the estuary. Water is exchanged with the ocean via Sydney Harbour and so ocean inflow quality is impacted by the water quality in Sydney Harbour.

In-estuary processes are complex and involve biological interactions, as well as interactions between estuarine waters and sediments, estuarine waters and the atmosphere. In general, in-estuary processes are strongly influenced by climate and hydrodynamic processes.

Water quality is usually defined in terms of objectives for environmental protection or specific water uses. Appropriate target or trigger values have been set by ANZECC and ARMCANZ (2000) for various water uses including:

- Protection of aquatic ecosystems,
- Primary and secondary contact recreation,
- Aquaculture and human consumers of marine resources (e.g. fish or shellfish),
- Potable water uses,
- Industrial uses,
- Livestock uses, and
- Agricultural uses.

In addition, DECC provides specific water quality and river flow objectives for the Parramatta River (DECC, 2006a). These objectives incorporate the ANZECC and ARMCANZ (2000) guidelines, but also include consideration of the attributes and goals for the Parramatta River estuarine system in particular.

Water quality has been defined for the purposes of this study in terms of:

- Physical parameters – temperature, salinity, dissolved oxygen, turbidity and total suspended solids.
- Chemical parameters – concentrations of phosphorous, nitrogen, heavy metals and pesticides, and
- Biological parameters – faecal contamination indicator organisms and biomass indicators such as chlorophyll-a.

9.1 Data Sources

Data sources on water quality within the Parramatta River Estuary include:

- Anon. (2006a)
- Anon. (2006b)
- ANZECC and ARMCANZ (2000)
- Ball (1995)

- Barry, Taylor and Birch (1999)
- BCC (2006f)
- Birch, Evenden and Teutsch (1996)
- Birch and Taylor (2000a)
- Birch and O'Hea (2007)
- Bishop (2007)
- Cady and Figtree (1972)
- CoR (2004)
- DECC (2006a)
- DECC (2008c)
- DECC (2008d)
- DNR (2006a)
- Ecowise Environmental (2006)
- Gibson (2006)
- Hatje, Rae and Birch (2001)
- Hatje, Apte, *et al.* (2003b)
- Laxton, Laxton and Gittins (2008)
- McCready, Birch and Long (2006)
- McCready, Birch, *et al.* (2006e)
- Revelante and Gilmartin (1978)
- Robinson GRC Consulting (1999b)
- Sydney Water (2006)
- Sydney Water (2007)
- Water Board (1993)
- Woodlots and Wetlands, Molino Stewart Environmental Services, *et al.* (1999)
- (Insert WSROC, 2002)
- WSROC (2002)
- WSROC (2006)
- Wolanski (1977).

Ongoing water quality monitoring sites are shown in **Figure 9.1**.

9.2 Physical Parameters

9.2.1 Oils and Scums

For estuaries associated with urban and industrialised catchments, oils and scums may be introduced to the waterway due to increase road runoff, spills and stormwater discharge.

The presence of detergents and other surface active material can generate foams. These materials can block out light thus preventing plants from generating oxygen. They also inhabit the transfer of oxygen between the atmosphere and the water. Oils depress the natural foaming ability of water. Oils also prevent light from penetrating into the water column and can inhabit oxygen transfer between the atmosphere and the water column. In addition, their breakdown may lead to oxygen consumption, depleting oxygen in the water column. Both oils and detergents are often toxic to biota and furthermore can be poisonous to humans (Cady and Figtree, 1972).

No detailed references regarding oils and scums were found for the Parramatta River Estuary during the research undertaken for this project.

9.2.2 Litter and Floatables

There are a number gross pollutant traps (GPTs) and litter booms installed across the catchment and in the study area. These devices collect gross pollutants such as rubbish and debris from stormwater draining to the estuary. **Figure 9.2** shows an example of litter booms in place at the time of the site visit. In addition to these litter collection devices, it is understood that NSW Maritime has a water-based litter collection program for the Parramatta River estuary. **Figure 9.3** shows the amount of litter removed from the Parramatta River Estuary by NSW Maritime over the period of 1995–2004.

CCBC has a record of volumes of gross pollutants collected from GPTs located in the catchment. **Table 9.1** shows the total volumes of gross pollutants collected from GPTs by Council over three years.

Table 9.1 Volumes of Gross Pollutants Collected from City of Canada Bay Council GPTs within the LGA 2004-2007

Site	Locations	Year		
		2004-05 (Tonnes)	2005-06 (Tonnes)	2006-07 (Tonnes)
1	The Esplanade/ Hendricks Ave Drummoyne	9.9	2.7	9.6
2	Weddle St/ Allison Park, Chiswick	29.2	3.5	10.6
3	Bampstaple Rd, Five Dock	11.3	6.9	7.6
4	Duchess Ave / Noble St Five Dock	8.2	3.6	6.8
5	Walton Cres, Abbotsford	6.5	1.8	12.8
6	Henley Marine Dr / Bent St, Rodd Point	3.4	4.6	2.1
7	Roseby St, Birkenhead Point	5.5	7.9	2.6
8	St Georges Cres, Drummoyne	7.2	6.5	7
9	Edwin St / Victoria Rd, Drummoyne	6.2	5.2	1.7
10	Edwin St / Victoria Rd, Drummoyne	n/a	n/a	n/a
11	Edwin St / Victoria Rd, Drummoyne	n/a	n/a	n/a
12	Drummoyne Oval, Drummoyne	n/a	n/a	3.4
13	Barnwell Park Golf Course, Canada Bay	n/a	n/a	1.2
14	Massey Park Concord	72.4	13.6	111
	Total	**159.8**	**56.4**	**176.4**

With respect to the Ashfield LGA, it is understood that there are two litter booms located at either end of the Dobroyd and Hawthorne Canals, which are maintained by Sydney Water and NSW Maritime (pers. comm, J. Harris, AMC, 26 February 2008). In addition, there are around three GPTs in use around Iron Cove.

It is the responsibility of councils within the catchment area to monitor and manage gross pollutants that may become entrained in stormwater and thereafter make their way to the estuary. Gross pollutants are not only aesthetically unappealing, but also affect water quality where degradation occurs. Little information was identified during the research conducted for this study with respect to gross pollutants. However, given the urbanised nature of the catchment and observations made on the day of the site visit, it is apparent that litter and floatables contribute significantly to water quality issues in the Parramatta River Estuary. It is likely that several other Councils hold information on inputs of gross pollutants into the estuary and this may be sourced if required for any future studies.

9.2.3 Suspended Solids and Turbidity

Suspended solid concentrations provide a measure of particulate inflow, as well as re-suspension of sediments. The presence of suspended sediments in the water column is important for the transport of pollutants attached to particles, and for issues relating to smothering of biota and alteration in aquatic habitat. Turbidity is a measure of light attenuation is due to suspended particulate matter (SPM) and total suspended solids (TSS), which consist of suspended clay and silt, phytoplankton and detritus. High turbidity impacts the aesthetic quality of the water, along with reducing aquatic plant growth.

SPM can originate from point sources such as sewer outfalls, industrial sites and stormwater drains. However, often most of the SPM deposited in estuaries and coastal areas comes from soil and stream bank erosion within the upstream catchment (ANZECC and ARMCANZ, 2000). For this reason, turbidity in most estuaries is highly dependent upon flow, with very large increases noted during flood events. In rivers, SPM concentrations generally increase considerably during the early part of a flood event as sediment is washed into the river from the catchment and deposited sediment is re-suspended (ANZECC and ARMCANZ, 2000).

TSS concentrations and turbidity can fluctuate during periods of heavy rain. Mean TSS concentrations may be reduced during high rainfall and heavy rainfall/high wind conditions, but increase during periods of high-precipitation alone. For example, Birch and O'Hea (2007a) determined that during such conditions there is little variation between typical distributions of TSS for bottom and surface waters within Homebush Bay. However, Hatje *et al.* (2001) analysed the temporal variations in total suspended solids (TSS) at various locations along the Parramatta River Estuary. Their results suggested that anthropogenic influences, such as sediment delivery associated with runoff and stormwater outfalls, cause higher variability at smaller temporal scales.

Diurnal variability of the concentrations of SPM has been assessed within the Parramatta River Estuary at 14 locations from Duck River and Port Jackson. Influences such as water column mixing and bottom sediment re-suspension, are known to contribute greatly to overall turbidity, whilst seasonal influences have some limited effect within the estuary (Hatje *et al*., 20012003b). A number of authors note that the main cause of sediment re-suspension within the estuary is due to the presence of wind waves (particularly during the windy summer months) and that tidal re-suspension of sediments is negligible (Birch and O'Hea, 2007b; Pitbaldo, 1978; Taylor and Birch, 1999; Taylor 2000).

Turbidity levels in Archers Creek (Upper Parramatta River Estuary) have been sampled during spring in both 2006 and 2007 (Sydney Water, 2006 and 2007). During the 2006 sampling period, heavy bank erosion caused the turbidity levels to increase beyond the ANZECC (2000) guidelines. A similar effect was not observed in the following year due to the absence of heavy rainfalls coincident with the sampling times.

Robinson GRC Consulting (1999b) has monitored turbidity levels within the upper reaches of the Parramatta River Estuary over the period of 1990 - 1997. The mean turbidity values for the Parramatta River, downstream of the weir, ranged around 15-20 NTU during dry weather to over 50 NTU following wet weather, due to the influx of suspended sediment associated with bank erosion and overland flow. The mean annual turbidity for the surface waters immediately downstream of the Silverwater Bridge was recorded at 7.7 NTU while bottom waters had turbidities of 21.9 NTU. Turbidity values for the sampling station just downstream of the Gasworks Bridge were of a similar range, with surface waters recording a mean annual turbidity of 13.3 NTU and bottom waters was 21.5 NTU (Robinson GRC Consulting, 1999b).

Bishop (2007) assesses the impacts of bottom sediment re-suspension with regards to turbidity for the Upper Parramatta River Estuary (between Ermington and Rydalmere). The study concentrates on the effects of boat generated waves (wash-waters). This section of the river is heavily utilised by purpose-built low-wash boats, however, other vessels also commonly pass through this area. For this location, turbidity can be directly liked to boat wash and whilst it is stated that there is no significant effect on the sedimentology, the distribution of sediment particles was said to affect water quality, thereby altering the local ecology (Bishop, 2007).

9.2.4 Temperature

Aquatic ecosystem functioning is closely regulated by temperature. Biological, physical and chemical processes, such as oxygen solubility and hydrophobic interactions, are sensitive to temperature changes. Temperature changes can occur naturally as part of normal diurnal (daily) and seasonal cycles, or as a consequence of human activities (anthropogenic). Estuaries, being at the interface between the freshwater and marine environments, are generally quite dynamic environments and this also extends to temperature fluctuations.

Water temperature can have significant effects on various other water quality parameters and may be used as an indicator of human impact within a catchment. Examples include (on a very large scale) the impacts of climate change on atmospheric temperature, the discharge of water from coastal industries and the interference of man made structures such as weirs (DECC, 2008b; ANZECC, 2000).

Laxton (2008) observed surface water temperatures for the Upper Parramatta River Estuary over 2007 at 12 sample sites, with temperatures ranging from 12.2ºC to 25.0^{o}C. Historical data indicates that there has been little variation in water temperatures for the upper reaches of the Parramatta River Estuary (Laxton, 2008).

Robinson GRC Consulting (1999b) also report on estuarine temperature ranges for two locations in the Parramatta River Estuary:

- Immediately downstream of Silverwater Bridge; and
- Immediately downstream of the Gasworks Bridge.

During 1997, average surface water temperatures were 19.0 - 20.1^{o}C and average bottom water temperatures were 19.5 - 20.4^{o}C for these two sites, respectively (Robinson GRC Consulting, 1999b).

Measures of water temperature indicate how much an ecosystem's normal temperature regime is being disturbed by human activities. Cady and Figtree (1972) have identified that an increase in water temperatures was associated with increased rates of biological activity and, therefore, increased rates of consumption of available oxygen. In addition, water temperature markedly effects the concentration of dissolved oxygen, whereby higher temperature waters are able to absorb a lower concentration of dissolved oxygen than colder waters. This may be relevant to summer conditions where high temperatures place a finite limit on the amount of dissolved oxygen (ANZECC, 2000), although this is only likely to be an issue in portions of the estuary that are shallow and/or poorly mixed.

Hatje *et al.* (2003b) has undertaken a comprehensive study of the influence of water temperatures on trace metal concentrations within Parramatta River Estuary. There is strong evidence to suggest that the concentration of dissolved trace metals is correlated to water temperatures i.e. there is a higher concentration of particulate trace metals within warmer water compared with a greater concentration of dissolved trace metals in cooler water. Furthermore, Hatje *et al.* (2003b) makes reference to the seasonal variability of salinity and SPM concentrations. Whilst there was no significant variation in salinity between seasons, SPM proved to be significantly lower during the winter months.

The literature provided a number of data sources relating to water temperatures in the estuary. However, there does not appear to have been a comprehensive study of water temperature variability on an estuary-wide basis. The existing data sets typically represent limited spatial and/or temporal scales. In addition, the available data does not always account for tidal influences and ocean temperature variability.

9.2.5 Electrical Conductivity and Salinity

Salinity or electrical conductivity (EC) is a measure of the total concentration of inorganic ions (salts) in the water column. Salinity is used to measure the total ion (salt) concentration (mainly Na^{+} and Cl^{-}, but also Ca_2^{+}, Mg_2^{+}, K^{+}, $CO_3^{\ 2-}$ and $SO_4^{\ 2-}$) in estuarine and marine waters, with ocean water having a salinity around 35 ppt. EC is typically used to measure the total ion concentration in fresh and brackish waters. Freshwaters are generally considered to have an EC of less than 1000µS/cm. Measures of salinity and EC can be used to indicate whether the chemical nature of aquatic ecosystems is being altered and provides a warning of the potential loss of native biota (ANZECC, 2000).

A range of studies of estuarine salinity have been conducted up to the present day for the Parramatta River Estuary. Robison GRC Consulting (1999b) discusses the direct influence of stormwater on salinity in the upper estuary, or in association with stormwater outlets, whereby freshwater inflows may significantly lower estuarine salinties. However, salt water intrusion associated with oceanic influences is the key driver of salinity within the Parramatta River Estuary, particularly within the lower to middle regions.

The lower Parramatta River Estuary is well mixed under conditions of no precipitation, with salinities equivalent to sea water, but is well stratified after high-precipitation events (Birch and Taylor 2004; Wolanski 1977). At these times, the freshwater will typically sit on top of the water column and the more saline water will be below this freshwater layer. Robinson GRC Consulting (1999b) also notes that surface waters of the lower Parramatta River Estuary are predominately 'fresh' during periods of heavy precipitation.

Catchment geology may also have an influence on estuarine salinity. An assessment of the salinity problems within western Sydney conducted by WSROC (2002) identifies the conflict between managing dry land salinity and the overall water quality of the Parramatta River Estuary. Percolation of water though the saline soil profile is one method for addressing saline soils. However, the saline runoff or groundwater resulting from this process will ultimately enter the waterways, thereby increasing salinities. However, were the amount of infiltration of the percolated waters be minimized, dry land salinity will continue to be evident (WSROC, 2002).

Salinity is a significant parameter in assessing the overall water quality. Salinity is an important environmental factor and may determine the distribution of species within the estuary in relation to their species-specific salinity tolerances.

9.2.6 pH

pH is a measure of the acidity or alkalinity of water, and has a scale from 0 (highly acidic) to 7 (neutral), and through to 14 (highly alkaline). Pure distilled water has a neutral pH of 7. In sea water the pH is buffered to approximately 8.2 by the carbonate salts present. Any substantial departure from this can have severe effects. Freshwater is typically not buffered to any great extent and values from ranging from 5.0 – 8.5 can be encountered naturally.

Catchment geology may have an impact on pH. However, the pH of water within rivers and creeks may also be altered by submerged concrete structures or concrete pipes. Where human structures are in contact with surface waters, the pH may be altered by calcium and magnesium ions leached from concrete structures (Laxton, 2008). ASS can also affect pH, as outlined within **Section 7.4** of this report.

Table 9.2 provides average pH figures for water bodies located along the east coast of Australia draining from urbanised, partially disturbed or undisturbed catchments (Laxton, 2008).

Table 9.2 pH Ranges for Australian Coastal, Estuarine and Freshwater Systems (after Laxton, 2008)

	pH			
	Mean	**Maximum**	**Minimum**	**ANZECC**
Fresh Water				
Undisturbed	7.38	9.07	4.48	6.5 – 9.0
Partially Disturbed	7.56	10.11	5.91	-
Urban Catchments	7.25	10.03	2.6	-

	pH			
	Mean	Maximum	Minimum	ANZECC
Salt Water				
Open Estuaries	7.9	8.63	6.62	7.0 – 8.5
Closed Saline	8.11	9.33	6.94	-
Coastal Waters	8.36	8.55	8.12	7.0 – 8.4

The average pH levels within the upper Parramatta River Estuary are said to have decreased slightly over the period 1990 – 1997 from 8.2 to 7.6 (Robinson GRC Consulting, 1999b). Significantly, the freshwater pH guidelines for the upper Parramatta River as outlined by ANZECC (2000) have not been exceeded over 17 years of sampling, whilst the guideline values for saline waters have only been exceeded on occasions during 1990, 1991, 1995 and 1998 based on data collected by Laxton (2008).

Sampling undertaken in Archers Creek during spring 2006, recorded pH levels above the recommended ANZECC (2000) guidelines on several occasions (Sydney Water, 2006). While a single result above the guideline values is not necessarily an issue, historical data shows that several samples exceeded the recommended guidelines and a management response may be required. Localized variations in pH often are directly related to anthropogenic influences or stormwater influx.

Tidal intrusion in the Parramatta River Estuary can significantly affect the pH. DECC (2008d) presents the tidal limits for creeks and tributaries flowing into the Parramatta River Estuary. The extent of tidal intrusion in the Parramatta River Estuary is addressed in **Section 8.8.2** of this report.

Although tidal intrusion typically affects the full length of the Parramatta River Estuary, modifications of the foreshore and estuary bed, and also freshwater inflows can lead to stratification of the water column producing variations in pH levels throughout the water column. Data is required assessing pH levels throughout the water column over the course of the tidal cycle.

9.2.7 Dissolved Oxygen

The dissolved oxygen (DO) concentration in a waterbody is highly dependent on temperature, salinity, biological activity and the rate of transfer from the atmosphere. Exchange with the atmosphere may be the main source of oxygen in an ecosystem, with this exchange increased under turbulent conditions. Diurnal changes in dissolved oxygen are common due to the presence of aquatic plants, which produce oxygen as a byproduct of photosynthesis during the day, but consume oxygen when they respire at night. The net oxygen input to ecosystems from plants may be quite small. Under natural conditions, DO concentrations may change considerably over a daily (or diurnal) period. Severe DO depletion can occur, particularly in the lower portion of the column where the water column is stratified (ANZECC, 2000).

The Biochemical Oxygen Demand (BOD) is the amount of oxygen consumed by biological and chemical processes. Oxygen consumption is a result of the breakdown of organic material by micro-organisms (Cady and Figtree, 1972).

The solubility of oxygen in water decreases with increasing temperature but the respiratory rate of aquatic organisms increases with temperature. Aquatic ecosystems are thus acutely sensitive to any reduction in DO levels. DO concentrations are often subject to large diurnal and seasonal fluctuations as a result of changes in temperature and photosynthetic rates. Therefore, a DO measurement taken at a single time of the day may not truly represent the oxygen regime in the water body. Many creeks and tributaries of the Parramatta River Estuary record Dissolved Oxygen concentrations outside of the recommended ANZECC (2000) range of 85-110% saturation levels. This suggests the creeks have been influenced by urban pollution for a long period of time (Sydney Water, 2007). Reduction in flow as a consequence of human structures can significantly affect the DO saturation within water bodies. Specifically the weirs, culverts and detention basins found throughout the Parramatta River Estuary catchment collect and pool water, reducing its velocity and raising its temperature, thereby leading to low concentrations of DO and creating poor localised water quality (WSROC, 2006).

The results for water quality parameters measured at Archers Creeks in spring 2006 have been compared with ANZECC (2000) guidelines in Sydney Water (2006). The DO saturation levels for Archers Creek during this period were well below the 85% recommended level within ANZECC (2000) for the protection of aquatic ecosystems for all samples. In October 2006, DO levels fell as low as 41.5% for Archers Creek. These results indicate that the water quality in Archers Creek may be having a severe impact on the survival of aquatic life. However, Sydney Water (2006) attribute the low DO concentrations to the presence of low flows in relation to drought conditions. Furthermore, the accumulation of organic matter in the form of plant debris during this period of low flow was said to increase the BOD within this relatively small stream.

9.3 Chemical Parameters

9.3.1 Nutrients and Nutrient Flux

Natural sources of Nitrogen (N) and Phosphorus (P) include decaying organic matter, weathering of rocks or the leaching of catchment soils. Other sources of N and P include sewage outfalls or overflows, leaching of N and P from cleared land, fertiliser run-off, industrial effluents and agricultural effluents (ANZECC, 2000). The most common forms of N available for plant growth in water are inorganic forms such as nitrate (NO_3^-), nitrite (NO_2^-) and ammonia (NH_4^-). Phosphorus exists in water in both dissolved and particulate forms. Particulate P includes P bound up in organic compounds such as proteins and P adsorbed to suspended particulate matter such as clays and detritus.

Laxton (2008) assessed the mean annual organic nitrogen concentrations within surface and bottom waters for the upper Parramatta River Estuary between 1990 and 2007. **Table 9.3** presents typical total nitrogen values from east coast waterways with the guideline values for the coastal and estuarine and freshwater systems within Australia. Within the upper Parramatta River Estuary, organic nitrogen concentrations were extremely variable and fluctuated between 0 and 2.0mg-N/L. For the majority of locations sampled, organic nitrogen was less than 1.0mg-N/L. Within the freshwater creeks leading into the Parramatta River Estuary, the organic nitrogen concentrations ranged between 0 and 3.0mg-N/L. However, the mean annual organic nitrogen values varied considerably from creek to creek and within the upper Parramatta River Estuary. Some significant variation occurred from year to year, thought to be due to the prevailing climatic conditions i.e. ‘wet’ and ‘dry’ years, although these impacts are thought to be exacerbated by anthropogenic impacts in the catchment (Laxton, 2008).

Table 9.3 Total Nitrogen Concentrations for Australian Coastal, Estuarine and Freshwater Systems (after Laxton, 2008)

	Total Nitrogen Concentrations (TN mg/L)			
	Mean	**Maximum**	**Minimum**	**ANZECC (2000)**
Freshwater				
Undisturbed	0.33	3.82	0.00	0.35
Partially Disturbed	0.40	3.08	0.00	-
Urban Catchments	0.69	12.50	0.00	-

	Total Nitrogen Concentrations (TN mg/L)			
	Mean	Maximum	Minimum	ANZECC (2000)
Salt Water				
Open Estuaries	0.42	3.71	0.01	0.35
Close Saline	0.57	2.70	0.01	-
Coastal Waters	0.24	1.46	0.01	0.10

Orthophosphate concentrations for surface and bottom waters within the upper Parramatta River Estuary showed significant variability from each sampling location and from year to year (Laxton, 2008). **Table 9.4** shows typical total phosphorus (TP) concentrations and guideline values for east coast aquatic systems. Surface water concentrations at four sampling locations within the upper Parramatta River Estuary ranged from 0.010 – 0.088 mg-P/L from 1990 to 2007. Similarly, historical data shows some large variation of orthophosphate-P concentrations in the bottom waters at the same locations, ranging between 0.020 and 0.068mg/L.

Table 9.4 Total Phosphorus Concentrations for Australian Coastal, Estuarine and Freshwater Systems (after Laxton, 2008)

	Total Phosphorus Concentrations (TP mg/L)			
	Mean	Maximum	Minimum	ANZECC
Fresh Water				
Undisturbed	0.05	1.35	0.00	0.02
Partially Disturbed	0.07	1.42	0.00	-
Urban Catchments	0.13	5.89	0.00	-
Salt Water				
Open Estuaries	0.07	0.90	0.00	0.03
Closed Saline	0.06	0.66	0.00	-
Coastal Waters	0.02	0.16	0.00	0.02

Nutrient inputs into the Parramatta River Estuary can be significantly distributed through bottom sediments. Birch *et al.* (1999) assessed the availability of nutrients in fine particle surficial sediments and the distribution within the lower, middle and upper regions of the Parramatta River Estuary as shown in **Figure 9.4**.

Sydney Harbour sediments contain large nutrient stores, but to determine whether they are a substantial source of phosphorus and nitrogen requires further information, for example, on the flux of phosphorus and nitrogen across the sediment and water interface, and on the mechanisms that control uptake and release by bottom sediment of phosphorus and nitrogen, including the role of re-suspension, settling and decomposition of organic material (Birch *et al.,* 1999).

The total concentrations of N and P in the water column are useful measures of the potential for algal blooms but they can often overestimate what is actually bioavailable for plant growth. Moreover, only measuring the concentration of nutrients in the water column does not take into account the fact that some water bodies will have significant stores of N and P in the benthic sediments and associated with SPM. Importantly, the net nutrient concentrations may not change in a particular system but nutrients may still be cycling rapidly from one compartment to another. In particular, the flux of nutrients from the sediment to the water column, and vice versa, is often important (ANZECC, 2000).

9.3.2 Organic Chemicals

Organic contaminants are recognized as a major contributor to the degradation of the aquatic environment. However, their effect on the aquatic environment will be dependent upon their chemical structure. For example, most organochlorine (OC) pesticides are hydrophobic and, therefore, are more commonly enriched in sediments than in the water phase in aquatic environments. Sediments are important carriers of toxicants and can store large volumes of these materials. Sediments also integrate toxicants over time and are thus useful for temporal and spatial studies. Sediments are now being used frequently in the initial phase's environmental assessment to locate areas of possible concern and to determine their potential to act as important secondary sources of contaminants in aquatic environments (Birch *et al.,* 2003b). **Section 7** of this report, further assesses the contribution of organic chemicals through sediment transport.

In general, there is little information on the occurrence of organic chemicals within the Parramatta River Estuary.

9.3.3 Heavy Metals

Heavy metal concentration in waterways is typically attributed to the influx of coarse and fine sediments. Sediments within the Parramatta River Estuary are known to contain high levels of contamination (see **Section 7**).

The results of a study of dissolved heavy metal concentrations in the Parramatta River are presented in **Table 9.5** (Hatje *et al.,* 2003b). Hatje *et al.* (2003b) states that the causes of seasonal variability in dissolved metal concentrations in estuarine waters can be complicated by interrelationships among potential controlling factors and anthropogenic inputs. Dissolved metal concentrations generally show empirical relationships with discharge. However, the significant temporal variation observed (as indicated in **Table 9.5**), is unlikely to be associated with variations in freshwater discharge, since all surveys were undertaken during low-flow conditions.

Table 9.5 Heavy Metal Concentrations within the Upper, Middle and Lower Parramatta River Estuary 1999 – 2001 (after Hatje *et al.,* 2003b)

Survey Date		Ni (µg/L)	Cu (µg/L)	Zn (µg/L)	Cd (µg/L)	Mn (µg/L)
Feb-99	**Average**	0.85	1.97	NS	0.03	14.5
	S.D.	0.41	0.17		0.01	16.9
	Minimum	0.39	1.67		0.01	1.5
	Maximum	1.46	2.23		0.05	52.2
Mar-99	**Average**	0.8	1.63	NS	0.02	19.9
	Std	0.38	0.25		0.01	23.7
	Min	0.18	1.24		0.01	1.4
	Max	1.23	1.94		0.04	64.6
Jan-01	**Average**	0.8	1.98	6.47	0.04	8.1
	Std	0.41	0.48	1.99	0.01	8.6
	Min	0.29	1.27	3.27	0.02	0.3
	Max	1.41	2.55	9.66	0.06	22.0
Jul-99	**Average**	0.87	1.35	NS	0.03	39.2
	Std	0.41	0.28		0.02	41.9
	Min	0.35	0.93		0.01	2.0
	Max	1.45	1.77		0.05	101.0
Aug-99	**Average**	0.9	1.45	NS	0.06	22.6
	Std	0.47	0.32		0.03	23.1

Survey Date		Ni (µg/L)	Cu (µg/L)	Zn (µg/L)	Cd (µg/L)	Mn (µg/L)
	Min	0.36	1.07		0.03	2.0
	Max	1.61	1.85		0.10	58.9
Sep-99	**Average**	0.91	1.73	NS	0.07	15.9
	Std	0.41	0.23		0.03	18.0
	Min	0.37	1.51		0.02	1.4
	Max	1.38	2.07		0.1	48.3

NS = Not Sampled

Concentrations of Mn and Ni were significantly lower in summer than in winter. This variation in Mn concentrations possibly reflects the oxidation of Mn (II) to Mn (IV). During winter, Mn showed a preference for the dissolved state, whereas during summer, on average, Mn was in the particulate state (Hatje, *et al*., 2003b).

Based on a comparison with other coastal and estuarine systems in Australia and overseas, Hatje *et al.* (2003b) determined that the concentrations of a range of heavy metals, including Ni, Cu, Cd, Zn and Mn, were higher in the Parramatta River than for any of the other locations examined.

Table 9.5 provides a comparison of dissolved heavy metal concentrations in the Parramatta River Estuary and other coastal and estuarine waters (Hatje *et al*., 2003b).

Stormwater runoff from extensive urban and industrial development within the catchment has adversely impacted the quality of water and sediments within the Parramatta River Estuary (Birch, 1999). The ability of the estuary to disperse and flush pollutants is largely dependant upon fresh water inputs, tidal flow and the storage capacity of the estuary below the tide level. Heavy metals are concentrated within tributaries and creeks, and are subsequently transported into the estuary during high flow conditions. Contaminants (such as heavy metals) are exported as a discrete surface layer, partitioning from a particulate to a dissolved phase upon mixing with the more saline estuarine waters (Barry, Taylor *et al*., 1999).

As well as diffuse catchment-based sources, there are also pollutants associated with particular locations which may run off or be leached into the estuary, thereby compromising water quality. Rezoning for redevelopment of former industrial sites generally requires a contamination assessment, which facilitates the process of remediation of contaminated lands. However, it is likely that there remain a number of foreshore sites from which leachates enter the estuary. It is understood that there are significant water quality impacts in the estuary with Chromium VI being leached into the estuarine waters behind Thackery Street (behind Numbers 37 and 39) in Camellia (pers. comm, Environmental Health Officer, PCC, 14 February 2008). The source is thought to be associated with known 'hotspots' associated with historic land filling activities and is thought to have migrated into the groundwater. It is understood that waters contaminated with Chromium VI may also rise to the surface after rainfall. It is noted that there is a sensitive receptor in the form of a mangrove forest immediately downstream of the affected area.

9.4 Biological Parameters

9.4.1 Faecal Coliforms

Faecal Coliform (FC) bacteria are natural inhabitants of the guts of mammals and birds. The presence of these organisms in water can be used as an indicator that the water is contaminated by faecal material. In addition to FC, enterococci can be used as a faecal contamination indicator. FC typically enter urbanised estuaries through stormwater outfalls, overland flow and more specifically, sewage overflows (including known locations such as pumping stations and unknown locations such as cracked pipes). Faecal contamination decreases the overall water quality and limits safe recreational water usage. The trigger values of FC contamination within recreational waters (marine and freshwater) are as follows:

- Primary contact - 150 faecal coliform organisms/100mL
- Secondary contact – 1,000 faecal coliform organisms/100mL (ANZECC, 2000).

Robinson GRC Consulting, (1999b) noted that there are several sewer overflow sites which drain directly into the Parramatta River Estuary, including:

- Brush Farm Park (off Marsden Road), Eastwood;
- Brush Road and Tramway Street, West Ryde;
- Lambert Park (off Lambert Street), West Ryde;
- Denistone Park (off Terry Road), Denistone;
- Symons Reserve (off West Parade and between Darvall and Denistone Parks), Denistone;
- Darvall Park(off Chatham Road), Denistone;
- Sir Thomas Mitchell Reserve(off Alexander Street);
- Dundas Valley;
- 98 Kissing Point Road, Dundas;
- 272 Kissing Point Road, Dundas;
- Anthony Road, West Ryde;
- 22 Station Street, West Ryde;
- 28 Station Street, West Ryde;
- Constitution Road, Meadowbank;
- Cobham Street, West Ryde;
- Low Level Pumping Station 105 Meadowbank Park;
- Meadowbank;
- Addington Street, West Ryde; and
- Parkes Street, West Ryde.

The present status of the overflow sites listed above is not known and these overflows may have been rectified under the Sydney water Sewerfix program. Furthermore, there is no additional information regarding other known locations of sewer overflow. Known overflow sites within Sydney and the greater metropolitan region are recorded by Sydney Water as part of the Environmental Protection Licence Conditions issued by DECC.

The City of Ryde Council carried out a water quality monitoring program during 2004 which incorporated five boat ramp launching sites on the Parramatta River. The monitoring involved the collection of water samples and analysis for FC. ANZECC (2000) guidelines were used to identify the suitability of the area for primary and secondary contact. The results indicate that all sites sampled along the Parramatta River failed to meet the primary contact guidelines, but were able to meet the secondary contact recreational guidelines.

FC and enterococci monitoring have been undertaken by Sydney Water and DECC under the EPA Harbourwatch Program for a number of known swimming sites within the lower Parramatta River Estuary (Woodlots and Wetlands, 1999) including;

- Dawn Fraser Pool;
- Cabarita Beach;
- Henley Baths; and
- Greenwich Baths.

Harbourwatch data over the period of 1996/1997 showed 100% compliance with primary contact guidelines. Woodlots and Wetlands (1999) also note that 47% of FC within the lower Parramatta River Estuary is an outcome of sewer overflows.

DECC (2008) also has ongoing water quality monitoring programs at the abovementioned sites. DECC's website (http://www.environment.nsw.gov.au/beach/hbrupd.aspx) provides a simple notification of predicted bacteria levels and the suitability of the location for primary contact. The website is updated daily and makes one general assessment for the entire Parrramatta River Estuary.

9.4.2 Phytoplankton and Chlorophyll-a

Chlorophyll-*a* can be used as a non-specific indicator of the trophic status of a waterbody, i.e. where high concentrations of chlorophyll-*a* are observed, it is reasonable to assume that high nutrient levels have contributed to the biomass of algae in that waterway. Chlorophyll-*a* concentrations are often used as a general indicator of plant biomass because all plants contain about 12% (dry weight) chlorophyll-*a* (ANZECC, 2000). However, there is not always a clear relationship between chlorophyll-*a* concentration and cell number or biomass because of inter- and intra-specific variation (ANZECC, 2000).

WSROC (2006) note that the weirs, culverts and detention basins located throughout the Parramatta River Estuary catchment can be affected by algal blooms. For the Parramatta River Estuary the mean chlorophyll-*a* concentrations in surface and bottom waters varied from 0 - 150mg/L over the period from 1990 to 1997 (Robinson GRC Consulting, 1999b).

Revelante and Gilmartin (1978) provide a study of the phytoplankton levels within the Parramatta River Estuary. Sampling was undertaken throughout the Parramatta River Estuary and into Sydney Harbour at 16 locations (nine of which fall within the study area). That study found that the extent and the nature of phytoplankton blooms can be assessed based on the location within the estuary i.e. upper, middle, lower estuary. Revelante and Gilmartine (1978) stated that the three basic characteristics of phytoplankton communities (rates of primary production, chlorophyll-*a* standing crops, and cell densities) all showed increases with progression up the estuary. **Table 9.6** outlines the rates of primary production and chlorophyll-*a* concentrations as used to classify regions of phytoplankton within the Parramatta River Estuary.

Table 9.6 Defining Characteristics of Phytoplankton within Parramatta River Estuary (after Revelante and Gilmartin, 1978)

	Mean rate of primary production (mg C m^{-3} h^{-1})	Mean standing crop of chlorophyll-*a* (mg chl-*a* m^{-3})
Lower estuary	11	1.8
Middle estuary	54	8
Upper estuary	127	17

The three regions of the estuary had production rates and crop values typical of a spectrum ranging from inshore coastal regions to shallow eutrophic embayments, with the upper estuary clearly receiving an enhanced nutrient supply (Revelante and Gilmartin,1978).

This analysis was based on samples and data collected following an extended period (> 30 days) without rain and consequently with little freshwater inflow to the Estuary. Under these conditions the oceanic influence was at a maximum, horizontal gradients were emphasized and the effects of local nutrient regeneration were most easily evaluated (Revelante and Gilmartin, 1978). With no coastal upwelling occurring, the nutrients necessary to support the high standing crops and rates of primary production observed were thought to be of local origin, although the possibility of 'nutrient trapping' could not be eliminated. Given the low input of nutrients from river inflow and local runoff, the most probable source of nutrients was *in situ* regeneration, perhaps from an accumulation of introduced organic compounds in the sediments (Revelante and Gilmartin, 1978). It was considered difficult to determine whether these compounds were of historical or contemporary origin. However, in either case, Revelante and Gilmartine (1978) determined that nutrients (apparently derived from their re-mineralisation) supported relatively high standing crops of phytoplankton.

With respect to more problematic groups of plankton, it is understood that eutrophication has lead to numerous outbreaks of the toxic blue-green algae within the Parramatta River Estuary (WSROC, 2006). This renders the waterway toxic for human contact and for animal consumption. While public amenity is impacted upon during an algal bloom event, there can be significant impact upon some user groups.

Red algal blooms have also been a problem in the upper estuary in the past. The causes of the blooms are unclear but appear to be related to high nutrients, low oxygen levels and poor flushing of the system (WSROC, 2006).

The Metropolitan and South Coast Regional Algal Coordinating Committee (RACC) is an organisation that assists in the monitoring and management of algal bloom Parramatta River Estuary. In conjunction with ANZECC and the National Health and Medical Research Council (NHMRC), the RACC have established recreational guidelines for algae. The guidelines utilise a colour coded warning system based on algal concentrations, ranging from Green to Amber and Red (red being the highest levels of alert).

The NHMRC algae guidelines for coastal waters for recreational uses are only based on a few species due to limited knowledge on toxic algae. Red Level mode is triggered when *Karenia brevis* levels exceed 10 cells/mL or when *Lyngbya* or *Pfiesteria* species are in high numbers (http://www.naturalresources.nsw.gov.au/water/algae_guidelines.shtml, accessed 18 June 2008).

Furthermore, the RACC within the department of Water and Energy issue media releases for algal blooms in recreational waters. The process of issuing an algal alert is as follows:

- Recreational sites are monitored for algae by local councils, trusts, water supply authorities and the member departments of the RACC.
- Results of algal monitoring are sent to the Regional Algal Coordinating Committee (RACC).
- When the level of blue–green algae in a recreational water body is greater than the recreational guideline a high alert is issued by the RACC, and a media release is sent to the media and to relevant State and Local Government representatives.

Algal warning signs are another method which the RACC has adopted to warn the public about water quality and suitability for primary contact.

The literature search undertaken for this study failed to identify any further studies of phytoplankton or chlorophyll-*a* concentrations in the estuary. In particular, contemporary studies of phytoplankton dynamics in the Parramatta River Estuary are lacking.

9.5 Illegal Dumping and Spills

The Parramatta River Estuary is infrequently affected by spills and illegal dumping. However, there is little information directly reporting illegal spills and dumping within the Parramatta River Estuary. Staff from PCC stated that records of spills occurring in the portion of the estuary located within Parramatta LGA are held by PCC (pers. comm, Environmental Health Officer, PCC, 14 February 2008). In addition, Council staff have indicated that the portion of Duck River near the Parramatta Speedway has historically been used as an illegal dump site (e.g. car batteries or rubbish) (pers. comm, Environmental Officer, PCC, 14 February 2008).

In 2007 CSR were charged in relation to breaches of the *Pollution of the Environment Act* in relation to an incident affecting the Parramatta River in 2006. Around 1000 litres of the gluey chemical acrylic polymer, used in paint, clogged the river between Rydalmere and Olympic Park in July 2006. While the white residue was not toxic to humans, it caused devastation to local plants and wildlife, while ferries were cancelled for two days during the clean-up (Anon, 2007c).

It is understood that illegal chemical spills have been recently documented within the media (Anon., 2006a and b; Gibson, 2006). DECC have established a contact reference list with regards to water pollution (www.environment.nsw.gov.au/water/, accessed 18 June 2008).

9.6 Management Issues

Water quality management issues within the Parramatta River Estuary which have been identified as an outcome of this report include:

- **Primary Contact** – Based on data collected under DECC's Harbourwatch program, the waters of the estuary are often unsuitable for primary contact recreation due to high FC counts. Also of concern is the presence of organic chemical and heavy metal contaminants.
- **Secondary Contact** – Overall there are only limited areas of the Parramatta River Estuary which would be considered suitable for secondary contact.
- **Eutrophication** – Human activities within the catchment have significantly altered nutrient inputs and nutrient flux within the estuary. It is noted that a major shift from diffuse to point sources of nutrient inputs (such as urban stormwater outfalls) has occurred over the past 50 years.
- **Sediment Contamination** – Increased urbanisation and industrialisation of the catchment has increased the diversity and the range of contaminants entering the estuary. Sediment quality in and around the Parramatta River Estuary has a major influence to the overall water quality and aquatic biodiversity. Variation in water temperature and salinity due to human interference can affect the transition of contaminants into the water column (i.e. from a particulate to a dissolved state).
- **Tidal mixing** – Extensive alteration to the estuary foreshore and its tributaries has affected some locations, for which the mixing of the water column has been reduced. This can have significant impacts on water quality and the ecological characteristics of the estuary.
- **Gross Pollutants** – The high levels of gross pollutants observed within the estuary indicate that the existing network of GPTs is insufficient. Urbanised catchments produce vast amounts of litter, which can blow directly into the estuary or be entrained in stormwater runoff and make its way to the estuary via creeks. Trapped litter can be unsightly and dangerous to many aquatic species.
- **Illegal dumping and spills** – Dumping and spills significantly contribute to the total amount of pollution within the Parramatta River Estuary. However, there is little publicly available information on this issue. Catchment monitoring at a local council scale may assist in reducing the amount of illegal pollution entering the Parramatta River Estuary.

9.7 Data Gaps

The following data gaps have been identified with respect to water quality:

- Whilst there have been a number of studies conducted in the Parramatta River Estuary with respect to water quality, these are highly variable in terms of quality and spatio-temporal scales. As a result, a comprehensive, estuary-wide data set on water quality is lacking.
- Faecal coliform data for the lower, middle and upper Parramatta river estuary is limited to a small number of sites and does not adequately characterise the water quality of the estuary.

- In particular, there is a limited amount of information which deals with water quality in the lower Parramatta River Estuary. The vast majority of data makes reference to water quality issues throughout the middle to upper Estuary. Many studies generalise the water quality of the entire Estuary and therefore cannot appropriately account for localised influences in the lower estuary. The effects of saline/brackish water intrusion from Port Jackson and moreover the Pacific Ocean are rarely addressed.
- Limited data is available that quantifies the influx of organic and inorganic chemicals to the estuary.
- There is little information on how nutrient levels affect the estuarine ecology.
- There is no comprehensive assessment of volumes and types of gross pollutants being delivered from the catchment.
- There is little information as to how alterations to the estuary foreshore and its tributaries impact on mixing and other water quality processes in the estuary.
- There is little information available on the extent of water quality issues associated with oils and scums.

9.8 Further Studies

General:

- An analysis of the effects of anthropogenic influences on tidal mixing within the estuary is required.

Physical Parameters:

- There is limited information addressing the extent of impacts associated with oils and scums within the Parramatta River Estuary. Further assessment is needed to identify significant sources and the effect of these pollutants on water quality.
- The existing quantitative data on gross pollutants within the Parramatta River estuary should be incorporated into a centralized database (where available). This should include the numbers, types and locations of GPTs within the catchment, along with quantity and type of material removed, as well as other incidental litter collection, such as that undertaken by NSW Maritime and on Clean Up Australia Day. This would facilitate a more coordinated approach to the management of catchment-based controls on gross pollutants.
- The turbidity data collected to date only provides a snap-shot of the spatio-temporal variation in concentrations of suspended particulate matter and total suspended solids, and therefore yields a poor estimation of overall water quality.
- The significance of water temperature in relation to aquatic ecosystem health and water quality is not well understood. The effects of human activities on water temperature and the subsequent effects on the estuary may require assessment.

Chemical Parameters:

- Quantification of organic and inorganic chemical influx into the estuarine system is required. Whilst there is limited information outlining the inputs as a response of sedimentation, such studies need to be expanded upon in order to account for the transition of chemicals and heavy metals into the water column.
- Further studies are needed within the Parramatta River Estuary with respect to nutrient dynamics. Where data exists it is commonly limited in spatio-temporal extent. A more extensive analysis may incorporate the effects of nutrient inputs at both a local and a catchment scale. This may include defining the nutrient budget of the estuary and the potential for eutrophication and/or algal blooms.

Biological Parameters:

- The extent and sources of faecal contamination within the Parramatta River estuary needs to be assessed with regards to both primary and secondary contact. Outlining potential hotspots and local catchment areas which may require further attention is a priority. An up to date catalogue of sewer overflow points is also required.

10. ECOLOGY

10.1 Data Sources

The following databases were searched for information on flora and fauna:

- Australian Museum FaunaNet (http://faunanet.gov.au/)
- BioNet (http://www.bionet.nsw.gov.au/)
- DECC *Threatened Species Conservation (TSC) Act* Database (http://www.threatenedspecies.environment.nsw.gov.au/)
- DPI – Fisheries FishNotes Database (http://www.dpi.nsw.gov.au/aboutus/resources/factsheets/fishfacts)
- Environment Protection and Biodiversity Conservation (EPBC) Act Protected Matters Search Tool (http://www.environment.gov.au/biodiversity/threatened/)
- NSW NPWS Wildlife Atlas (http://wildlifeatlas.nationalparks.nsw.gov.au/wildlifeatlas/watlas.jsp)
- Botanic Gardens Trust PlantNet Database (http://plantnet.rbgsyd.nsw.gov.au/).

In addition to these online database searches, the following data sources relating to *flora* have been identified:

- Vegetation mapping provided by DECC and the Sydney Metro CMA
- Adam (1991)
- Adam (1993)
- Allen, Benson*, et al.* (2007)
- Burchett and Pulkownik (1995a)
- Burchett and Pulkownik (1995b)
- Chapman (2004)
- Clouston (1994a)
- DEAP (1986c)
- DIPNR (2003b)
- Earth Tech (2008)
- Eco Logical (2005)
- Fairfull and Witheridge (2003)
- Hamilton (1919)
- Ian Perkins Consulting (1994)
- Kelaher, Underwood and Chapman (1998a)
- Kelleway, Williams and Allen (2007)
- Laegdsgaard (2006)
- MacFarlane (2002)
- MacFarlane and Burchett (2000)
- MacFarlane, Pulkownik and Burchett (2003)
- McLoughlin (2000a)
- Melville and Pulkownik (2006)
- Melville, Pulkownik and Burchett (2005)
- MHL (2006)
- Olympic Co-ordination Authority (1995a)
- Olympic Co-ordination Authority (1996a)
- Olympic Co-ordination Authority (1996b)
- Paul (2001)
- Paul (2005)
- Paul and Loveridge (2001)
- Paul and Young (2005)
- Paul, Young and MacKay (2006)
- PCC (2002d)
- PCC (2003a)
- Revelante and Gilmartin (1978)
- Robinson GRC Consulting (1999b)
- Rogers, Saintilan and Cahoon (2005)
- Rogers, Wilton and Saintilan (2006)
- Saintilan and Williams (1999)
- Saintilan and Williams (2000)
- Schaeper, Torrible and Burns (2007)
- SKM (2003)
- SKM (2005a)
- SMCMA (2008a)
- SMCMA (2008b)

- Thorogood (1985)
- West, Thorogood, *et al.* (1985)
- West, Williams and Laird (2004)
- West and Williams (2008)
- Williams (1990)

The following data sources relating to *estuarine fauna* have been identified:

- Alquezar, Markich and Booth (2006a)
- Alquezar, Markich and Booth (2006b)
- AMBS (1993)
- Bartlett (2007)
- Berents (1993)
- Bishop (2004)
- Bishop and Chapman (2004)
- Bishop (2007)
- Cogger (1995)
- Cogger (2005)
- Courtenay, Gladstone and Schreider (2005)
- DEAP (1986c)
- DEC (2005)
- DPI (2004)
- DPI Fisheries (2002)
- DPI Fisheries (2005)
- DPI Fisheries (2006a)
- DPI Fisheries (2007a)
- Flannery, Parnaby and Tasker (1993)
- Greer (1994)
- Hughes, Recsei, *et al.* (1997)
- Hurst (2006)
- ICPMR (2007)
- Jones and Frances (1988)
- Kelaher, Chapman and Underwood (1998b)
- Leary (2007)
- Liggins, Kennelly and Broadhurst (1996)
- Lincoln-Smith, White and Hawes (1994a)
- Lincoln-Smith, White and Hawes (1994b)
- Lloyd, Monaco and Metten (2006)
- Mazumder, Saintilan and Williams (2006)
- McCready, Greely, *et al.* (2005)
- Morris, Tyler, *et al.* (1990)
- NSW Food Authority (2006)
- NT (1976)
- Olympic Co-ordination Authority (1995b)
- Olympic Co-ordination Authority (1996a)
- Olympic Co-ordination Authority (1996b)
- Parkland Environmental Planners, Pod Landscape Architecture, *et al.* (2008b)
- Paul (2007)
- Paxton and Collett (1975)
- Pyke (1995)
- Roach and Runcie (1998)
- Robinson, Gibbs and Van Der Velde (1983)
- Rubinstein and Wicklund (1991)
- Safe (2000)
- Saunders (2008)
- SOPA (2006a)
- SOPA (2006b)
- SOPA (2007b)
- SOPA (2007c)
- SOPA (2007d)
- SOPA (2007e)
- SOPA (2008f)
- Straw (1993)
- Straw (1996a)
- Straw (1996b)
- Straw (1998)
- Taylor (1994)
- Taylor, Taylor and Larmour (1996)
- The Ecology Lab (1992)
- The Ecology Lab (1993a)
- The Ecology Lab (1993b)
- The Ecology Lab (1993c)
- The Ecology Lab (1993d)
- Urban Bushland Management Consultants Pty Ltd (2006)
- Water Board (1993)
- Woodford (2004b)
- Woodlots and Wetlands, Molino Stewart Environmental Services, *et al.* (1999)

The following data sources relating to *introduced species* have been identified:

- AMBS (2002)
- Flannery, Parnaby and Tasker (1993)
- SMCMA (2008b)
- SOPA (2008e)
- Urban Bushland Management Consultants Pty Ltd (2006)

The following data sources relating to *threatened species* have been identified:

- Mapping provided by the Sydney Metro CMA
- DPI Fisheries (2007b)
- SOPA (2008e)
- Urban Bushland Management Consultants Pty Ltd (2006)

However, it must be noted that many of these studies are restricted by duration and/or areal extent. It is recommended that existing mapping and data be integrated into a standard format and compiled in a meta-database.

The following studies represent spatio-temporally limited surveys of flora and fauna in the study area. These studies have typically been undertaken as part of a larger flora and fauna assessment or environmental impact assessment. They have been grouped (where possible) into the relevant zone in which their respective study areas fall as listed below:

- *Upper Parramatta River Estuary* – Biosphere Environmental Consultants (2006); Urban Bushland Management Consultants (2006).
- *Mid Parramatta River Estuary* – Greer (1994), Pyke (1995).
- *General* – DEAP (1986c); Hughes, Recsei, *et al.* (1997); NT (1976); Woodlots and Wetlands, Molino Stewart Environmental Services, et al. (1999).

It is understood that Sydney Olympic Park Authority has made a commitment to undertaking long-term biodiversity monitoring in the park. This is thought to represent the only ongoing monitoring of flora and fauna in the study area.

10.2 Flora

Flora species records were compiled for each foreshore LGA based on a search of the NPWS Wildlife Atlas conducted on 13 December 2007. The full results of that search are provided in **Attachment 4**. This data has been summarised in **Table 10.1**. In terms of floral diversity, the most diverse LGA is Parramatta, closely followed by Auburn and Ryde LGAs. The least diverse was Ashfield. This is likely a function of the small areas of open space and also poor reporting for that LGA.

Table 10.1 Flora Species Records for the Parramatta River Estuary

LGA	Number of Species
Ashfield	0
Auburn	313
Canada Bay	45
Hunters Hill	109
Leichhardt	143
Parramatta	324
Ryde	288
Strathfield	46

10.2.1 Riparian Flora

The riparian environment describes those terrestrial flora and fauna that live in the catchment adjacent to waterways, but above the tidal range (e.g. above mean high water).

Royal Botanic Gardens in partnership with Sydney Metro CMA, NSW Maritime and NSW DPI has undertaken mapping of foreshore (riparian) vegetation (Allen, Benson, *et al*., 2007), as shown in **Figures 10.1** to **10.3**. Allen, Benson *et al.* (2007) provide the following details with respect to the mapping:

- All discernable plant communities were mapped commencing within the first 40m of the MHWM to their end or at least 200m landward from MHWM,
- Terrestrial communities were classified based as per the Cumberland Plain 1:16,000 vegetation map,
- Vegetation was assessed based on orthorectified aerial photography and ground-truthing, and
- Also included were vegetation cover, condition and structure.

It is noted that in Allen, Benson, *et al.* (2007), mangroves and saltmarsh have been classified as foreshore/riparian vegetation. However, for the purposes of this study, these two vegetation categories have been classed as aquatic flora due to the fact that these are intertidal communities (i.e. are inundated by the tide and/or recruit via waterborne propagules) and, therefore, are discussed in **Section 10.2.2**. This Section of the report makes reference only to that vegetation above the mean high water mark.

In terms of riparian vegetation, the maps prepared by Allen, Benson, *et al.* (2007) show that “Turf/man-made hard surface” and “Garden/weeds” are the prevalent vegetation categories (see **Figures 10.1** to **10.3**). It is evident that the foreshores have been highly modified and that where vegetation is present, it is composed primarily of exotic species. Native vegetation, where it occurs, is present in small isolated patches scattered throughout the study area.

It is understood that the Councils within the study area foster restoration of riparian vegetation through partnerships with local volunteer Bushcare Groups. A list of Bushcare Groups known to operate in the study area is provided in **Table 10.2**. Guidelines for bush regeneration in western Sydney have been prepared by DIPNR (2003b).

Table 10.2 Local Bushcare Groups

LGA	Bushcare Sites / Groups	Meeting Times
City of Canada Bay	Queen Elizabeth II Park, Concord	1st and 3rd Wednesday of the month, 9am – 12pm during daylight savings time, otherwise 12-3pm
	Lovedale Place, Concord West	
	Prince Edward Park, Cabarita	3rd Thursday of the month, 9am – 12pm
	Sisters Bay and Half Moon Bay, Drummoyne	Last Saturday of the month, 8.30am – 12 pm
	Figtree Bay Reserve, Chiswick	2nd Saturday of the month, 9am-12pm
Auburn	Duck River	2nd Saturday of the month, 9am – 12pm
Parramatta	Mighty Duck River Restoration	3rd Saturday of the month, 9am – 12pm
	Vineyard Creek Reserve Park Committee	3rd Saturday of the month, 1 – 4pm
	Friends of Duck River Bushland	3rd Sunday of the month, 8.30am – 12pm

LGA	Bushcare Sites / Groups	Meeting Times
	George Kendall Bushcare Group	3rd Sunday of the month, 9am – 12pm
	Rapanea Community Forest	4th Saturday of the month, 9am – 12pm
	Duck Down after Work	Last Friday of the month, 10am – 12pm
Leichhardt	Elkington Park	4th Saturday of the month, 9.30am-12pm
	Callan Park	1st Saturday of the month, 9.30am – 12pm
	Rozelle Bay	Every Wednesday and Friday, 8.30am – 2pm
Strathfield	Mason Park, Homebush Bay	Unknown
Hunters Hill	Friends of Kellys Bush	Every Monday, 8.30 – 11 am
	Tarban Creek Community Action Group	1st Sunday of the month, 9 – 11.30am
	Friends of Betts Park and Gladesville Reserve	2nd Saturday of the month, 9.30 – 11.30am

It is important to note that this list may not be entirely comprehensive, with records based on discussion with the various Councils.

As discussed in **Section 5.7**, the remaining natural vegetation in the catchment is not infrequently associated with creeklines. A number of vegetation assessments have been undertaken in the study area; however, many of these studies were undertaken several years ago. A summary of these studies is provided below:

- Newington, RAN Armaments Depot (Adam, 1991)
- Upper Parramatta River estuary (Clouston, 1994a; Ian Perkins Consulting, 1994; Urban Bushland Management Consultants Pty Ltd, 2006)
- Along the River (DEAP, 1986c)
- Lynch, Spence and Pearson (1976).

The key issues raised in these reports include loss of riparian vegetation due to reclamation works and/or clearing and the prevalence of exotic species. Where riparian vegetation is present, it is typically in poor condition and fragmented and therefore has poor habitat value.

More recent studies are discussed below.

PCC (2002d) provides an overview of historic changes in riparian flora and fauna since European settlement and notes a general trend towards degradation of riparian habitat until recent years. Parramatta City Council's Rivers of Opportunity document (PCC, 2002d) establishes a range of goals, objectives and strategies for managing waterways within the LGA.

McLoughlin (2000a) provides an overview of changes in foreshore vegetation along much of the estuary over the period 1788 to 1940 based on an assessment of a variety of materials including historical records and cartographic mapping. However, this study primarily focuses on estuarine vegetation (saltmarshes and mangroves). Further discussion on McLoughlin (2000a) is provided in **Section 10.2.2**. Ian Perkins Consulting (1994) also includes some historical accounts of vegetation present in the Parramatta and Homebush Bay areas during the early period of European settlement. Historical accounts provided in these studies agree that vegetation along the river was much more extensive than it is today.

SKM (2003) conducted an assessment of riparian vegetation in the Lower Parramatta River catchment which included a literature review of the role of riparian vegetation. However, this study covered only a portion of the study area. A summary of their findings is presented in **Table 10.3**. Several of these creekline corridors were recommended for incorporation into vegetation corridors (SKM, 2003).

Table 10.3 Brief Overview of Riparian Vegetation in the Lower Parramatta River catchment (after SKM, 2003)*

Watercourse	Condition of Riparian Vegetation
Parramatta River (from Merrylands to the Ryde Bridge, excl. the Homebush Bay area)	• Overall the vegetation is comprised of numerous large and small stands of mangrove vegetation, dominated by the Grey Mangrove (*Avicennia marina*), although small stands and isolated individuals of the River Mangrove (*Aegiceras corniculatum*) were also evident. Width 1-50m. • Small pockets of saltmarsh in the areas behind the mangrove vegetation were in poor condition. Size range 1-40m^2. • Small stands and individuals of Swamp Oak (*Casuarina glauca*) were also evident. Generally this community type was extremely fragmented. • Areas of riparian/floodplain forest containing Cabbage Gum (*Eucalyptus amplifolia*) and Rough-barked Apple (*Angophora floribunda*) were present, but again in a highly fragmented state and infested with weeds. • There were also small areas of poor quality vegetation containing rainforest elements.
Duck River	• The majority of vegetation consisted of areas of dense mangrove forest, dominated primarily by Grey Mangrove with small areas of River Mangrove. The width of the riparian zone formed by these mangroves was 10-30m and was fairly consistent along the length of Duck River until the constructed weir near the rail bridge. • A moderately large area of high quality saltmarsh was present in the vicinity of Derby Street, Silverwater, containing several significant flora species. • Scattered remnants of the original riparian species were evident, albeit intermingled with numerous introduced species. • Small intact sections of sedgeland were present in the vicinity of the junction of Duck Creek.
Vineyard Creek	• The area contains a small section of mangrove forest near the confluence of Vineyard Creek and Parramatta River. • Small sections of relatively intact riparian woodland are also present. This vegetation is dominated by Eucalypts, is degraded and exotic species are also present. It appears that some restoration works had been done at the time.
Subiaco Creek	• Beyond a small stand of Grey Mangroves near the confluence of the creek and the Parramatta River, the riparian vegetation is of very poor quality with only a few scattered shrubs and trees present. The majority of the remaining vegetation consists of exotic species.
Duck Creek / A'Becketts Creek	• Stands of mangroves are present in the intertidal zone, forming a buffer of 15-25m width. • Further upstream of this point few, if any, native species are represented. Areas of replanting have been initiated.
Archer Creek	• This is primarily a constructed drainage line containing a small stand of Swamp Oak Forest. • Remnant trees and scattered stands of riparian forest are also present, with representative species being Sydney Blue Gum (*Eucalyptus saligna*) and Turpentine (*Syncarpia glomulifera*).

* It is noted that this study includes mangroves and saltmarsh as riparian vegetation. However, this classification has not been used herein. Mangroves and saltmarsh are discussed further in Section 10.2.2.

A *Toongabbie Creek Waterways Maintenance and Rehabilitation Masterplan* has been prepared by PBP and EDAW (2002), although it is not known at what stage of implementation this masterplan is currently at.

PCC (2003a) have also prepared a masterplan for Vineyard Creek, which provides details of activities required for management riparian vegetation. It is apparent that weeds are a significant problem and require a range of management actions. Revegetation and bushfire management are also required with respect to the Vineyard Creek riparian vegetation.

In addition, it is understood that PCC has commissioned consultants to conduct a waterways prioritisation study for the Parramatta LGA. To date, a report has been prepared discussing the methodologies (Eco Logical, 2005), which will include an estimate of the percentage of each waterway that has riparian vegetation.

Sydney Metro CMA in partnership with Auburn and Parramatta City Council, has recently completed an *Icon Area Project* for Duck River near Webb Avenue Playing Fields, Auburn, and Mackay Road, South Granville. This project involved weed control, revegetation works and preservation of remnant native vegetation, including a portion of the endangered ecological community, Cooks River Casuarina Ironbark Forest.

It is understood that a Management Plan has been prepared for wetlands located on the site of the Shell (Refining) Australia Pty Ltd refinery located at Clyde (Pers. comm., Environmental Advisor, 3 June 2008). It is assumed that this refers to freshwater wetlands. However, this Management Plan report was not available at the time this study was undertaken and cannot be commented on in more detail.

It is apparent that, within the study area, much of the riparian vegetation has been lost through the urbanisation of the catchment. The existing vegetation is typically degraded and infested with weeds, although there are ongoing efforts by Councils and other organisations to improve the condition of riparian vegetation.

10.2.2 Intertidal and Aquatic Flora

NSW DPI – Fisheries, in partnership with the SMCMA, NSW Maritime and the Royal Botanic Gardens have recently mapped aquatic flora for the Parramatta River (West, Williams and Laird, 2004). This mapping has been presented in **Figures 10.1** to **10.3**. West, Williams and Laird (2004) mapped the following types of aquatic flora, defined as vegetation occurring within or below the intertidal zone: mangroves, saltmarsh, seagrass and kelp. The distribution of each of these different types of aquatic flora is discussed below.

It is understood that this study represents the first instance in which kelp has been mapped for Port Jackson. However, analysis of the mapping indicates that there are no kelp beds located in the Parramatta River estuary.

West, Williams and Laird (2004) also present a comparison of this mapping with a survey conducted in 1985 by West, Thorogood, *et al.* (1985).

There are several resources that survey aquatic flora for a specific location within the study area as listed below:

- *Mangroves and saltmarsh:* George Kendall Riverside Park (Burchett and Pulkownik, 1995a), Charles Street Weir to Silverwater Bridge (Robinson GRC Consulting, 1999b), Charles Street weir to Ermington Bay (Clouston, 1994a), Homebush Bay (Berents, 1993; Burchett and Pulkownik, 1995b).
- *Saltmarsh:* RAN Armaments Depot, Newington (Adam, 1991), north-eastern shore of Iron Cove (Earth Tech, 2008), Homebush Bay (Adam, 1993), mid-upper Parramatta River Estuary (SKM, 2003 and 2005), Shell Refinery site, Rosehill (Urban Bushland Management Consultants, 2006).

A number of other resources also discuss the extent and condition of aquatic flora within the general study area:

- *Both mangroves and saltmarsh:* DEAP, 1986c.
- *Saltmarsh:* Kelleway, Williams and Allen, 2007.

The condition of mangroves and saltmarsh for the Lower Parramatta River was also considered by SKM (2003) in their study of riparian vegetation (refer to **Table 10.3** for details).

Some of those studies listed above are quite dated and may not accurately reflect the present situation. However, historical surveys may be used to gain an indication of any changes in the extent and/or condition of aquatic vegetation.

The Bicentennial Park and Newington estuarine wetland complexes have been assessed under a Wetland Prioritisation Technique developed by Schaeper, Torrible and Burns (2007) for the Sydney Metro CMA.

It is understood that CCBC have prepared an estuarine vegetation management plan for the Canada Bay LGA that incorporates vegetation mapping and management actions. However, that management plan was not available at the time this report was prepared.

It is understood that mosquitoes are associated with wetlands located in the study area. This is discussed further in **Section 10.3.4**.

Estuarine Vegetation and Climatic Cycles

The potential impacts of global climate change are discussed in **Section 8.4**. Any future changes in sea level, wave climate and/or rainfall patterns are likely to have significant impacts on estuarine vegetation either directly (e.g. dessication/inundation due to sea level rise) or indirectly (e.g. changed estuarine morphology as a result of altered hydrodynamic regime). This issue is discussed with reference to NSW estuaries by Williams (1990). However, the effects of climate on aquatic vegetation can also be assessed with respect to climatic processes occurring over shorter timeframes, such as the El Niño-Southern Oscillation.

MHL (2006) notes that changes to the upstream extent of mangroves may be used as a biological indicator of changed salinity gradients and tidal regimes due to alterations to freshwater flows, tidal hydrodynamics and sea level rise.

Rogers, Saintilan and Cahoon (2005) conducted a study in Homebush Bay that assessed vertical accretion and surface elevation change rates as a guide to understanding mangrove die-back. They determined that repeated drought cycles may have significant detrimental impacts on the structure and function of mangroves and, therefore, their long-term sustainability. Placing their findings in the context of climate change, Rogers, Saintilan and Cahoon (2005) identified sub-soil processes, such as organic matter accumulation and groundwater flux, as being important for the sustainability of mangrove forests under sea level rise scenarios.

Paul (2001) proposes a simple, cost-effective method for mapping tidal limits in small mangrove forests, trialled in Homebush Bay. Where any assessments of tidal limits are required as part of any future studies in the Parramatta River Estuary, this method may be applicable.

10.2.2.1 Saltmarsh

Figures 10.1 to **10.3** show the extent of saltmarsh habitat within the Parramatta River estuary. The major concentrations of saltmarsh are in Yaralla Bay*, Bicentennial Parklands*, Millennium Parklands*, Wilson Park, at Rosehill at the confluence of the Parramatta and Duck Rivers and along Duck River opposite the Shell site*. Those locations marked with an asterisk are listed Endangered Ecological Communities under the TSC Act.

The three saltmarsh meadows located by West, Thorogood, *et al.* (1985) (two at Homebush Bay and one at Duck River) are still present in the most recent survey (West, Williams and Laird, 2004). However, the survey by West, Williams and Laird (2004) was based on aerial photography and Kelleway, Williams and Allen (2007) have subsequently demonstrated that that survey may have failed to identify small patches of saltmarsh. Ground-truthing led to the identification of additional saltmarsh patches that were obscured by the plant canopy. Kelleway, Williams and Allen (2007) also includes an assessment of the condition of each patch of saltmarsh and observed site-specific impacts. Most of the saltmarshes within the study area were deemed to be in poor condition.

Threats to saltmarsh, as identified by Kelleway, Williams and Allen (2007), include:

- Public access,
- Dumping, mowing and pollution,
- Altered tidal regime due to engineering works (e.g. weirs),
- Displacement by stormwater infrastructure and declining salinity due to stormwater discharges,
- Incursion by mangroves,
- Weeds,
- Sea level rise, and
- Lack of a comprehensive management arrangement for saltmarshes along the Parramatta River Estuary.

Sensitive species located in the study area included the threatened species, *Wilsonia backhausei*, as well as *Selliera radicans**, *Lampranthus legens* and *Halosarcia pergranulata subsp. Pergranulata** (Kelleway, Williams and Allen, 2007). Those species marked with an asterisk are not known from any locations outside of the study area. Three of these rare species, W. backhausei, L. legens and H. pergranulata, were assessed in terms of their survival and growth patterns in Homebush Bay (Burchett and Pulkownik, 1995b).

Saltmarsh communities are defined in floristic terms for Homebush Bay by Adams (1993).

Hamilton (1919) provides an overview of saltmarsh ecology with specific examples from the study area. While this document is somewhat dated, it may prove useful for providing historical context relating to the study area.

Mangrove Incursion into Saltmarsh Areas

Mangrove encroachment into saltmarsh areas is not only a problem along the Parramatta River, but has also been observed in other estuaries in NSW (Laegdsgaard, 2006).

Saintilan and Williams (1999 and 2000) and Laegdsgaard (2006) provide a discussion on mangrove incursion into saltmarsh areas and suggest a number of mechanisms by which this process may occur, including:

- Increased average annual precipitation,
- Sea level rise,

- Increased freshwater inputs,
- Colonisation of areas previously cleared and used for agriculture,
- Alterations to the tidal regime,
- Increased delivery of sediments and nutrients in association with human activities in the catchment, and
- Subsidence in the intertidal zone.

For example, bike riders have been implicated in damaging saltmarshes located in Yaralla on the grounds of the Thomas Walker Convalescent Hospital (pers. comm, P. Nelson, CCBC, 27 February 2008).

It is understood that SOPA has a program of removing mangrove seedlings found within saltmarsh areas within Sydney Olympic Park.

Rogers, Wilton and Saintilan (2006) suggested that mangrove encroachment on saltmarsh may be facilitated by local factors contributing to saltmarsh compaction during drought conditions. That study included Homebush Bay as one of seven study sites. This has implications for the present distribution and condition of saltmarsh along the Parramatta River Estuary, given that drought conditions have prevailed in recent years (see **Section 5.2.13**).

Saltmarsh Reinstatement / Revegetation

Laegdsgaard (2006) reports that saltmarsh restoration efforts in Australia have typically focussed in actions such as fencing to prohibit access by cattle, diversion of stormwater away from saltmarshes, weed removal and restoration of tidal inundation. That study also provides a literature review of the success of such programs in Australia, and also provides some information on transplantation as a restoration technique (Laegdsgaard, 2006).

Leichhardt Municipal Council has recently investigated the feasibility of extending the small, isolated patches of saltmarsh found around the margins of Iron Cove. Earth Tech (2008) determined that the foreshore immediately west of Callan Point would be suitable for this purpose, while maintaining public access and recreational requirements. It was noted that, where seawalls have collapsed or are otherwise in disrepair, there was an opportunity to reinstate saltmarsh via integration with the need to repair or replace the seawall. An example is illustrated in **Figure 10.4**, as observed in the region of Rydalmere on the day of the site visit (28 November 2007).

Earth Tech (2008) note that the main impediments to reinstating saltmarsh vegetation around Iron Cove are reclaimed lands (for which remediation is likely to be required and costs are likely to be high) and land availability. Where land was available, it was in a narrow strip running parallel with the foreshore and would therefore be highly susceptible to edge effects. These issues are likely to be an issue throughout the study area.

Examples of saltmarsh reinstatement projects previously undertaken within the study area are also provided in Earth Tech (2008). An overview of these projects is provided below:

- *Federal Park, Leichhardt (LMC)* – A fenced-off area was excavated to facilitate tidal inflow (1.6-2.0m tides) and saltmarsh species planted. The saltmarsh is now well established. However, it is thought that catchment inflows high in nutrients have stimulated the growth of filamentous algae.
- *Haslams Creek, Homebush Bay (SOPA)* – During the widening and ‘naturalisation’ of Haslams Creek, saltmarsh was established along the creekline at various elevations within gabion lined terraces. However, unauthorised vehicle traffic, poor soils and insufficient tidal inundation have left several areas devoid of vegetation. Ongoing trials are being undertaken to develop a method for addressing some of these issues.

In 1995 Burchett and Pulkownik (1995a) provided recommendations for the restoration of saltmarshes in George Kendall Reserve focussing on weed eradication and re-vegetation with native species. The detailed outcomes of that program of restoration are unknown.

Burchett and Pulkownik (1995b) undertook saltmarsh transplantation studies of six species found within Homebush Bay. Their findings could be applied to propagation of saltmarsh for transplantation as part of saltmarsh revegetation activities.

10.2.2.2 Mangroves

Figures 10.1 to **10.3** show the extent of mangroves within the Parramatta River estuary (after West, Williams and Laird, 2004). Mangroves are found along much of the foreshore above the confluence of the Parramatta and Duck Rivers, along the northern bank between George Kendall Riverside Park and John Whitton Bridge, in Millennium and Bicentennial Parklands and in Brays, Yaralla and Majors Bays. Scattered stands of mangroves are also found throughout the Parramatta River Estuary.

According to West, Williams and Laird (2004), the mangroves found in the Parramatta River Estuary represent the most substantial stands of mangroves in Port Jackson and it is thought that there has been a considerable increase in the extent of mangrove cover over the last 20 years since the survey by West, Thorogood, *et al.* (1985).

There are some other studies assessing historic changes in the extent of mangrove cover in the Parramatta River. McLoughlin (2000a) assessed changes in the extent of estuarine wetlands along the Parramatta River between 1788 and 1940, based on written, cartographic and other historical material. That study indicates that mangroves appear to have increased in extent at the expense of other estuarine vegetation (e.g. saltmarsh). For example, McLoughlin 2000a states that, for the upper estuary between Subiaco Creek and Parramatta, there is no evidence of mangroves until the 1870's. McLoughlin (2000a) attributes the extensification of mangroves to increased sedimentation, expansion of mud flats and consequent recruitment of mangroves after settlement of the area by Europeans.

Thorogood (1985) goes on to assess changes in the extent of mangroves from 1930 to 1985, based on historical aerial photography. A net increase in mangrove cover was observed. Any losses of mangroves were typically due to reclamation and/or drainage of tidal lands, while the processes governing mangrove extensification were more complex (Thorogood, 1985). However, an increase in mangrove cover in Homebush Bay was said to be due to the construction of drainage channels into mangroves and adjacent tidal land, thereby increasing the area available for mangrove colonisation (Thorogood, 1985).

Advice from Shell (Refining) Australia Pty Ltd indicates that the growth of mangroves along the Duck River and Parramatta River over the last 20 years may be assessed using aerial photographs held by that company (Pers. comm., Environmental Advisor, 6 June 2008).

It is important to note that mangroves fulfil a number of ecological functions, such as the provision of habitat, nutrient cycling, primary production, acting as nursery grounds and shoreline protection. For these reasons, mangrove forests represent important habitat and their expansion in the study area does not necessarily equate to being a negative process, except where it comes at the expense of other intertidal habitats such as saltmarsh or mud flats (i.e. where the affected mud flats represent important habitat for wading birds). In addition, it is important to differentiate naturally occurring changes in vegetation patterns from those occurring as a result of human activities.

The propagation of both normal and suspected-albino propagules of Grey Mangrove (*A. marina*) was trialled at Sydney Olympic Park by Paul and Loveridge (2001). It is understood that albinism may occur in mangroves as a result of gene mutations associated with contamination. Normal propagules were more easily propagated, however, plants grown from both normal and albino propagules did not differ in rates of deformities (Paul and Loveridge, 2001). These findings should be considered in the context of levels of contamination in the study area.

Mangroves and Pollution

Given the contamination status of the Parramatta River Estuary sediments and water column (see **Sections 7.4** and **9**), it is appropriate that some studies relating to the effects of various pollutants on aquatic vegetation have been conducted within the study area.

The links between heavy metal contamination of estuarine sediments and bioaccumulation in mangroves have been outlined by MacFarlane (2002). Bioaccumulation of heavy metals in the leaves of *A. marina* was variable, dependent upon sediment concentrations and the co-occurrence of other heavy metals. However, accumulation of lead in leaf tissues was not as common as for copper and zinc (MacFarlane, 2002; MacFarlane, Pulkownik and Burchett, 2003). MacFarlane (2002) also showed that bioaccumulation of heavy metals has the potential to affect photosynthesis by causing changes in leaf chlorophylls (a and b), carotenoids and the antioxidant enzyme peroxidase. Other studies show that heavy metals also accumulate in the roots of *A. marina* (MacFarlane and Burchett, 2000; MacFarlane, Pulkownick and Burchett, 2003). However, metals vary in terms of the rate at which they are accumulated in mangrove roots and/or leaves in relation to, for example, the sedimentary concentration or pH (MacFarlane, Pulkownik and Burchett, 2003). In addition, metals may be excreted through pores found in the leaves of the mangrove in association with salt excretion (MacFarlane and Burchett, 2000).

The abovementioned studies highlight the importance of mangroves in the removal of metals and other pollutants, which can lead to improved water quality. However, this process has important implications for mangrove ecology as many fauna species (e.g. crabs, benthic infauna) consume fallen mangrove leaves, and are themselves consumed by other species, which may lead to bioaccumulation up the food chain.

Mangrove Boardwalks

Boardwalks may be used in the management of mangrove forests to facilitate public access, while minimising damage to the mangrove forest and associated fauna. Mangrove boardwalks have been constructed at a number of locations in the study area and some studies have been conducted focussing on their ecological impact, although most of these studies examine impacts of fauna, rather than the mangroves themselves.

In a study of two mangrove forests, one of which was located in Homebush Bay, Kelaher, Chapman and Underwood (1998a) found that the density of pneumatophores, cover of leaf litter and proportion of root-material in sediments were significantly greater away from the boardwalk, when compared to areas close to the boardwalk. These findings indicate that boardwalks have a detrimental impact on mangrove forests.

The feasibility of facilitating public access to the mangrove forest in George Kendall Riverside Park was investigated by Burchett and Pulkownik (1995a).

It is understood that mangrove boardwalks are currently (or have previously) been considered by several of the Councils located along the estuary foreshore. However, it is understood that for some locations, due at least in part to the fact that the environmental impacts were determined to be much greater than was originally anticipated, these plans have been discontinued (Pers. comm., Open Space and Recreation Officer, PCC, 14 February 2008). However, if uncontrolled public access through mangroves is an issue, boardwalks are likely to at least control access and limit impacts to a small section of the mangrove forest. They also have many other benefits such as allowing easy access for public appreciation and educational purposes.

Mangrove Undermining and Collapse

During the site visit, bank erosion and consequent mangrove undermining and collapse was observed at a number of locations (refer to **Section 7.6** and **Figure 7.8**). The general consensus appears to be that boat wakes are the chief cause of mangrove subsidence and the RiverCat has been implicated by a number of individuals / organisations. The mangroves in the upstream extent of the Parramatta River Estuary are affected to a large extent by this issue and it is noted that this location is coincident with the restriction of boat traffic to the RiverCat (and any other authorised vessels). However, it is understood that no explicit assessments linking changes to the hydrodynamic regime and the RiverCat have been undertaken to date. A representation was made to the relevant local and state Government agencies by NSW Maritime on the findings of a long-term wash monitoring study for the Parramatta River and trials relating to bank protection works, but the results have not been made publicly available to date.

However, there are several studies relating to the impacts of boat wash on mangrove ecology in the Parramatta River Estuary. These focus on the macrobenthic infauna and are discussed in **Section 10.3.6**.

Mangrove Removal

More recently there have been issues with damage caused to mangroves located in the study area by residents (Pers. comm., D. Wiecek, DECC, 28 November 2007). This issue has been raised by a number of local councils.

It is understood that there is a perception in the community that mangroves are unsightly, emit odours and are mosquito breeding sites. In many cases, stands of mangroves obscure water views. The latter point is thought to be the primary motivation for mangrove removal by residents. Mangroves may be removed by uprooting seedlings or by cutting down larger trees, poisoning is also commonly used to kill and remove mangroves. It is noted that a permit is required under the *Fisheries Management Act* 1994 for the removal or destruction of any marine vegetation, including mangroves. However, enforcement of this regulation is difficult as mangrove trees are usually vandalised or removed overnight and it is exceptional that an offender can be identified.

On the day of the site visit (28 November 2007) a number of affected stands of mangroves were observed, as shown in **Figure 10.5**. In being unable to identify the offenders, many local Councils install large signs in place of the removed mangroves noting the vandalism and observing that this is an illegal activity under the *Fisheries Management Act*. An example is shown in **Figure 10.5**.

Consultation with Council's indicated that this was a somewhat ineffective method of enforcement. Erection of the signage was said to lead to complaints by residents that their view was being obstructed and consequently the signage typically remains in place for only a short time (Pers. comm., N. Bertus, City of Canada Bay Council, 27 February 2008).

Particular locations known to be affected by mangrove vandalism include:

- Canada Bay LGA – The Esplanade, Henley Marine Drive, Halliday Park on Winston Parade and Kendalls Inlet on Breakfast Point (Pers. comm., N. Bertus, Canada Bay City Council, 27 February 2008).

10.2.2.3 Seagrass

As shown in **Figures 10.1** to **10.3**, seagrass has been recorded in the study area in Iron Cove, near Spectacle Island, Drummoyne Bay, Five Dock Bay and Hen and Chicken Bay.

Small isolated patches of seagrass are also scattered in some other locations throughout the Lower Parramatta River Estuary, chiefly towards the southern shoreline. The largest seagrass beds are found in Hen and Chicken Bay.

According to West, Williams and Laird (2004), seagrasses found within the study area are mainly represented by monospecific beds of *Zostera*, followed by beds of *Zostera* mixed with other species (*Posidonia* and *Halophila*).

As discussed by West, Williams and Laird (2004), those seagrass beds located in Iron Cove, Five Dock Bay and Hen and Chicken Bay were not previously recorded by West, Thorogood, *et al.* (1985). This is thought to be due to high turbidity in the river at the time of survey and subsequently prevents analysis of any historic changes in seagrass cover.

West and Williams (2008) built upon the study by West, Williams and Laird (2004) by considering historical changes in seagrass mapped as part of the latter study in 2003, and comparing this to mapping of seagrass derived from aerial photography taken in 1978 and 1986. Seagrass cover was estimated at 50ha based on surveys conducted in 2000 and 2003, but was much greater in 1986 at 87.4ha and in 1978 at 59.4ha (West and Williams, 2008). Significantly, data collected to the present date indicate that the Parramatta River Estuary has the highest cover of seagrass at 70-80% when compared to other locations in Sydney Harbour.

The geomorphic and hydrodynamic characteristics of the estuary were found to be key determinants of seagrass distribution, with little seagrass present in the upstream sector of the estuary represented by the 'Riverine Channel' or 'Fluvial Delta' (West and Williams, 2008). Instead, seagrass predominated in the 'Central Mud Basin' or 'Tidal Delta' of the estuary.

A secondary objective of West and Williams (2008) was to develop a predictive model of the distribution of seagrasses in the Parramatta River. A range of factors likely to influence the distribution of seagrasses in the study area were listed in terms of the type of disturbance and occurrence of disturbance. Predictive modelling indicated that there were considerably more parts of the Parramatta River Estuary suitable for seagrass growth than were actually colonised, although it is noted that the model did not account for factors such as proximity to point sources of pollution and may therefore overestimate the extent of locations suitable for seagrass growth (West and Williams, 2008).

West and Williams (2008) determined that exposure to stormwater and/or physical damage remain the key threats to seagrasses and need to managed appropriately, and suggested that any future works involving modification of the foreshore and/or bed of the estuary be assessed in terms of the potential for seagrass to grow in those locations, rather than the actual presence of seagrasses.

No other resources were identified with respect to seagrasses. Where seagrasses are mentioned in the resources listed in the reference list, little specific or applicable information is provided.

10.2.2.4 Macroalgae

There are a limited number of resources relating to the occurrence and ecology of macroalgae in the Parramatta River Estuary. However, it is understood that macroalgal blooms have previously occurred in the wetlands located in the Sydney Olympic Park complex. Chapman (2004) notes that these algal blooms typical arise in poorly flushed wetlands within the park and may cause odours and other problems. The factors causing these blooms include rates of algal growth and mortality, as well as the rates at which algae may arrive from another location or are flushed away by flowing water (Chapman, 2004).

There were no clear relationships between nutrient concentrations and algal bloom conditions.

However, macroalgae are also known to occur naturally in the estuary and may be epiphytic on other species. Spatial and temporal patterns of variation in macroalgae epiphytic on Grey Mangrove (*Avicennia marina*) pneumatophores were studied at three sites along the Parramatta River estuary: Powells Creek, Brays Bay and Duck River (Meville, Pulkownik and Burchett, 2005). Interestingly, zonation amongst macroalgae species occurred, with individual species dominating at different positions within the intertidal zone. The intertidal position was the key determinant of algal frequency and biomass (Melville, Pulkownik and Burchett, 2005). These findings highlight the importance of maintaining suitable habitat within the full tidal range and are likely to have implications for the distribution and abundance of grazer species.

In other studies, macroalgae have been assessed for use as indicators of estuarine contamination. The distribution and abundance of macroalgae epiphytic on mangroves were compared to water and sediment metal concentrations, nutrient concentrations and physio-chemical parameters for a number of sites in NSW, including one located in the Parramatta River Estuary (Melville and Pulkownik, 2006). The key findings of Melville and Pulkownik (2006) are as follows:

- Macroalgal diversity and distribution was highly influenced by contaminant concentration,
- Macroalgal biomass was linked with nutrient concentrations,
- The Rhodophyta species, *Catenella nipae* Zanardini, showed high potential for use as an indicator of heavy metal contamination.

Melville, Pulkownik and Burchett (2005) also identify species that may be used as bioindicators of estuarine pollution.

These findings have important implications for the Parramatta River Estuary in terms of identifying and prioritising areas requiring impact mitigation. In addition, locations affected by heavy metal contamination may be differentiated from those affected by nutrient pollution, which may also assist in source identification.

It is understood that the SMCMA and NSW DPI – Fisheries are currently mapping the instream vegetation of the Parramatta River and that this information is likely to be available in late-2008 (Pers. comm., L. Diver, SMCMA, 3 June 2008).

10.2.2.5 Phytoplankton

Information on the phytoplankton ecology of the Parramatta River Estuary is very limited and is restricted largely to plankton sampling conducted as part of various water quality monitoring programs.

A study by Revelante and Gilmartin (1978) investigated primary productivity and characterised the phytoplankton community of Port Jackson and the Parramatta River Estuary. The study was conducted during low flow conditions (>30 days without rain) when the estuary was under a high degree of oceanic influence. During these conditions, nutrients were not limiting and processes such as predation and competition were the primary drivers of phytoplankton community dynamics (Revelante and Gilmartin, 1978). Those phytoplankton species forming the majority of the microplankton species sampled from surface waters by Revelante and Gilmartin (1978) were: *Thalasiosirra rotula*, *Chaetoceros compressus*, *Skelenonema costatum*, *Chaetoceros socialis* and *Chaetoceros didymus*. It is noted that this study represents a "snap shot" in time and cannot in itself be considered a comprehensive assessment of the phytoplankton ecology for the Parramatta River.

Phytoplankton is discussed with reference to water quality in **Section 9.4.1**. In addition, **Section 9.4.1** also makes note of historic instances of red algal blooms.

10.3 Estuarine Fauna

Fauna species records were compiled for each foreshore LGA based on a search of the NPWS Wildlife Atlas conducted on 13 December 2007. The full results of that search are provided in **Attachment 5**. This data has been summarised in **Table 10.4**. The highest biodiversity with respect to fauna is found in the Auburn and Ryde LGAs. Parramatta and Canada Bay LGAs also have high numbers of species. The lowest diversity of fauna was recorded for Ashfield, which is likely a function of the small size of this LGA and its highly urbanised nature. Poor reporting may also be a function for some of the LGAs found within the study area.

Table 10.4 Fauna Species Records for the Parramatta River Estuary Foreshore Councils

LGA	Number of Species
Ashfield	7
Auburn	176
Canada Bay	131
Hunters Hill	79
Leichhardt	86
Parramatta	168
Ryde	176
Strathfield	71

There are several surveys of fauna within the Parramatta River Estuary, although the majority focus on specific locations and are also limited in temporal extent.

It is worth noting that most aquatic estuarine fauna have life cycles incorporating planktonic larval stages and most species will spend at least part of their lives in the plankton. Therefore, even sedentary species may have a mobile phase during their development.

Estuarine fauna (both aquatic and avian) may also be supplemented by marine species temporarily using an estuary. This may include visitors to the estuary, or those species for which a developmental phase occurs in the estuary. For example, some species may spawn in and recruit to estuarine habitats before moving to other coastal waters. Alternatively, some mobile species of animals may visit the estuary during seasonal movements or to take advantage of a particular estuarine resource.

It is noted that there are a number of Intertidal Protected Areas (IPAs) that are located within the study area, including the Parramatta River foreshores of Ashfield, Auburn, Canada Bay, Hunters Hill, Leichhardt, Parramatta and Ryde LGAs (http://www.dpi.nsw.gov.au/fisheries/closures/general/invertebrates-ipa). Within these IPAs, which are gazetted under the *Fisheries Management Act*, fishing is permitted, but bait collection is not allowed. These IPAs extend from the mean high water mark to 10m seaward of the mean low water mark. They aim to conserve the structure and biodiversity of intertidal communities and ensure that the harvesting of intertidal invertebrates is not conducted in an unsustainable fashion.

10.3.1 Fish

Generally, there is a lack of information about the fish populations within the Parramatta River Estuary. It is understood that no detailed survey of the fish in Port Jackson had been conducted until 1972 (Paxton and Collett, 1975). As such, changes in fish population structures and potential local extinctions are unlikely to be identified, other than through anecdotal evidence. To compound this problem, many of the older fish specimens held by the Australian Museum are not labelled with a location, as reported by Paxton and Collett (1975).

Henry (1984) provides a general literature review of resources relating to the fish found in the wider Port Jackson, including the Parramatta River Estuary. Henry (1984) notes that, in all, a total of 581 species representing 143 families have been recorded by the Australian Museum, with the greatest number of species being from the families: Labridae (50 species), Gobiidae (34 species), Apogonidae (24 species), Chaetodontidae (21 species) and Monacanthidae (20 species). It is understood that the species counts provided by the Australian Museum probably represent all historic records and are therefore unlikely to represent the contemporary fish fauna of Sydney Harbour. Additionally, while it is noted that fish are highly mobile species, it is considered unlikely that all these species occur within the study area for a number of reasons. Many of these species will be marine, rather than estuarine, or may not be present in the study area due to a lack of suitable habitat or similar.

Paxton and Collett (1975) report on the initial results of the 1972 fish survey, covering the area between the Charles Street weir and the Gladesville Bridge. A decrease in the abundance and diversity of fish was observed in the upstream extent of the study area, thought to be function of both the high levels of pollution observed in this region and limited physiological tolerances to upstream estuarine conditions. Of particular note is the fact that the surveys failed to catch a single specimen in the vicinity of Silverwater Bridge (Paxton and Collett, 1975). Species recorded upstream of the Ryde Bridge included the Yellowfin Bream (*Acanthopagrus australis*), Anchovy (*Engraulis australis*), Mulloway or Jewfish (*Johnius antarcticus*), Tailor (*Pomatomus saltatrix*) and Trumpeter Whiting (*Sillago maculate*).

It is noted that the survey by Paxton and Collett (1975) utilised a prawn (twin otter) trawler for sampling, and while this was supplemented by a limited use of beach seine, gillnet and drop net sampling, it is likely that the survey did not adequately target a large number of species or difficult to sample locations (as acknowledged therein).

Fish populations have been surveyed for Homebush Bay (The Ecology Lab, 1992, 1993a-d; Lincoln-Smith, White and Hawes 1994a and b; Mazumder, Saintilan and Williams, 2006). Some of these studies also included Brays and Yaralla Bays.

Mazumder, Saintilan and Williams (2006) compared fish assemblages from saltmarsh and mangrove wetlands in three geographically distinct estuaries in the Sydney region, one of which was located in Bicentennial Parkland, Homebush Bay. They found that the Bicentennial Parkland wetlands, which were said to have been reclaimed from dredge spoil in the 1960's, exhibited significantly lower diversity and abundance of fish when compared to other estuaries (Mazumder, Saintilan and Williams, 2006). This finding was said to highlight questions about the efficacy of artificially created wetlands as habitat for fish. This latter point is important in the context of the Parramatta River Estuary as it relates to the push to create wetlands with a view to increasing available habitat for fauna.

It is understood that the papers prepared by The Ecology Lab (1992 and 1993a-d) consist of progress reports on the fish studies presented in the *Homebush Bay Ecological Studies 1993-1995* (Olympic Coordination Authority, 1996a and b) – Lincoln-Smith, White and Hawes (1994a and b). For that reason, The Ecology Lab (1992 and 1993a-d) reports will not be discussed hereafter.

Lincoln-Smith, White and Hawes' (1994a) fish survey of Homebush Bay was conducted on four occasions between February and October 1993 in Homebush Bay itself, in Powells and Haslams Creeks, and outside of Homebush Bay in Brays and Yaralla Bays. The authors begin with an excellent literature review of the types of fish habitat found within

Homebush Bay, the fish species that could be expected to occur there and previous surveys conducted in Homebush Bay and the Parramatta River.

A total of 33 fish species were recorded for Homebush Bay, for which species lists are provided in Lincoln-Smith, White and Hawes (1994a). Key habitats for fish in Homebush Bay included mangrove forest, saltmarshes and mud channels and banks in the open part of the bay, while elements such as shipwrecks and seawalls can function to provide microhabitats (Lincoln-Smith, White and Hawes, 1994a). It was shown that assemblages of fish sampled from the creeks differed from those sampled from the open bay (Lincoln-Smith, White and Hawes, 1994a), highlighting the importance of protecting a range of habitats when aiming to conserve biodiversity.

Of the open bay habitats, mud flats had relatively high species diversity and abundances of fish, and the mudflat near the entrance of Powells Creek had especially high numbers of fish, in particular the Yellowfin Bream (*Acanthopagrus australis*). The fish assemblages associated with mudflats were found to be similar when comparing Homebush Bay and Brays and Yaralla Bays (Lincoln-Smith, White and Hawes, 1994a). When considering wetland habitats located at Homebush Bay and Newington, fish assemblages were considered depauperate, with only six species collected. This was thought to be due to inadequate flushing which limits their value as fish habitat. When considering intertidal habitats, maintenance of tidal flushing is an important factor in the maintenance of the associated flora and fauna.

Lincoln-Smith, White and Hawes (1994a) also made note of evidence of pollution likely to impact on fish, including the presence of gross pollutants.

The fish survey included in Lincoln-Smith, White and Hawes (1994b) related to the 2SM Pond located of Haslams Creek, Homebush Bay. It is understood that this pond has subsequently been pumped dry, excavated to a depth of 1.5m and converted to a tidal wetland.

Anecdotal evidence suggests that the combined result of the banning of commercial fishing in Sydney Harbour and warnings of dioxins in fish have led to at least a partial recovery of fish numbers in the wider Harbour (Bartlett, 2007).

There have also been reports of occasional visits from sharks in the Parramatta River Estuary, with reports of a Bull Shark (*Carcharhinus leucas*) ramming a rowing scull crewed by students from Scots College (Safe, 2000). However, whilst there is certainly potential for sharks to be present in the study area, this is not thought to be a common occurrence.

The abovementioned studies represent the sum of all resources on the general fish ecology of the Parramatta River Estuary compiled during the current literature review, as was also noted by Lincoln-Smith, White and Hawes (1994a). It is noted that almost all of these reports were prepared over 10 years ago and may not represent the existing conditions. Whilst the current study targeted a wide range of literature sources and was fairly comprehensive, it is anticipated that there may be additional, more recent references in existence.

Fish and Ecotoxicology

The taking of fish (and other species) from the Parramatta River Estuary has been banned and/or restricted in one form or another due to concerns over the levels of contaminants in estuarine fauna (refer to DPI, 2004). Of particular concerns, are levels of dioxins in fish and prawns. Further information is provided by NSW DPI (DPI Fisheries, 2005, 2006 and 2007a).

In response to notification by NSW DPI -Fisheries, the NSW Food Authority prepared a report on *Dioxins in Seafood in Port Jackson and its Tributaries* (NSW Food Authority, 2006). Further information is provided in that report on the effects of dioxins on human health and the observed concentrations of dioxins in prawn tissues. On the basis of their findings, the NSW Food Authority recommended that people should consume no more than one 150g serve of fish per month, or more than two 150g serves of prawns, from Port Jackson (NSW Food Authority, 2006). Signage to this effect has been placed near popular recreational fishing spots around Port Jackson, including those in the Parramatta River Estuary (see **Figure 10.6**). This information was also disseminated to the recreational fishing community via brochure prepared by the NSW Food Authority (Hurst, 2006). Fishing closures is discussed in more detail in **Section 11.4.2**.

Rubinstein and Wicklund (1991) previously reported on the results of a monitoring program of the effects of dioxin contamination of estuarine sediments on fish and other estuarine fauna. They calculated sediment bioaccumulation factors for several fish species, as well as prawns, mussels, polychaetes and crabs. The levels of dioxins in the tissue of estuarine fauna sampled from Homebush Bay was above safe levels for several species (Rubinstein and Wicklund, 1991).

The levels of hydrocarbons (PCBs and OCs) in the tissues of edible fish species was investigated for the Parramatta River Estuary as part of a study by Roach and Runcie (1998). Contaminants were found in fish tissues from all locations sampled and included PCBs and the Group A OC pesticides (which includes dieldrin, chlordane and heptachlor epoxide) at levels higher than those considered safe for human consumption (Roach and Runcie, 1998). The highest concentrations of PCBs were found in fish from Duck River and Homebush Bay and fish from Duck River had the highest concentrations of OCs (Roach and Runcie, 1998). DDT was also detected but not at levels unsafe for human consumption. Roach and Runcie (1998) also identified the fish species with the highest concentrations of these contaminants. They included Yellowfin Bream, Pink-eye Mullet and Silver Biddy.

Alquezar, Markich and Booth (2006a) have conducted research on metal accumulation in the Smooth Toadfish (*Tetractenos glaber*) collected from a number of estuaries, including the Parramatta River Estuary. The authors report that levels of metals in fish were higher from contaminated estuaries such as the Parramatta River Estuary. The following key observations were recorded by Alquezar, Markich and Booth (2006a):

- On average, gonads contain the highest concentrations of metals, followed by muscle, gill and liver tissues.
- Gender specific outcomes of metal accumulation.
- There appears to be more than one uptake pathway, e.g. from sediments and water.

These results confirm that bioaccumulation of estuarine pollutants is occurring, however, the biological and ecological effects of this process must also be considered. Alquezar, Markich and Booth (2006b) followed up these findings with a study on the effects of metal contamination on the condition and reproductive output of *T. glaber*. Metal accumulation in fish tissues was shown to reduce egg size and fecundity, suggesting a corresponding decline in the reproductive output for females of the species (Alquezar, Markich and Booth, 2006b). In addition, female *T. glaber* from contaminated estuaries were smaller and younger than in uncontaminated estuaries, although it was acknowledged that this finding may be confounded by other factors, such as the nutritional value of prey species (Alquezar, Markich and Booth, 2006b). It is not unlikely that these processes would affect the population size, biomass and demographic structure. Male fish were not included in the study. The findings of these studies are likely to have implications for other fish species found in the Parramatta River Estuary.

Bioaccumulation in fish may also impact on other species. The literature review did not identify any studies on the wider ecological effects of bioaccumulation in fish species, however, there have been reports that toxins present in fish are impacting on other species. Woodford (2004) reported on the deaths of the last two remaining Sea Eagles (*Haliaeetus leucogaster*) nesting on the Parramatta River, thought to be due to consuming fish affected by bioaccumulation of toxins. It is understood that a post-mortem of the dead birds was conducted by veterinarians at Taronga Zoo, however the findings are unknown.

Fish and Fishing

Paxton and Collett (1975) provide a review of the literature on fish and fishing in Sydney Harbour. They make reference to other studies that identified the depletion of fish stocks in the Harbour due to overfishing between 1860 and 1880.

By-catch is the term applied to commercial fishing and refers to those species that are caught incidentally to the target species. It is understood that commercial prawn trawling has been conducted in the Parramatta River Estuary in the past. Trawling can cause a number of negative impacts, by-catch being one of them. In 2002 DPI – Fisheries released the *Estuary Prawn Trawl Fishery EIS* which included information on catches of target and non-target (i.e. by-catch) species. Based on reported landings during 1997-1998 and 1998-1999, the average annual catch (by weight) of a number of species is reported below:

- Eastern King Prawns – 35%
- School Prawns – 5%
- Whiting, Trumpeter – 29%
- Blue Swimmer Crab – 6%
- Squid – 2%
- Silver Biddy – 2%
- Greasyback Prawn – 2%
- Cuttlefish – 2%
- Trumpeter – 2%
- Fish spp. – 7%
- Flounder spp. – 2%
- Other – 6%.

However, the target species for the fishery are the Eastern King Prawns (*Penaeus plebejus*), with the fish, molluscan and other species representing by-catch.

Liggins, Kennelly and Broadhurst (1996) prepared an observer-based survey of by-catch from prawn trawlers operating in Port Jackson. They report a mean annual ratio of by-catch to prawns for Port Jackson of 1.8:1, representing around 38 tonnes of by-catch, including large numbers of recreationally and commercially important finfish.

Paxton and Collett (1975) make reference to a government study that determined that prawn trawling did not have significant adverse effects on harbour fishes, although it is understood that there was still some level of concern over fish stocks at that time.

However, commercial fishing was banned in Sydney Harbour in January 2006 and so these issues are no longer applicable to management of fish populations in the study area.

Impacts of Flood Mitigation Works

Flood mitigation works and other structures that impeded or otherwise alter natural flows in the Parramatta River can have a significant impact on the passage of fish and other aquatic plants and animals. In recent years NSW DPI – Fisheries has reviewed all development proposals that have the potential to impact on fish passage under Part 7 of the *Fisheries Management Act 1994* and have also issued advice on the requirements for fish passage for waterway crossings (Fairfull and Witheridge, 2003).

It is understood that four existing weirs in the upper Parramatta River, including the Charles Street weir, are currently being updated with fish ladders to facilitate the passage of fish between the river and estuary (pers. comm, A. Collins, Waterways Systems Manager, Parramatta City Council, 4/06/08).

10.3.2 Avifauna

There a number of bird watching societies from which data can be sourced. Birds Australia maintain a number of databases including the Atlas of Australian Birds (for a specific search area), the Nest Record Scheme and Shorebirds 2020. The Cumberland Bird Observers Club (http://www.cboc.org.au) can also provide geo-referenced data of species sightings. A map available on their website provides an indication of the number of records available (i.e. intensity of effort expended) for different locations. This is important when considering that the database entries are contributed on a voluntary basis and that survey may not be evenly distributed across an area. Attributes such as the reliability of data are unknown.

An overview of the attributes of these databases can be found in **Table 10.5**. Records from bird watchers represent an excellent resource for characterising the avifauna of the study area.

Table 10.5 Overview of the Attributes of Bird Watching Databases

Society/Club	Database Name	Attributes
Birds Australia	Atlas of Australian Birds	• Search area (coordinates) • Months • Species counts • Common name • Scientific name • Survey count
	Nest Record Scheme	• Location coordinates • Altitude • Nest location (e.g. branch, ground, etc.) • Height of nest above ground/water/structure etc. • Scientific name • Common name • Land use at nesting site • Year • No. of visits • Season • Date and time • No. of eggs • No. of young (in and out of nest) • Developmental stage • Outcome of nest (no. leaving nest, not sure, failure) • Stages of breeding recorded • Any additional information
	Shorebirds 2020 (Australasian National Shorebird Count)	• Species counts either directly or as estimates of % cover of site or site complex
Cumberland Bird Observers Club		• Database records go back to 1997 • Location coordinates • Type of search conducted (e.g. 2ha/20min) • Date • Breeding status

Society/Club	Database Name	Attributes
		• Abundance • Habitat type (if wetland: empty/partly full/full/flooding)

There are a number of resources relating to the avifauna of the Parramatta River, although as with other ecological surveys, these are typically limited in spatial and temporal extent.

Morris, Tyler, *et al.* (1990) have surveyed the wetlands of the Parramatta River throughout the study area. The census was fairly comprehensive, consisting of 29 individual surveys conducted between October 1983 and June 1986 (Morris, Tyler, *et al.,* 1990). A total of 73 species, 37 of which occur regularly, were counted. The key habitats used for roosting and feeding by waterbirds were the estuary intertidal zone, mangroves, saltmarsh, freshwater wetlands and sheltered rocky shores (Morris, Tyler, *et al.,* 1990). The Parramatta River Estuary was considered to have important conservation value for the Chestnut Teal (*Anas castanea*), Pied Stilt (*Himantopus himantopus leucocephalus*) and certain migratory waders.

Some information of the ecology of bird species along the Parramatta River Estuary, specifically relating to competition and foraging, can be found in Taylor, Taylor and Lamour (1996).

The following locations in the study area have been surveyed for avifauna:

- *Leichhardt* (Saunders, 2008)
- *Sydney Olympic Park* (SOPA, 2007b-d)
- *Homebush and Homebush Bay* (Olympic Coordination Authority, 2005b; Parkland Environmental Planners, POD Landscape Architecture, *et al.,* 2008; Straw, 1993 and 1998; Water Board, 1993; and Straw, 1996a and b, and Taylor, 1994 in Olympic Coordination Authority 1996a and b)
- *Clyde Refinery Site* (Urban Bushland Management Consultants Pty Ltd, 2006).

Upper Parramatta River Estuary

Clyde Refinery Site

A fauna assessment of the Clyde refinery site located at the confluence of the Duck and Parramatta Rivers was undertaken by Urban Bushland Management Consultants (2006). In conducting the survey, direct observations of 46 bird species were recorded, including a nesting pair of Black Swans (*Cygnus atratus*).

Mid Parramatta River Estuary

Mason Park, Homebush

As part of the *Mason Park Plan of Management* (Parkland Environmental Planners, POD Landscape Architecture, *et al.,* 2008) the conservation value of the site relating to shorebirds was assessed. An overview of the shorebird species present, their habitat requirements and conservation status is provided. Specific recommendations, goals and strategies relating to the shorebirds found in Mason Park were developed as part of *Plan of Management* (Parkland Environmental Planners, POD Landscape Architecture, *et al*., 2008).

Homebush Bay

A number of studies have been conducted in Homebush Bay as part of the *Homebush Bay Ecological Studies 1993-1995* prepared under the auspices of the Olympic Coordination Authority (1996a and b). These studies of waterbirds and woodland birds (Straw, 1996 a and b, and Taylor, 1994) are complemented by several additional studies conducted in Homebush Bay (Straw, 1993 and 1998). The Water Board (1993) and Straw (1993) reports appears to consist of a series of progress reports prepared to update the status of the avifauna studies conducted as part of the *Homebush Bay Ecological Studies*.

Taylor (1994) focussed on the ecology and management of shorebirds (Aves: Charadrii) for Homebush Bay. The key findings are as follows:

- 11 species were recorded, with the most abundant being the Black-winged Stilt (*Himantopus himantopus leucocephalus*), Curlew Sandpiper (*Charadrius ferruginea*) and Bar-tailed Godwit (*Limosa lapponica baueri*).
- The two key habitat types were the shallow, saline lagoons and intertidal mudflats. The former supported the greatest diversity and abundances of shorebirds. Not surprisingly, water depth was a key variable with respect to habitat.
- It was thought that the lagoon system could support a much greater diversity and abundance of shorebirds and recommendations made at the time included regulation of water depths.
- Five percent of the Bar-tailed Godwit population was found in Homebush Bay, but the main population within the study area was found in Hen and Chicken Bay.
- Key management issues identified were –
    - Impacts related to the use of insecticide for mosquito control,
    - Poor water quality,
    - Management of edge habitats (for roosting and minimising predation),
    - Provision of nesting sites, and
    - Disturbance and habitat degradation in relation to human activities.

Additional information regarding the ecology of particular species is also available (Taylor, 1994).

Straw (1996a) researched the waterbirds of Homebush Bay. That study was confined to a habitat assessment (types, condition, value) and species observations, from which the importance of different locations and/or habitats to waterbird species was assessed. The key observations were as follows:

- The remaining wetlands in Homebush Bay were part of an extensive system of wetlands that would have historically supported large and diverse bird populations.
- A diverse suite of waders were observed, including migratory waders protected under international treaties (e.g. JAMBA and CAMBA, see **Section 10.5.4**).
- Mason Park and the adjacent Powells and Saleyard Creeks were identified as important resources for feeding and roosting.
- Hen and Chicken Bay plays an important role in supporting populations of wading birds found in Homebush Bay.
- Much of the saltmarsh and wetland areas in existence at that time were artificially created and in a degraded condition. Nonetheless, these areas constitute important habitat for waterbirds.

The woodland birds of Homebush Bay were also researched by Straw (1996b). The woodland birds survey (Straw, 1996b) was conducted in a similar fashion to that relating to waterbirds (Straw, 1996a) discussed above. The key observations were as follows:

- Despite being a highly modified environment, Homebush Bay supported important locally rare woodlands (including Casuarina and mangrove forests and shale associated woodlands).
- A number of regionally rare bird species, such as the White-fronted Chat, Red-rumped Parrot, Osprey, White-bellied Sea Eagle, Marsh Harrier and Peregrin Falcon, were observed.

- The eucalypt woodland found at Newington supported a surprisingly large variety of parrots considering its small size.

In a later study of the impacts of the development of Homebush Bay ahead of the Sydney 2000 Olympics, Straw (1998) noted that, while some bird habitat was removed as part of the works, the overall outcome was at that time expected to be positive due to the provision of additional areas of habitat in landscaped areas.

Sydney Olympic Park

It is understood that the Sydney Olympic Park Authority is currently conducting ongoing monitoring of bird populations within the park and has also undertaken some targeted habitat management activities.

SOPA (2007b) detail the installation of a new tidal gate in the Badu Mangroves, Bicentennial Park that facilitates maintenance of a more natural tidal regime, thereby improving habitat quality for birds residing in the mangroves. A list of species found in the Badu Mangroves Waterbird Refuge is also provided (SOPA, 2007b). A brief mention is also made to recurring algal blooms in the Waterbird Refuge compromising the water quality, leading to the production of odours as the algae decays. It is understood that the Sydney Olympic Park Authority is undertaking ongoing management of these wetlands.

Regular, seasonal monitoring of the White-fronted Chat and nocturnal birds is also undertaken (SOPA, 2007c and d). The Autumn 2007 survey indicates that the existing population of White-fronted Chat in Sydney Olympic Park is in decline and had become unrecoverable, leading to extinction (SOPA, 2007c). Their small population sizes (11 in the Main Lagoon and 33 in Newington Nature Reserve) make them susceptible to environmental perturbations, either natural or anthropogenic ally induced.

Nocturnal species are also regularly surveyed by the Sydney Olympic Park Authority and the findings of a recent survey are provided in SOPA (2007d). Species lists, counts and other ecological information are provided therein. SOPA (2007d) notes the importance of wetlands within the Park and in surrounding areas in providing habitat for a number of species, particularly migratory species, thereby highlighting the importance of coordinated habitat management by the Sydney Olympic Park Authority and other agencies, such as City of Canada Bay and Strathfield Council.

Lower Parrramatta River Estuary

Leichhardt

Saunders (2008) presents the results of a survey of birds in Leichhardt, focussing on the 15 reserves found within Leichhardt LGA. Bird species lists and habitat preferences are provided for each reserve. The key findings of Saunders (2008) are listed below:

- Of 115 bird species previously recorded in Leichhardt LGA, only 35 were observed during that survey, 21 of which are considered locally rare. Of these, five species are considered to be at risk within the LGA.
- Birds tended to prefer unmanaged, weed infested habitat that was structurally complex with dense vegetation cover. The newly landscaped areas provided good habitat structure but consist of small, isolated patches. Local gardens also provide suitable habitat.
- Over-clearing of weeds and disturbance during landscaping may be an issue for birds.
- The need to work with other local councils and relevant agencies on establishing habitat linkages/corridors was also noted.

10.3.3 Mammals

The literature review only identified two studies of mammals relating to the Parramatta River Estuary, both of which relate to a particular site (and are similarly limited in temporal scale).

A bat census was conducted in the Sydney Olympic Park as a requirement for their ongoing management of the park. SOPA (2006a) provides an overview of the bat fauna of Sydney Olympic Park in terms of diversity and abundance. The breeding status of microbat species was also investigated. A total of 7 bat species were observed, which did not include 3 of the species previously recorded on the site (SOPA, 2006a). This included some protected and threatened species (discussed in Section 10.5). The greatest diversity of bat species were observed in Newington Nature Reserve. The survey of breeding populations identified a number of buildings currently being used as roosts sites or maternity roosts. Of particular importance is the Newington Armoury due to the presence of a maternity colony of White-striped Freetail Bats *Tardarida australis* (SOPA, 2006a).

A mammalian survey was previously conducted on the Newington site by Flannery, Parnaby and Tasker (1993), who utilised a range of search methodologies in order to target different mammalian groups. Five species of insectivorous bats, or microbats (Microchiroptera), were observed, which led to Flannery, Parnaby and Tasker (1993) considering the diversity relatively depauperate when compared to what could be expected for a more natural, unmodified environment. However, the forest area in the Newington Nature Reserve was said to be highly significant in terms of providing a high proportion of trees with hollows, which are an increasingly scarce resource. Management recommendations made by Flannery, Parnaby and Tasker (1993) include:

- Retention of hollow-bearing trees and continual recruitment of younger trees,
- Minimisation or elimination of pesticide application in the area,
- Reduce the presence of domestic cats (known predators of insectivorous bats),
- Retention of adjoining wetlands as habitat for the bats' food source – insects, and
- Generally maintain insect populations.

Other mammal species observed were Common Ringtail Possum (*Pseudocheirus peregrinus),* Common Brushtail Possum (*Trichosurus vulpecular*) and the Grey-headed Flying Fox (*Pteropus poliocephalus*), which is a megabat (Megachiropteran) (Flannery, Parnaby and Tasker, 1993). The Newington woodland and Casuarina forest was considered to have limited mammalian fauna. However, the Newington woodland represents important remnant habitat in its regional context (Flannery, Parnaby and Tasker, 1993). Key factors in the decline of mammalian species in the area are attributed to:

- Long period of human impacts/disturbance,
- The small size and fragmented nature of the remaining habitat,
- The floral composition, and
- Effects of introduced species.

Other mammal species thought to occur in the Newington area, but for which there are no recorded sightings, include Antechinus (probably *Antechinus stuartii*) and the Common Dunnart (*Smithopsis murina*) (Flannery, Parnaby and Tasker, 1993).

In addition to these studies discussed above, a bat survey of Goat Island was recently prepared by Leary (2007). Whilst Goat Island is outside of the study area, it has been referenced herein because those species will also have the potential to occur in the Parramatta River Estuary study area.

Importantly, a literature review by Flannery, Parnaby and Tasker (1993) provides information on mammalian fauna present at the time of European settlement of the Homebush Bay area dating back to the late 18th Century.

10.3.4 Macroinvertebrates

Site specific surveys of macroinvertebrates have been conducted at the following locations:

- *Homebush Bay* (Lincoln-Smith, White and Hawes, 1994, in Olympic Coordination Authority 1996b)
- *Iron Cove* (Courtney, Gladstone and Shreider, 2005).

Upper Parramatta River Estuary

Homebush Bay

In their survey of fish and crustacea in Homebush Bay, Lincoln-Smith, White and Hawes (1994) found six species of crustaceans from five families, including three economically important species (the Eastern King Prawn *Penaeus plebejus*, Schooling (or Harbour) Prawn *Metapenaeus* spp. and the Mud Crab *Scylla serrata*.

Lower Parramatta River Estuary

Iron Cove

The response of intertidal assemblages on rocky shores to urban run-off was investigated by Courtney, Gladstone and Shreider (2005), including for two sites located in Iron Cove. These assemblages are composed almost entirely of macroinvertebrate species. Courtney, Gladstone and Shreider (2005) found that intertidal rock assemblages do respond to the quality and quantity of stormwater runoff. Therefore, it is reasonable to assume that the intertidal assemblages located in the study area are significantly impacted by stormwater runoff (dependent on rainfall levels).

Mosquitoes

Mosquitoes are also present in the study area and it is understood that the majority of the research effort in the field has been directed at the major mosquito pest species the Saltmarsh Mosquito *Aedes vigilax*. There have been a number of studies of their ecology to complement the ongoing control programs run by various local Councils and other organisations. Mosquito habitats have been surveyed by ICPMR (2007). ICPMR (2007) determined that the most significant mosquito habitats are located in the Sydney Olympic Parklands and exceptionally large populations are found here after major rainfall events or in association with spring tides.

It is understood that mosquito control programs are run by SOPA (SOPA, 2007e), City of Ryde and Parramatta City Council (Lloyd, Monaco and Metten, 2006). Treatment with insecticide is the preferred method of control, although it does not eradicate the mosquitoes entirely (ICPMR, 2007). Published research by Paul (2007) provides an account of SOPA's success in reducing mosquito numbers through the re-introduction of tidal flushing to the wetlands of Bicentennial Park. Further, this process led to an increase in the numbers of fish and crustaceans in the wetlands, while vegetative growth was promoted and patterns in vegetative cover altered (Paul, 2007).

Mosquitoes may also be controlled to some extent by predation by fish. Where wetland managers wish to ensure this occurs, it is important to ensure that fish passage is maintained.

10.3.5 Reptiles and Amphibians

Surveys of reptiles and/or amphibians have been conducted for the following locations:

- *Homebush Bay* (AMBS, 1993; SOPA, 2007f; Cogger, 1995 in Olympic Coordination Authority, 1996b)
- *Sydney Olympic Park* (Cogger, 2005; SOPA, 2006b).

Much of the available literature relates to the Green and Golden Ball Frog (*Litoria aurea*), for which a couple of key populations were located in the Parramatta River estuary catchment (DEC, 2005) at:

- Homebush Bay within Sydney Olympic Park, including elements that occur in Bicentennial Park, Wilson Park and the Newington Nature Reserve, and as far as the Silverwater Correctional Facility.
- Wetlands located at Clyde/Rosehill near the confluence of the Duck and Parramatta Rivers on land owned by Shell (Refining) Australia Pty Ltd and CSR Emoleum Plant.
- Greenacre in the Punchbowl Brickpit, Freightcorp and RailCorp lands and the adjacent Cox's Creek Reserve.
- Merrylands, representing a small population within the Holroyd Gardens residential sub-division. This population is thought to be also making use of the Walpole Street Park and Duck Creek.

Management Plans have been prepared for populations at Cox's Creek Reserve, Greenacre, the Punchbowl Brickpit Site, the Shell Refinery, Holroyd Gardens and the CSR Emoleum Plant. A Recovery Plan has also been prepared by DEC (2005) to direct management of the species across the whole of NSW, including key threatening processes and management issues, objectives and actions. That document also contains useful information on the biology and ecology of the Green and Golden Bell Frog and current research, some of which relates to those populations found within the study area.

It is understood that DECC currently have in preparation a Green and Golden Bell Frog Management Plan for the Parramatta River, to be issued shortly (Pers. comm., Natural Resource Project Officer (Coasts and Estuaries), DECC, 3 June 2008).

Upper Parramatta River Estuary

Clyde Refinery Site

Urban Bushland Management Consultants Pty Ltd (2006) observed the Green and Golden Bell Frog during surveys of the wetlands located on the Clyde Refinery site.

Homebush Bay and Sydney Olympic Park

Cogger (2005) reports on long-term biodiversity monitoring at Sydney Olympic Park as it relates to reptiles and amphibians. To date a total of seven species of frog and 13 species of reptile have been observed in the park (Cogger, 2005). That report also provides an overview of the conservation status for each of these species. The limitations associated with the methods used in the on-going monitoring program are also discussed.

An update on Cogger (2005) is provided in the latest reptile monitoring report by SOPA (2006b).

Additional detail specifically relating to the monitoring of the Green and Golden Bell Frog (*Litoria aurea*) can also be found in Cogger (2005). It is understood that, despite the long time over which this species has been monitored at Homebush, little is known about the factors governing population size, reproductive success, movements and distribution, temporal and spatial changes in habitat utilisation, longevity and survivorship (Cogger, 2005). Further complicating the issue, it has been observed that the reproductive success and larval/juvenile survival rates are highly variable from year to year.

General information on the Green and Golden Bell Frog and its history at the Sydney Olympic Park can be found in SOPA (2007f).

Cogger (1995) prepared a fauna impact statement with respect to the Green and Golden Bell Frog population at Homebush Bay. The primary population is located in the brickpit, although at that time other specimens were observed scattered throughout the site, albeit as individuals or in ephemeral habitat. Cogger (1995) also lists the anticipated impacts of the Homebush Bay development and appropriate ameliorative measures.

AMBS (1993) appears to comprise a progress report relating to Cogger (1995) and so has not been discussed herein.

10.3.6 Benthic Fauna

Boat wash has been highlighted elsewhere as potentially having a negative impact on benthic fauna. Bishop (2004) investigated the ecological impacts of boat wash by comparing wash and no-wash zones (where boat speed is reduced to a speed such that boat wake is reduced) within the Parramatta River Estuary. Assemblages of macrobenthic infauna were found to differ between wash and no-wash zones (Bishop, 2004), which indicates that boat wash does have an impact on benthic fauna. This finding was supported by a ‘manipulative’ study undertaken during the Sydney Olympics, during which time RiverCat traffic was not running. Bishop (2007) attempted to identify a particular causative mechanism for these observed changes, in this case coarsening sediment grain size.

Site specific surveys of benthic fauna have been conducted at the following locations:

- *Homebush Bay* (Jones and Frances, 1988; Robinson, Van Der Velde and Gibbs, 1983; Berents, 1993 in Olympic Coordination Authority 1996b).

A survey of Homebush Bay by Robinson, Van Der Velde and Gibbs (1983) found a total of 4 worms, 7 molluscs and 12 crustaceans. They determined that the benthic fauna was similar to that found in other NSW estuaries that are subject to variable physical factors (e.g. salinity).

In a 1988 study of the sub-littoral (below the low tide mark) macrobenthos of Homebush Bay (Jones and Frances, 1988), a total of 32 species were found, consisting of 17 species of crustaceans, 9 polychaetes and 6 molluscan species. The polychaetes *Minuspio cirrifera* and *Ceratonereis aequisetis* and the bivalve *Notospisula trigonella* were the most abundant species. At that time, Homebush Bay had higher diversity and abundance of benthic invertebrates than Brays Bay, but was quite similar to Ermington Bay. However, the benthic invertebrate fauna were depauperate when compared to other estuaries (Jones and Frances, 1988).

Berents (1993) recorded a total of 42 species of polychaetes, molluscs and crustaceans in Homebush. Grab samples were numerically dominated by the polychaete *Nephtys australiensis* and *Prionospio yuriel*, the amphipod *Victoriopisa australiensis* and the bivalves *Spisula trigonella* and *Tellina deltoidalis*. Increases in biodiversity were observed compared to earlier studies (see Berents, 1993), thought to be due to the improved condition of the estuary. However, the species diversity of benthic invertebrates was generally considered to be depauperate (Berents, 1993).

Impacts of Mangrove Boardwalks

There is a relatively large body of research available on the impacts of mangrove boardwalks on flora and fauna. This issue has already been discussed with respect to the potential impacts on mangroves themselves (**Section 10.2.2.2**). The impacts on the macrobenthic fauna have also been considered, with some study sites located within the Parramatta River Estuary. Kelaher, Chapman and Underwood (1998b) found that macrobenthic invertebrate assemblages close to (within 3m) boardwalks were different to those located farther away, thus boardwalks were associated with localised, but measurable disturbances to benthic macrofauna.

Benthic Invertebrates and Sedimentary Contamination

Benthic invertebrates, infauna in particular, may be directly exposed to any contaminants bound to the sediments. Many species recycle nutrients by consuming detritus from the sediments and are then consumed by other estuarine species such as fish. In this manner, sedimentary contaminants (where present) may be introduced to the estuarine food chain. This issue is briefly discussed in **Section 7.3.3**.

McCready, Greely *et al.* (2005) have studied the effects of sedimentary contamination on amphipods (*Rhepoxynius abronius* and *Ampelisca abdita*) using sediments from the Parramatta River Estuary. The incidence of toxicity in these species was found to increase with corresponding increases in the level of sedimentary contamination, suggesting that they may effectively be used as indicators of sedimentary contamination (McCready, Greely, *et al.,* 2005).

10.3.7 Zooplankton

No studies of the zooplankton of the Parramatta River Estuary were identified during the course of the literature review and consultation process undertaken for this study.

10.4 Introduced Species

It is understood that a number of introduced (or “exotic”) aquatic and terrestrial species are present throughout the study area. Exotic species may be introduced to an area via advection on wind or water currents, via animal droppings or via shipping. Many invertebrate and plankton species in particular may survive long sea journeys in the ballast water of ships. Introduced species have the potential to pose significant risks to the natural ecology, human health and economy.

A survey for introduced aquatic species in Sydney Harbour was conducted by AMBS (2002) on behalf of the Sydney Ports Corporation. Target species were grouped in the following categories:

- Schedule 1 species – Australian Ballast Water Management Advisory Committee target introduced pests,
- Schedule 2 – Marine pest species that pose a threat to Australia, or
- Schedule 3 – Known or likely exotic marine species in Australian waters.

The only of Schedule 1 species that were found were dinoflagellate cysts, the majority of which were dead (AMBS, 2002). The only species from Schedule 2 found was the Blue Mussel (*Mytilus galloprovincialis*). This species is said to be well established in southern Australia and it is thought that its arrival may predate European arrival (AMBS, 2002). A total of 17 species of Schedule 3 plants and animals were found, in addition to 10 species that are already known from records held by the Australian Museum but were not found in the survey by AMBS (2002).

While none of the study sites were located within the Parramatta River Estuary, it is reasonable to assume that some of the pest species found in the wider harbour may also be present in the study area, dependent upon their species specific environmental tolerances (e.g. relating to salinity). Full lists of introduced species, both flora and fauna, are provided in AMBS (2002). That report also provides data on sediment grain size analysis, and water quality, as well as lists of native species incidentally recorded during the survey (AMBS, 2002). These lists of native species provide an additional resource on the biodiversity of the Harbour as a whole, including the Parramatta River Estuary.

Sydney Metro CMA, in partnership with NSW DPI – Fisheries, are currently finalising a risk assessment of marine pests for the Sydney Metropolitan area. A survey of recreational boaters has also been undertaken to assess potential risks associated with the movement of recreational boats between estuaries and boat maintenance measures, such as hull cleaning and antifouling application.

Introduced Plant Species

Introduced estuarine plant species may alter the estuarine vegetation community structure by displacing and/or out-competing native species. This process will have flow-on effects for any associated fauna species. As has been noted elsewhere, weeds are a widespread problem in the study area and this extends to aquatic vegetation species, although it is noted that weeds are generally less problematic in mangrove and saltmarsh areas due to tidal inundation.

Most of the resources on weed species affecting the study area relate to saltmarshes or terrestrial riparian habitat. Some anecdotal evidence is also provided. The discussion below focuses on aquatic weeds.

Juncus acutus is an exotic saltmarsh species known to occur in the study area. *J. acutus* observed in 89 saltmarsh patches along the Parramatta River Estuary (Kelleway, Williams and Allen, 2007). Locations affected by *J. acutus* were identified by Kelleway, Williams and Allen (2007). Recommendations are made with respect to control of this pest species, including prohibiting public access to affected saltmarshes.

Paul and Young (2005) report on experiments on the control and eradication of *J. acutus* in Sydney Olympic Park. Removal of *J. acutus* from plots and transplanting of native saltmarsh species in their place was the most successful method in terms of re-colonisation by native species. Other methods, such physical removal of *J. acutus* followed by mulching and the application of Glysophate and salt, were also trialled. Paul and Young (2005) concluded that a combination of two or more methods of control were likely to constitute the best approach for controlling *J. acutus*. The effects of these various treatments on other vegetation is considered in Paul, Young and McKay (2006).

Cortaderia selloana, commonly referred to as Pampas Grass, is said to infest saltmarsh in Sydney Olympic Park around Haslams Creek, and *Alternanthera philoxeroides*, or Alligator Weed, has also been observed amongst saltmarshes at Yaralla Bay, west of Kissing Point and in the Pemberton Street wetland, Parramatta (Kelleway, Williams and Allen, 2007). Alligator Weed is also known to occur in Hen and Chicken Bay and Iron Cove (pers. comm, P. Nelson, CCBC, 27 February 2008). It is understood that Alligator Weed is occasionally found along the foreshores of the estuary after being deposited there by floodwaters (pers. comm, Environmental Officer, PCC, 14 February 2008).

Hydrocotyle bonariensis is another weed known to occur in Port Jackson, although it is unclear whether this species is present within the study area (Kelleway, Williams and Allen, 2007).

The following weed species have been recorded in Homebush Bay (Adam, 1993):

- *Philoxeroides*,
- *Chrysanthemoides monilifera* (Bitou Bush),
- *Selloana*, and
- *Pennisetum clandestinium* (Kikuyu).

Paul (2005) provides a method for controlling *Salvinia* blooms in the freshwater waterways of Sydney Olympic Park by applying salt water.

While it is understood that *Caulerpa taxifolia* has not been recorded within the estuary to date, there is a risk that this marine pest could be transferred from other affected estuaries. For example, this species has been recorded in Pittwater and Brisbane Water and there is potential for *C. taxifolia* to be transferred (e.g. via boat traffic) to Sydney Harbour and impact on the ecology of the Parramatta River estuary.

Introduced Animal Species

Introduced fauna are a significant issue in Australia, particularly in highly urbanised areas similar to that found around the Parramatta River Estuary. These exotic species may not only displace native species, but may also out-compete them for resources and degrade the natural habitat.

A number of exotic species were recorded as part of the fauna survey conducted by Flannery, Parnaby and Tasker (1993) at Homebush Bay and Newington, including:

- House mouse (*Mus musculus*)
- Rat species (*Rattus sp.)*
- Black Rat (*Rattus rattus*)
- Fox (*Vulpes vulpes*)
- Domestic Dog (*Canis familiaris familiaris*)
- Hare (*Lepus capensis*).

Urban Bushland Management Consultants Pty Ltd (2006) also report on the occurrence of Foxes in the study area, on this occasion with reference to the Clyde refinery site at the confluence of the Duck and Parramatta Rivers. The results of the flora and fauna survey undertaken as part of that study report on the occurrence of a number of introduced plant and animal species.

It is understood that Rabbits (*Oryctolagus cuniculus*) and Water Rats (*Hydromys chrysogaster*) are present in most of the foreshore parks in the Ryde LGA (Pers. comm., A. Smith, City of Ryde, 3 March 2008). It is thought that many of the rabbits were previously pets that have either escaped or been released. The City of Ryde has attempted to eradicate these rabbits via trapping, poison baiting and shooting them (Pers. comm., A. Smith, City of Ryde, 3/03/08). It is understood that foxes are also a problem, but are difficult to manage as they are more commonly observed on private land where Council does not have recourse to take action.

It is not known at this time if any other local Councils implement pest species control programs, although it is anticipated that pest fauna species are prevalent throughout the study area.

10.5 Threatened Species

Species of animals, plants or ecological communities may be listed as threatened under Commonwealth or State legislation, including the *EPBC Act*, *TSC Act* and *Fisheries Management Act*. Australia is also a signatory to a number of international treaties that provide protection for species such as migratory birds that are protected under the Japan

Australia Migratory Bird Agreement (JAMBA) or the China Australia Migratory Bird Agreement (CAMBA).

Threatened species and communities that are listed under State legislation are considered in **Sections 10.5.1 to 10.5.3**. The information provided in these sections was sourced from searches of the online databases (see **Section 10.1**) conducted on 12 and 13 December 2007 and 7 January 2008. Key threatening processes, as listed under the *TSC Act*, are considered in **Section 10.5.4**. Those species, communities or sites that are protected under Commonwealth legislation are considered in **Section 10.5.5**. For each of these threatened species a number of associated key threatening processes are defined by the Scientific Committee.

10.5.1 Flora

Table 10.6 provides a list of threatened flora species found within the study area, with the search area defined by those eight LGAs with foreshore frontage on the Parramatta River Estuary. The full list of both protected and threatened flora species located within this search area is provided in **Attachment 6**.

A total of 15 Vulnerable species and nine Endangered species as listed under the *TSC Act* have been recorded for the study area (**Table 10.6**). In addition, there is one seaweed species, Bennett's Seaweed (*Vanvoorstia bennettiana*), that was previously recorded in Port Jackson, but is now presumed extinct (DPI Fisheries, 2007b). The species was discovered at Spectacle Island and extensive searches of this area, as well as Shark Island where it was also sighted, have failed to re-discover it. It is thought that this species was lost due to human activities, including shipping, dredging and urban runoff, all of which cause siltation (DPI Fisheries, 2007b). However, it is possible that Bennett's Seaweed still exists in some locations.

It is noted that there may be other listed species located in the wider catchment. However, these have not been considered here.

Table 10.6 Threatened Flora Species Located within the Study Area

Scientific Name	Common Name	Legal Status
Acacia flocktoniae		V
Acacia pubescens	Downy Wattle, Hairy Stemmed Wattle	V
Bothriochloa biloba	Lobed Blue-grass	V
Callistemon linearifolius	Netted Bottle Brush	V
Darwinia biflora		V
Epacris purpurascens var. purpurascens		V
Eucalyptus nicholii	Narrow-leaved Black Peppermint	V
Eucalyptus scoparia	Wallangarra White Gum	E1
Genoplesium baueri	Bauer's Midge Orchid	V
Grammitis stenophylla		E1
Hypsela sessiliflora		E1
Leptospermum deanei		V
Melaleuca deanei	Deane's Paperbark	V
Persoonia nutans		E1
Pimelea curviflora var. curviflora		V
Pimelea spicata		E1
Pomaderris prunifolia var. prunifolia		E2
Pultenaea pedunculata		E1

Scientific Name	Common Name	Legal Status
Syzygium paniculatum	Magenta Lilly Pilly	V
Tetratheca glandulosa		V
Triplarina imbricata		E1
Tetratheca juncea	Black-eyed Susan	V
Vanvoorstia bennettiana	Bennett's Seaweed	Extinct*
Wahlenbergia multicaulis	Tadgell's Bluebell	E2
Wilsonia backhousei	Narrow-leafed Wilsonia	V

V = Vulnerable (*TSC Act*)
E1/E2 = Endangered (*TSC Act*)
*As listed under the *Fisheries Management Act*

10.5.2 Fauna

Table 10.7 provides a list of threatened fauna species found within the study area, with the search area defined by those eight LGAs with foreshore frontage on the Lower Parramatta River. The full list of both protected and threatened fauna species located within this search area is provided in **Attachment 7**.

A total of 28 vulnerable species and seven endangered species have been recorded for the study area (**Table 10.7**). This includes 20 species of bird, 11 mammalian species, two amphibians and two invertebrate species.

It is noted that there may be other listed species located in the wider catchment. However, these have not been considered here.

Table 10.7 Threatened Fauna Species Located within the Study Area

Scientific Name	Common Name	Legal Status
Avifauna		
Botaurus poiciloptilus	Australasian Bittern	V
Calidris tenuirostris	Great Knot	V
Callocephalon fimbriatum	Gang-gang Cockatoo	V
Charadrius leschenaultii	Greater Sand-plover	V
Ephippiorhynchus asiaticus	Black-necked Stork	E1
Haematopus longirostris	Pied Oystercatcher	V
Ixobrychus flavicollis	Black Bittern	V
Lathamus discolor	Swift Parrot	E1
Limicola falcinellus	Broad-billed Sandpiper	V
Limosa limosa	Black-tailed Godwit	V
Neophema pulchella	Turquoise Parrot	V
Ninox connivens	Barking Owl	V
Ninox strenua	Powerful Owl	V
Pandion haliaetus	Osprey	V
Pezoporus wallicus	Ground Parrot	V
Ptilinopus superbus	Superb Fruit-Dove	V
Sterna albifrons	Little Tern	E1
Stictonetta naevosa	Freckled Duck	V
Tyto capensis	Grass Owl	V
Xanthomyza phrygia	Regent Honeyeater	E1
Mammals		
Dasyurus maculatus	Spotted-tailed (Tiger) Quoll	V
Dasyurus viverrinus	Eastern Quoll	E1
Miniopterus schreibersii	Common Bent-wing Bat	V
Miniopterus schreibersii oceanensis	Eastern Bentwing-bat	V

Scientific Name	Common Name	Legal Status
Mormopterus norfolkensis	Eastern Little Mastiff-bat	V
Myotis adversus	Large-footed Myotis	V
Petaurus australis	Yellow-bellied Glider	V
Phascogale tapoatafa	Brush-tailed Phascogale	V
Pteropus poliocephalus	Grey-headed Flying-fox	V
Saccolaimus flaviventris	Yellow-bellied Sheathtail-bat	V
Scoteanax rueppellii	Greater Broad-nosed Bat	V
Amphibians		
Litoria aurea	Green and Golden Bell Frog	E1
Pseudophryne australis	Red-crowned Toadlet	V
Invertebrates		
Meridolum corneovirens	Cumberland Plain Land Snail	E1
Archaeophya adamsi	Adam's Emerald Dragon Fly	V*

V = Vulnerable (*TSC Act*), E1/E2 = Endangered (*TSC Act*)
*As listed under the *Fisheries Management Act*

10.5.3 Ecological Communities

As discussed below in **Section 10.5.4**, there are three ecological communities that are protected under the *EPBC Act*, including two Endangered and one Critically Endangered communities that occur within the study area (marked with an asterisk below). In addition, there are a further three ecological communities listed as Endangered Ecological Communities that are protected under the *TSC Act*.

Ecologically endangered communities which exist in the area include:

- Cumberland Plain Woodland*
- Shale/Sandstone Transition Forest*
- Turpentine Ironbark Forest in the Sydney Basin Bioregion (Critically Endangered)*
- Coastal Saltmarsh
- Swamp Oak Floodplain
- Freshwater Wetlands.

A list of species from the Sydney Turpentine Ironbark Forest located in the Newington Reserve, Sydney Olympic Park can be found in SOPA (2008e).

Urban Bushland Management Consultants (2006) identified Swamp Oak Floodplain Forest and Freshwater Wetlands within the Clyde refinery site.

Mapping provided by the Sydney Metro CMA indicates that there are some areas of saltmarsh vegetation within the study area that are listed as an Endangered Ecological Community. These are indicated in **Figure 10.1**.

10.5.4 Key Threatening Processes

Key Threatening Processes, as listed under the *TSC Act*, are defined as processes that currently do, or have the potential to, pose a threat to the survival of species, communities or populations. Those that are considered particularly relevant to the Parramatta River Estuary include:

- Predation by feral cats.
- Predation by the European Red Fox.
- Alteration of the natural flow regimes of rivers, streams, floodplains and wetlands.
- Human caused climate change.

- Entanglement in, or ingestion of, anthropogenic debris in marine and estuarine environments.

10.5.5 National and Internationally Protected Matters

Matters of national significance (with respect to flora and fauna) identified under an *EPBC Act Protected Matters Report* include:

- World Heritage places,
- National Heritage places,
- Ramsar wetlands,
- Threatened species and ecological communities,
- Migratory species, as identified under the Bonn Convention, Japan Australia Migratory Bird Agreement (JAMBA) and China Australia Migratory Bird Agreement (CAMBA), and other listed migratory species, and
- Commonwealth marine areas.

Nationally and internationally protected matters relating to the study area were identified via the generation of a series of *EPBC Act Protected Matters Reports* (undertaken 14/12/07) for each of the LGAs located within the study area and with foreshore frontage. The full reports can be viewed in **Attachment 8** and the results have been summarised below in **Table 10.8**.

In addition, a number of natural sites are listed under the Australian Heritage Database, including:

- Brays Bay Wetlands,
- Ermington Bay Wetlands,
- Haslams Creek Wetlands,
- Homebush Bay Wetlands,
- Lower Duck River Wetlands,
- Majors Bay Wetlands,
- Mason Park Wetlands,
- Meadowbank Park Foreshore Wetlands,
- Silverwater Saltmarsh, and
- Yaralla Bay Wetlands.

The Protected Matters Reports state that these nine wetlands together formed an extensive wetland system bordering the Parramatta River. In particular, the mangroves lining the Parramatta River represent a significant proportion of those remaining in the Sydney Region and those in the Lower Duck River represent the oldest known stand of mangroves in NSW. The Silverwater Saltmarsh complex incorporates highly significant saltmarsh species that do not commonly occur in the Sydney region. This saltmarsh complex is in excellent health and comprise a small intact ecosystem that representative of pre-European vegetation that can no longer be found. These wetlands and saltmarsh habitats support a wide range of fauna, including several important migratory bird species.

The Bicentennial Park and Newington Wetlands are listed as nationally important wetland sites. It is understood that a *Draft Plan of Management Homebush Bay Wetlands (Bicentennial Park)* is on the interim list for the Register of the National Estate.

The limitations of the Protected Matters Search Tool are acknowledged at the conclusion of each report.

Table 10.8 Species Protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999

		Threatened Species			Migratory Species			Marine Species (Overfly Marine Areas)	Threatened Ecological Communities	
		Extinct	Endangered	Vulnerable	Terrestrial	Wetland	Marine		Endangered	Critically Endangered
Avifauna										
Fork-tailed Swift	*Apus pacificus*						M	M		
Great Egret	*Ardea alba*					M	M	M		
Cattle Egret	*Ardea ibis*					M	M	M		
Latham's Snipe	*Gallinago hardwickii*					M		M		
White-bellied Sea Eagle	*Heliaeetus leucogaster*				L			M		
White-throated Needletail	*Hirundapus caudacutus*				M			M		
Swift Parrot	*Lathamus discolor*		*					M		
Rainbow Bee-eater	*Merops ornatus*				M			M		
Black-faced Monarch	*Monarcha melanopsis*				BM			M		
Satin Flycatcher	*Myiagra cayanoleuca*				BL			M		
Pacific Golden Plover	*Pluvialis fulva*					L		M		
Australian Painted Snipe	*Rostratula australis*			*						
Painted Snipe	*Rostratula australis s. lat.*					M		M		
Rufous Fantail	*Rhipidura rufifrons*				BM			M		
Little Tern	*Sterna albifrons*							M		
Regent Honeyeater	*Xanthomyza phyrgia*		*		L					
Amphibians										
Giant Burrowing Frog	*Heleioporous australiacus*			*						
Green & Golden Bell Frog	*Litoria aurea*			*						
Stuttering Frog	*Mixophyes balbus*			*						
Southern Barred Frog	*Myxophyes iterates*		*							
Mammals										
Large Pied Bat	*Chalinolobus dwyeri*			*						
Spotted-tail Quoll	*Dasyurus maculatus*		*							

		Threatened Species			Migratory Species			Marine Species (Overfly Marine Areas)	Threatened Ecological Communities	
		Extinct	Endangered	Vulnerable	Terrestrial	Wetland	Marine		Endangered	Critically Endangered
	maculatus									
Brush-tailed Rock Wallaby	*Petrogale penicillata*			*						
Long-nosed Potoroo	*Potorus tridactylus tridactylus*			*						
Grey-headed Flying Fox	*Pteropus poliocephalus*			*						
Reptiles										
Broad-headed Snake	*Holocephalus bungaroides*			*						
Plants										
Downy Wattle	*Acacia pubescens*			*						
Lobed Blue-grass	*Bothriochloa bilboa*									
Thick-lipped Spider Orchid	*Caledenia tessellata*			*						
Leafless Tongue-orchid	*Cryptostylus hunteriana*			*						
	Darwinia biflora			*						
	Deyeuxia appressa									
Camfield's Stringybark	*Eucalyptus camfieldii*			*						
	Grevillea parviflora subsp. Parviflora			*						
	Leptospermum deanei			*						
Deane's Maleluca	*Maleluca deanei*			*						
	Persoonia nutans		*							
	Pimelea curviflora var. curviflora			*						
	Prostanthera marifolia	*								
	Tetratheca glandulosa			*						
Communities										
Cumberland Plain Woodland									L	
Shale/Sandstone Transition Forest									L	
Turpentine Ironbark Forest in the Sydney Basin Bioregion										L

		Threatened Species			Migratory Species			Marine Species (Overfly Marine Areas)	Threatened Ecological Communities	
		Extinct	Endangered	Vulnerable	Terrestrial	Wetland	Marine		Endangered	Critically Endangered
Coastal Salt Marsh									L	
Swamp Oak Floodplain									L	

L=species or habitat likely to occur in area; M=species or habitat may occur in area; BM=breeding may occur in area; BL=breeding likely to occur in area.

10.6 Management Issues

Based on the data compilation and review provided in **Section 10**, a preliminary list of key management issues relating to estuarine ecology has been compiled:

- **Habitat loss** associated with the Parramatta River estuary has been a significant issue over the years. However, significant improvements have been made in recent years, in addition to which declines in industry along the estuary have occurred. This has addressed this issue at least in part. Nonetheless, foreshore development (including the construction of seawalls) remains a serious threat to estuarine habitats.

- **Habitat management** for biodiversity conservation needs to be coordinated across the entire study area. Whilst efforts are being made to restore natural habitats, these may be counterproductive in the short-term. For example, degraded, weed infested habitat may provide the structural complexity to act as a refuge that is not afforded by recently re-vegetated areas. In this case, a staged approach to habitat management should be adopted.

- **Management of mangrove expansion** is also an issue where it impacts on other estuarine habitats such as saltmarshes or mud flat areas commonly used by wading birds. While a certain amount of natural flux in mangrove extent is to be expected, the data review indicates that mangroves are currently expanding at the expense of other estuarine habitats such as saltmarsh and intertidal mudflats.

- **Conflicts between human activities and the ecology** are common. This is due to the proximity of the estuary to high density residential and urban areas. Issues include unauthorised removal and/or damage of estuarine vegetation by residents, trampling of off-path vegetative areas and the introduction of pest species. Human activities impacting on the environment include:
  - Damage to seagrass by boat moorings.
  - Damage to estuarine vegetation in relation to the informal storage of dinghies.
  - Pollution and contamination relating to urban and industrial land uses.
  - Access by pedestrians and cyclists to off-track areas.
  - Off-leash dog walking.
  - Removal of mangrove and saltmarsh plants.
  - Damage to estuarine vegetation as a result of bank erosion (by boat wake, scour associated with stormwater outlets, pedestrian traffic, etc.).
  - Reclamation and dredging activities.
  - Degradation and canalisation of natural waterways.

- **Introduced species** are prevalent throughout the study area. Whilst few targeted studies have investigated their impacts on native species, it is thought that they are having a significant negative impact on native flora and fauna, be it through simple displacement or more complex processes, such as competition for resources.

- **Poor water and sediment quality** lead to a range of impacts on the estuarine ecology, although the extent to which this occurs is not fully understood. The bioaccumulation of toxic contaminants in aquatic organisms is known to be an issue and is known to be negatively impacting of the health of estuarine flora and fauna, as well as human health. Other issues directly affecting estuarine flora and fauna include:
  - Sedimentation and/or smothering.
  - Ecotoxicology and bioaccumulation.
  - Scouring and/or erosion.
  - High levels of nutrients in stormwater runoff promoting algal growth.

- **Conservation and Management of Threatened Species/Communities** appears to be largely uncoordinated throughout the study area and corridors linking important habitats are lacking.

- **Climate change** has the potential to have a number of largely unknown impacts on the estuarine ecology. Whilst some effort has been directed towards this issue (see **Section 10.2.2.2**), a general appreciation of the impacts is lacking. This is a particular issue for such a heavily modified, urban environment such as that found on the Parramatta River Estuary, as the natural paths of retreat and coping mechanisms adopted by biota may not be feasible.

10.7 Data Gaps

The following data gaps have been identified with respect to the ecology of the Parramatta River Estuary:

General:

- The effects of pollution on the estuarine ecology are not fully understood. However, in general, it appears that the overall ecological health of the Parramatta River Estuary has improved in recent years.
- The impacts of introduced species on the native estuarine flora and fauna have not been characterised.
- The impacts of climate change and sea level rise on estuarine flora and fauna are currently unknown. It is noted that there is a currently ongoing research into this issue being conducted around Australia, including within the study area. However, the ecological response to climate change impacts is likely to be complex and difficult to predict.
- There is no definitive spatial database of the areas negatively impacted by human activities.

Flora:

- An up to date assessment of riparian vegetation has not been conducted for the all the tidal sections of the key tributaries to the Parramatta River Estuary. Sydney Metro CMA and DECC are currently mapping vegetation across the Sydney Metropolitan Basin with results expected during the second half of 2008.
- Patterns of change in estuarine flora are not adequately characterised for the study area.
- Methodical approaches to managing mangrove incursion into other estuarine habitats are currently lacking.
- Little is known about the macroalgal or phytoplankton ecology of the study area and how they support estuarine food webs.
- Whilst it can be reasonably concluded that the wake from the RiverCat service is causing bank erosion and undermining of mangroves in the upper estuary, the findings of the 2002 NSW Maritime study have not been made available. In addition, there does not appear to have been a targeted assessment of the effects of scour associated with stormwater outlets.
- Little information was available regarding the success of habitat restoration programs.

Fauna:

- Whilst there is some information available on the fish fauna of the estuary, very few comprehensive assessments covering the entire study area have been conducted.
- Bioaccumulation of toxins is known to be a problem. Whilst it is understood that there is ongoing monitoring of fish for toxin levels, no further details were found during the course of this study. In addition, the effects of bioaccumulation of toxins on other species are unknown, apart from a limited amount of anecdotal evidence.

- No data sources were identified with respect to the effect of recreational fishing on the fish ecology.
- Whilst there is a great deal of information on the avifauna of the area, data on patterns of change in bird populations is limited.
- Very little information was found on the occurrence of mammals, reptiles, amphibians and invertebrates in the study area as a contiguous unit.
- There is no known data on zooplankton in the estuary.

Introduced Species:

- Adequate information is known about the introduced species found in the study area, although the specific impacts that these exotic species have on the native flora and fauna is largely unknown, primarily for exotic aquatic species.

10.8 Further Studies

Below is a list of recommended further studies:

- Assess the foreshore vegetation of the study area as a whole and prioritise stretches of the foreshore for re-vegetation. Considerations of the site constraints and fauna communities present should be incorporated into the prioritisation process. This should include consideration of climate change processes such as sea level rise. For example, locations at which the landward migration of estuarine wetlands will not be impeded by foreshore development. Buffer areas for landward migration should be provided where possible.
- Condition assessment of estuarine vegetation to facilitate prioritisation of rehabilitation works. As mentioned above, key considerations for prioritisation should include site constraints (e.g. relating to human usage and tidal inundation) and fauna communities present.
- Identify locations in which mangroves are becoming established to the detriment of other estuarine habitats, or in otherwise inappropriate locations, and assess the need for management.
- Identify portions of the river bank affected by scour, recommend appropriate ameliorative actions and prioritise for works based on habitat values.
- The undertaking of an assessment of the impacts of RiverCat boat wake on foreshore stability may be included in the Estuary Processes Study. However, this may be considered a low priority given that the existing evidence reasonably implicates the RiverCat boat wake as being the chief cause of bank undermining and mangrove collapse in the upper portion of the estuary, coincident with locations in which the RiverCat is the primary form of boat traffic and private vessels are banned.
- Explicit assessment of the potential impacts of climate change and ongoing human usage on the estuarine flora and fauna. To incorporate as a priority an assessment of the potential impacts of sea level rise on estuarine flora.
- An assessment of the success of programs to re-establish estuarine vegetation.
- Identification of those natural areas most heavily impacted by human usage. Once identified, the types of impact can be assessed in order to develop methods to reduce these impacts.
- Develop an understanding of primary production in the estuarine environment.
- Ongoing monitoring of key ecological indicators of both ecological integrity and biodiversity as it relates to the estuary. This monitoring should aim to facilitate identification of patterns and directions of change.
- Undertake a study of the plankton ecology of the estuary.
- Undertake a comprehensive survey of the fish fauna of the estuary.
- Examine the existing data set on avifauna to assess any trends in birds populations associated with the estuary. This may be correlated with any changes in the available habitat or major land use changes.

11. HUMAN USAGE AND RECREATION

11.1 Data Sources

The following data sources have been used in relation to human usage and recreation within the study area:

- Anon. (2007b)
- Architectus (2005)
- Arup (2005)
- Bartlett (2007)
- Cherry (2007)
- Clouston (1994a)
- Cranston (2005)
- DEAP (1986a)
- DEAP (1986d)
- DoP (1989)
- DIPNR (2003a)
- DIPNR (2003a)
- DoP (2003)
- DoP (2004)
- DoP (2005a)
- DoP (2006)
- DoP (2007a)
- DoP, CMC and CoR (1989)
- DPI (2004)
- DPI Fisheries (2005)
- DPI Fisheries (2006a)
- DPI Fisheries (2006b)
- DPI Fisheries (2007a)
- DUAP (1999b)
- DUAP (2000)
- EDAW (1998)
- Environmental Partnership (2007)
- GHD (1990)
- Jamieson Foley Traffic & Transport and Sustainable Transport Solutions (2005)
- LMC (2004b)
- Maple, Paterson and Garrard (1984)
- Marla Guppy & Assoc. (1994)
- Mather & Associates and Storm Consulting (2003)
- Menzies (2007)
- NSW Maritime (2008e)
- Pac Rim Planning (1994)
- PCC (2007b)
- Pod Landscape Architecture, Cavanough and Jamieson Foley Traffic & Transport (2006)
- SHFT (2007a)
- SHFT (2008a)
- SOPA (2002a)
- SOPA and NPWS (2003a)
- Thomson (2007)
- Webb McKeown & Assoc. (1997)
- Whan (2007)
- Widmer and Underwood (2004).

11.2 Planning Context

There are numerous plans, policies and frameworks relating to the human usage and recreational usage of the estuary. While some of these documents are outdated it is important not to disregard the consultation and visions compiled in these documents. Some of the key documents have been listed below:

- *Open Space and Recreation – Parramatta River Regional Environmental Study* (DEAP, 1986a & 1986b). This study relates to the open space and recreation potential within the Parramatta River Region. It identifies the major issues at the time and provided a basis for future planning in the area.
- *Draft Sydney Regional Environmental Plan, Parramatta River* (Department of Planning Sydney, 1989). This document aims to provide a framework which encourages a consistent and coordinated approach to the planning, development and management of the water and foreshore open space and facilities of the Parramatta River.
- *Sydney Harbour Catchment Regional Environmental Plan 2005* (NSW Government, 2005). Provides an improved and clearer planning framework and better environmental outcomes for Sydney Harbour and its tributaries.

- *Sydney Harbour Foreshores and Waterways Area Development Control Plan 2005* (DoP, 2005b). Applies to the Foreshores and Waterways Area as identified in the Harbour REP. The DCP includes design guidelines for development, assessment criteria for marinas (including guidelines for undertaking visual impact assessments), and criteria for natural resource protection.
- *Boat storage policy 2004* (DIPNR & Waterways, 2004). Provides a more strategic and certain approach to regulating boat storage facilities such as marinas, single moorings, and dry boat storage. It has been prepared by the Department and NSW Maritime as a guide for State agencies, local government, the boating industry and the community.
- *Sharing Sydney Harbour Regional Action Plan* (2000). This document was prepared to provide a streamlined framework for the balanced and holistic management of the foreshore lands of the Parramatta River and Sydney Harbour. Framework plans were prepared for a number of strategic sites within the study area, including Camellia Peninsula, Homebush Bay West, Yaralla and Cockatoo Island.

It is important to note that many of the numerous parks and reserves have Plans of Management which provide guidance for managing those areas. Many of these Plans are compiled in the database for this study (see **Appendix B**). A number of Councils also have strategies or documents to guide planning for and management of recreational areas, open space areas and transport within each LGA (such as the *Parramatta Open Space Plan, 2003*). Many of these plans are also compiled within the database.

11.3 Foreshore Use

The Sharing Sydney Harbour Program provides guidance for the management of all Sydney Harbour foreshores, including those along the Parramatta River estuary. The vision for Sydney Harbour described in DUAP (2000) is as follows:

"[to take] wise and comprehensive care of the Harbour as a natural asset belonging to future generations, and sharing the Harbour with nature and for all human activities."

In addition, the Harbour REP (NSW Government, 2005b) identifies several foreshore sites that are considered to be strategically significant in terms of their prominent location, size and/or potential for redevelopment. Thirteen sites were identified in the Parramatta River Estuary. These sites are shown on **Figure 11.1**. Specific controls (including master planning provisions) apply to any development works (including provisions for open space and recreation) proposed at these sites.

11.3.1 Shore-Based Facilities and Infrastructure

The Parramatta River (along with Sydney Harbour) is the most significant waterway in Sydney. Since European settlement, the river and the harbour have presented a formidable barrier to development north of the waterway - it literally cuts Sydney in half. As a result, the many crossings are extremely important to the life of the City. From east to west they are:

- Gladesville Bridge
- Mortlake Ferry (the last vehicular ferry operating on the river)
- Ryde Bridge (now a dual bridge)
- Old Meadowbank railway bridge (converted into a pedestrian and cyclist bridge)
- John Whitton Bridge (the new railway bridge)
- Silverwater Bridge at Silverwater
- Pedestrian Bridge near Rydalmere ferry wharf
- Carlingford Line railway bridge and adjacent water pipe bridge
- James Ruse Drive bridge

- Gasworks Bridge, Parramatta (historic iron lattice bridge named for the Gasworks which used to be situated nearby).

In 2007 the NSW Government announced an extra $6.75 million in funding to extend its support for public walking and cycling tracks, and recreational boating facilities around Sydney Harbour to at least 2013. The boost is in addition to the $1.3 million also announced for the 2007 funding round of the Sharing Sydney Harbour Access Program (Whan, 2007).

Sharing Sydney Harbour Access Program is a NSW government initiative to improve public access to and enhance the recreational enjoyment of Sydney Harbour and its tributaries for the people of and visitors to Sydney. The Sharing Sydney Harbour Access Program was launched in February 2003 to assist with implementing the Sharing Sydney Harbour Access Plan (DIPNR, 2003a).

Up to 2008, 123 projects across 20 council areas had received grant funds under the Sharing Sydney Harbour Access Program. With matching funds from grant recipients, these projects will deliver at least $13 million worth of access and recreational improvements, including (DoP, 2003, 2004, 2005a, 2006, 2007a):

- 28 km of new or improved walking/cycling paths
- improvements to three boat ramps
- public domain improvements at 40 locations
- new or improved small boat access facilities at 32 locations
- dinghy storage facilities at 29 locations
- 14 new or improved pick-up and set-down wharves and jetties.

Twenty five capital works projects have also been funded under the Parramatta River Foreshores Improvement and Metropolitan Greenspace programs. These works include foreshore parks, cycle and pedestrian paths and foreshore access points (DoP, 2008).

As part of the Parramatta River Foreshores Improvement Program an audit was undertaken to assess the condition of the Parramatta River Estuary Foreshore and to identify priorities and cost remediation works. The audit found that there is approximately 46.6 km of public foreshore and 24.85 km of private foreshore. The replacement value of public foreshore seawalls was estimated to be $62.1 million (excluding Leichhardt City Council area) (Webb McKeown & Assoc., 1997). Leichhardt City Council undertook a separate audit. The locations of the seawalls in the study area are shown on **Figure 11.2**.

Upper-Parramatta River Estuary

Parramatta City Council have recently commissioned Environmental Partnership to revise the current Parramatta River Foreshores Reserves Concept Plan and Management Strategy (Clouston, 1994a) and develop a prioritised action / implementation plan to consistently guide the future management and development of the Upper-Parramatta River Estuary Foreshore over the next 20 years (Environmental Partnership, 2007). The findings of this study should be incorporated into the Estuary Management Plan.

The Parramatta Valley Cycleway (PVC) has been in existence since the early 1990s. The PVC at this time was a 15km route commencing in the west at the Tudor Gatehouse at Parramatta Park and finishing in the east at Putney Park in the Ryde LGA. The route was both on and off-road and was located on both the northern and southern shores of the Parramatta River. In 2005 Parramatta City Council developed a Master Plan for the cycleway which comprised of a complete off-road cycleway along the northern foreshore of the Parramatta River from Church Street, Northmead to Wharf Road, Ermington (Arup, 2005). At this time, 4.7km of the 12km cycleway had been constructed, although these sections were located some distance apart within the suburbs of Parramatta, Rydalmere and Ermington. The most significant constraint to the completion of the PVC to date has been due to the presence of land or properties along the route that are in non-Council ownership (Arup, 2005).

In 1998, a foreshore improvement plan was prepared for the Lower Duck River (EDAW, 1998). The Plan was prepared as part of the Parramatta River Foreshores Improvement Program and identifies a series of planning recommendations which direct a range of activities relating to improving the foreshore with respect to the natural and cultural context of the area.

The Parramatta River Walk is a loop beginning and ending at Rhodes Station with access points at various stages along the loop. The walk includes a river crossing by ferry and one by train (DoP *et al*, 1989).

Mid-Parramatta River Estuary

An assessment of the existing pedestrian and cyclist infrastructure was undertaken at Wentworth Point, Homebush Bay. It was considered that the site currently has a fairly high level of pedestrian and cyclist amenity (Architectus, 2005). *The Homebush Bay – Wentworth Point Master Plan* (Architectus, 2005) provides maps and descriptions of the pedestrian and cyclist infrastructure at this location.

The River Walk project undertaken by the City of Ryde is to provide a vision and working plan for a recreation trail focused along the Parramatta River within the Ryde Local Government Area (LGA). The trail proposes to connect existing foreshore parks and provide an important link in a regional system of recreation trails. The study develops a strategy for the staged implementation and enhancement of the recreation trail over time (Pod Landscape Architecture *et al*, 2006).

Lower-Parramatta River Estuary

The Bay Run is a 7km walking / cycling trail that provides a loop around the foreshore of Iron Cove (including the Iron Cove Bridge). The Bay Run is part of an open space corridor that links 9 park and reserve areas. Along the Bay Run there are also several playing fields, 2 swimming pools and 2 rowing clubs. The Bay Run draws thousands of walkers each day (DUAP, 1999b).

The Canada Bay Bike Plan (Jamieson Foley Traffic & Transport and Sustainable Transport Solutions, 2005) provides details of bicycle routes and facilities within the Canada Bay LGA.

11.3.2 Key Recreational Areas and Open Space

There is a public perception that there is a lack of physical access to and along the Parramatta River Estuary foreshores (Architectus, 2005). As a result of this perception, a key principle of the Sharing Sydney Harbour Regional Action Plan (DIPNR, 2003a) is the expansion of both opportunities for waterfront access as well as increased provision of waterfront open space. These principles are further reflected within the stated objectives of SEPP 56, now contained in the Harbour REP (NSW Government, 2005b).

Much of the foreshore is still in the hands of industry and private individuals as residences, however there is an increasing amount of waterfront land available as foreshore reserve with walkways and cycleways. As former industrial sites undergo remediation and redevelopment the foreshores are opened up for public access. Where there is no foreshore access, cycleways are routed through quiet residential streets with clearly marked sections of the road reserved for cyclists.

Major foreshore parks include:

- Cabarita Park
- Kissing Point Park, Ryde
- Meadowbank Park
- Putney Park
- George Kendall Riverside Park, Ermington
- Bicentennial Park, Homebush Bay
- Millennium Parklands, Homebush/Auburn.

An outdoor recreation study was undertaken in 1986 which identified the supply of outdoor land-based recreation on public land along the Parramatta River Foreshore. The study found that there was a dominance of single use activities and limited recreation diversity. It was recommended that action should be taken to establish a strong open space policy aimed at increasing recreation diversity and multiple-use management within the context of public demand (Maple *et al*,1984).

It is understood that a number of foreshore Councils, including Parramatta and Ryde, are making efforts to establish foreshore linkages and provide open space along the estuary foreshore. The redevelopment of former industrial sites has assisted this process, whereby the re-zoning of the land for residential use provides Councils with an opportunity to ensure that the foreshore areas are retained for open space and recreational usage.

During the consultation process, concerns were raised by a number of staff from the various foreshore Councils regarding the potential loss of foreshore open spaces due to sea level rise under climate change. The key point with respect to this issue is that, for several LGAs, the foreshore open spaces form the majority of the available open space for recreation within that LGA. At present, foreshore inundation occurs on spring high tides in Meadowbank Park and for all high tides for Putney Park (pers. comm, G. Johnston, CoR, 3 March 2008). Without intervention this issue is likely to compound existing shortages in open space within these LGAs.

Upper Parramatta River Estuary

The Parklands at Sydney Olympic Park cover 432 hectares. Remnant woodlands, rare saltmarshes and mangroves stand alongside constructed places of historical significance. They are a place of Aboriginal significance and of historic naval importance. An immense brick pit, now home to endangered frogs, once supplied clay for the characteristic red bricks of many Sydney houses. Under the Sydney Olympic Park Authority Act 2001, the Authority is obliged to protect, maintain and improve the Parklands as a means of promoting the recreational, historical, scientific, educational and cultural value of the Parklands. The legislation also requires that these obligations are translated into a viable operational plan. Parklands 2020 (SOPA, 2002a), was the main reference point for the plan of management (SOPA & NPWS, 2003a), it suggested how the future of this space could be shaped and showed how both the natural and the constructed physical characteristics of the Parklands could be enhanced within the context of available resources. Parklands 2020 is the current concept plan for the Parklands. As the concept plan, it is both the update and elaboration of the original Millennium Parklands Concept Plan.

Bankstown City Council prepared a biodiversity plan for the Duck River (Mather & Associates and Storm Consulting, 2003). In addition to enhancing biodiversity values of the Duck River Corridor, the study also aimed to enhance and promote recreational opportunities through the management of the reserves as a discrete corridor. The study developed a master plan which provided a strategy for staging and funding of action along the corridor.

Lower Parramatta River Estuary

The Sydney Harbour Federation Trust encourages visitation to Cockatoo Island (SHFT, 2007a & 2008a) organised tours are also available.

Off leash dog areas are of importance within the Leichhardt LGA. *The Access to Open Space Strategy for Dogs* (LMC, 2004b) provides details on all existing open space areas with off leash areas for dogs.

11.3.3 Boating Foreshore Facilities

Boating activities on the Parramatta River Estuary are discussed in more detail in **Section 11.4.1**. However, it is important to note that waterway activities such as boating, have an associated land requirement such as a means of access to the water (*e.g.* launching ramp, wharf or beach) or a building (*e.g.* marina or boat club).

One of the most prominent issues associated with boating foreshore facilities is the lack of formal dinghy storage facilities. Dinghies are scattered along the Parramatta River Foreshore, leaning against walls, rock shelves and trees. Informal access to these locations often results in the degradation of foreshore vegetation. Several examples of the ad hoc approach to dinghy storage are provided in **Figure 11.3**.

Facilities associated with boating activities (as identified by NSW Maritime) are shown on **Figure 11.4**. This figure includes both water based and foreshore facilities. The details on wharves, jetties and public access is summarised below in **Table 11.1**. It is understood that NSW Maritime also monitors the condition of foreshore infrastructure such as seawalls and wharves (pers. comm, Environmental Officer, PCC, 14 February 2008). However, it is not known if this is conducted in a formal or informal fashion, or what activities are undertaken as part of that monitoring program.

Table 11.1 Jetties, Wharves and Public Access (NSW Maritime)

Facility	Number
Public Wharf\Jetty or Landing	23
Marina Boatshed\or Boat Hire	9
Public Access\Available	4

The Boating Industry Association of NSW undertook a survey of boat owners in 1974 and 1975. This study is now outdated. However, the study found that over 70 percent of recreational craft were carried by a trailer and the large majority if these users held the opinion that the provision of launching ramps and facilities was inadequate (DEAP, 1986a).

The Harbour REP (NSW Government, 2005) through the implementation of the *Sydney Harbour Boat Storage Policy* (DIPNR & Waterways, 2004) lifts the 'moratorium' that resulted from the prohibition of large marinas (30 berths or more) under SREP 23 and NSW Maritime deferring consideration of all applications for land owner's consent for development applications for large marinas. The prohibition of large marinas has been removed through the zoning provisions permitting commercial marinas in several zones around the Harbour and the release of NSW Maritime's new Land Owner's Consent Manual.

In response to demand from the boating industry and the community for a more strategic approach to managing storage facilities for recreational boats, DIPNR (now DECC) and NSW Maritime jointly prepared a Boat Storage Policy for Sydney Harbour (DIPNR & Waterways, 2004). This document sets out the NSW Government's strategic policy for dealing with various forms of boat storage on the Harbour, including marinas, single moorings, private wharves and jetties and dry boat storage.

The boating storage policy:

- Discourages the proliferation of private storage facilities in order to free up navigable water space and limit privatisation of the foreshore and waterway.
- Permits the development of commercial marinas in appropriate locations in order to promote working harbour and recreational use of the foreshores and waterways.

There is a proposed Marina in Kendall Bay at Breakfast Point. The proposed commercial marina would comprise of seven jetties and 177 berths. There has been some community opposition to the proposal (Thomson, 2007).

11.3.4 Public Art

A Public Art and Design Study was undertaken for Parramatta in 1994 (Marla Guppy & Assoc., 1994). One of the objectives of this study was to develop opportunities for public art projects that reinforce links between the River and the social history of Parramatta.

Over the next ten years, Parramatta City Council will incorporate public art and other mediums into the LGA to share significant historical and contemporary stories of Parramatta (PCC, 2007b).

A public art strategy that animates and reveals the landscape and stories of the places of the local area has been proposed in conjunction with the Ryde River Walk trail (Pod Landscape Architecture *et al*, 2006).

11.4 Waterway Use

11.4.1 Boating

There were 15,100 registered boating vessels on Sydney Harbour in 2003. This represents an increase of only 1% since 1995. However, there has been a significant change in the type of boats owned, with a trend towards larger motor cruisers which need marina berths rather than individual mooring buoys. Over the eight years between 1995 and 2003, the number of sailing boats remained static at about 3,400, while motor cruisers increased in number by 10% up to a total of 2,100 (Dick *et al*, 2004).

Management of recreational boating is typically based on measures of numbers of boats (*e.g.* marina berths, vessel registrations). Potential environmental impacts and safety aspects may, however, be a function of the number of boat movements and not of the total numbers of boats kept in a harbour. A survey was undertaken in 2004 to test this hypothesis (regarding the traffic and anchoring patterns of recreational boats in Sydney Harbour). This study quantified and identified clear patterns of recreational boat traffic. Managers can now use this information to develop strategies aiming at the improvement of boating safety and the prevention of potential environmental impacts due to the use of recreational boats in urban waterways (Widmer *et al*, 2004).

The RiverCat

There are RiverCat services along the Parramatta River to Circular Quay. The main wharves are (Sydney Ferries, 2008):

- Cockatoo Island
- Drummoyne
- Huntleys Point

- Chiswick
- Abbotsford
- Bayview Park
- Cabarita
- Kissing Point
- Meadowbank
- Sydney Olympic Park
- Rydalmere
- Parramatta.

There have been discussions recently regarding the discontinuation of the RiverCat service on the grounds that it causes erosion of the banks along the Parramatta River posing a threat to both ecological habitats and private and public infrastructure. The undermining of the mangroves in the upper estuary is particularly evident. However, there have been some strong objections to this proposal. It has been suggested that the RiverCat reflects Sydney's history (boat travel before highways) and that if the times of the service were changed to peak afternoon and morning travel times, there would be a much higher usage (Anon, 2007b).

Interestingly, the EIS prepared for the ferry service (GHD, 1990) concluded that undermining of the mangroves would be unlikely. Based on this conclusion, the Department of Transport (1991) determined that the impact on foreshore vegetation would be monitored and if necessary restrictions would be placed on other vessels. Boats other than the RiverCat, NSW Maritime and the police are restricted from accessing the Parramatta River waterway upstream of the Silverwater Bridge, including Duck River (Holland, 2005).

Sailing and Yachting

There are a number of sailing and yachting clubs on the estuary, including:

- Abbotsford 12ft Flying Squadron in Abbotsford (http://www.abbotsfordsailingclub.org.au/),
- Concord & Ryde Sailing Club at Putney (http://www.concordrydesailing.org), and
- Parramatta River Sailing Club at Gladesville (http://www.prsc.org.au/).

Sailing takes place under an aquatic licence granted annually by NSW Maritime (NSW Maritime, 2008j).

Rowing

The estuary has a long historical association with rowing. There is a monument in honour of Henry Searle, a champion sculler of his day, in the river at Henley.

Some of the school rowing sheds are (Wikipedia, 2008):

- MLC School
- The King's School
- Sydney Boys High School
- Newington College
- The Scots College
- Sydney Grammar School
- Shore School.

There are a number of rowing clubs in the study area (Wikipedia, 2008):

- Leichhardt Rowing Club (Iron Cove)

- Drummoyne Rowers in Iron Cove
- Sydney Rowing Club at Abbotsford
- UTS Haberfield at Haberfield
- Balmain.

While a number of regattas are still held on the river each year, mainly in Iron Cove, many of the major regattas are now held at the Sydney International Regatta Centre (SIRC) where rowing was held for the 2000 Summer Olympics. Early GPS Schoolboy Head of the River races were held on the Parramatta River before moving to the Nepean River and later SIRC (Wikipedia, 2008).

Most rowing training is done in the middle to upper reaches of the river between Abbotsford and Homebush Bay because there is less water traffic and therefore less waves and more protection from wind. Rowing also takes place in Iron Cove which also has less traffic (Wikipedia, 2008).

In September 2007, Parramatta River hosted the World Dragon Boat Racing Championships (Cherry, 2007). Dragon boating is a popular sport in Iron Cove, particularly on Sunday mornings (Cranston, 2005).

Moorings

A summary of the private and commercial moorings in the study area is shown below in **Table 11.2** and on **Figure 11.5**.

The boat storage policy (DIPNR, 2004) supports the conversion of swing moorings to fixed berths in appropriate locations.

Table 11.2 Private and Commercial Boat Moorings (NSW Maritime, 2008e)

BAY NAME	No. of Private Moorings	No. of Commercial Moorings	Total No. of Sites	No. of Applications Pending
Bedlam Bay	39	1	40	5
Betts Bay	20	1	21	1
Glades Bay	53	-	53	-
Henley Bay	40	1	41	-
Huntleys Point	16	-	16	-
Kissing Point Bay	57	27	84	1
Looking Glass Bay	27	1	28	-
Lukes Bay	28	-	28	-
Meadowbank	20	1	21	-
Morrisons Bay	106	3	109	-
P'matta River, Gladesville	20	-	20	-
P'matta River, Hunters Hill	33	1	34	-
P'matta River, Woolwich	12	29	41	1
Tarban Creek East	20	1	21	-
Tarban Creek West	67	-	67	1
Abbotsford Bay	49	15	64	-
Birchgrove	82	1	83	31
Brays Bay	62	3	65	-
Cabarita Point	14	-	14	3
Callan Park Bay	26	-	26	5
Drummoyne Bay	51	1	52	1
Drummoyne East	84	49	133	7
Drummoyne West	31	44	75	2

BAY NAME	No. of Private Moorings	No. of Commercial Moorings	Total No. of Sites	No. of Applications Pending
Exile Bay	18	-	18	1
Fig Tree Bay	5	44	49	5
Five Dock Bay North	106	1	107	-
Five Dock Bay South	66	-	66	-
France Bay	31	1	32	-
Half Moon Bay	64	4	68	13
Hen & Chicken Bay	69	18	87	-
Leichhardt Bay	69	-	69	5
Majors Bay	20	28	48	-
Sommerville Point	30	8	38	18
TOTAL	**1435**	**283**	**1718**	**87**

11.4.2 Fishing

The Parramatta River is subject to a number of fishing bans because of its contaminated sediments (**Section 10.3.1**). There is a complete fishing ban in Homebush Bay because of the dioxin contamination, and a complete commercial fishing ban throughout the rest of Sydney Harbour and its tributaries, including the Parramatta River.

The Parramatta River is one of the few significant coastal rivers in New South Wales which has not been the subject of a Healthy Rivers Commission Investigation. The Cooks River and Botany Bay have been subject to such an investigation. Some have campaigned for a Healthy Rivers Commission inquiry to bring together all the information on the state of the river and its sediments and fish and assist in watershed management. In 2004 the Healthy River Commission was discontinued and the Natural Resources Commission (NRC) established. Government has asked the Natural Resources Commission to consider the incorporation of any outstanding Healthy River Commission recommendations into Catchment Action Plans and Government programs.

Fishing licence fees from leisure anglers accrue to approximately $10.5 Million a year (including Sydney Harbour). These fees go to the NSW Department of Primary Industries (Bartlett, 2007). It is understood that a survey of recreational fishers is currently being undertaken for the Parramatta River and Sydney Harbour (Pers. comm., L. Diver, SMCMA, 3 June 2008). However, the results of that survey were not available at the time this report was prepared.

In 2005, declining fish numbers were observed in the estuary and Sydney Harbour. However, by mid-2007 the abundance and diversity fish had increased. Factors that are thought to have contributed to the increase include the commercial fishing ban in January of 2006, the ban on King Fish traps and dioxin warnings (Bartlett, 2007).

A total ban has been placed on commercial fishing as a precautionary measure after test results revealed elevated levels of dioxin in a number of species of fish and crustaceans in Sydney Harbour (commercial fishing bans are discussed below). Residues of dioxins in seafood caught in the Harbour/Parramatta River are likely to have their sources in contaminated sediments in or near Homebush Bay. Current levels are likely due to many years of industrial activities along those waterways. The Government has announced a $5.8 million package that includes a voluntary buy out of commercial fishing businesses, further testing for dioxins in the fish, and a public information campaign to advise recreational fishers and the community about the risks of eating seafood caught in the Harbour. Millions of additional dollars are being spent on cleaning up the contamination, particularly near Homebush Bay (DPI Fisheries, 2005).

As mentioned above, all commercial fishing activities in Sydney Harbour and the Parramatta River were banned in January 2006. However, otter trawl netting for prawns was banned in the Parramatta River earlier in 2003. **Table 11.3** outlines the methods of fishing and areas of fishing that were prohibited under a Section 8 Notification under the *Fisheries Management Act 1994* in 2003 and 2004.

Table 11.3 Commercial Fishing Bans 2003 (DPI, 2004)

Fishing Method	Prohibited Waters	Conditions
Weekend and Public Holiday netting closure Nets of every description, except the hoop or lift net, hand-hauled prawn net, push or scissors net, dip or scoop net and the landing net, as prescribed by Regulation.	The whole of the tidal waters of Port Jackson and its creeks, bays and tributaries, upstream (west) of a line drawn from the most southern extremity of North Head, to the most northern extremity of South Head.	This closure only applies from 8am Saturday to 8am Monday in each week, and from 8am to 6pm on any weekday Public Holiday.
Otter Trawl Net (prawns) By means of an otter trawl net (prawns), as prescribed by Regulation.	All tidal waters of that part of the Parramatta River, (south of Cockatoo Island) enclosed by the following boundaries: a) a line drawn from the eastern extremity of Cockatoo Island, southerly to the baths adjacent to Elkington Park. b) a line drawn from the western extremity of Sutherland Dock on Cockatoo Island, generally south to the western extremity of Sommerville Point.	
Parramatta River – Gladesville to Silverwater By means of nets and traps of every description, except the hoop or lift net, the hand-hauled prawn net, the push or scissors net, the dip or scoop net, the landing net, the otter trawl net (prawns), the pilchard, anchovy and bait net (hauling) (when used to take Krill only), the crab trap and the bait trap, as prescribed by Regulation.	The tidal waters of Parramatta River, together with its creeks, bays and tributaries, from the Gladesville Bridge upstream to the Silverwater Road Bridge (excluding Homebush Bay, which is closed under a separate schedule).	Finfish must not be retained by otter trawl net. Finfish must not be taken for sale by any method upstream of Gladesville Bridge in Parramatta River.
Parramatta River – Silverwater to Parramatta Weir By means of nets of every description, except the dip or scoop net and the landing net, as prescribed by Regulation.	The tidal waters of that part of the Parramatta River and its tributaries, from the Silverwater Road bridge, upstream to the Parramatta Weir (excluding waters of Duck River, which is closed under a separate schedule).	All finfish, crabs and prawns must not be taken for sale by any method above Silverwater Road Bridge. Fishing regulations for 'inland waters' apply above Parramatta Weir (non-tidal waters).
Parramatta River – Duck River and Homebush Bay All methods of fishing prohibited.	Duck River: The whole of the waters of Duck River, together with its creeks and tributaries, upstream to its source from its junction with Parramatta River. Homebush Bay: The whole of the waters of Homebush Bay, together with its creeks and	

Fishing Method	Prohibited Waters	Conditions
	tributaries, upstream (south) to its source from a line drawn between Rhodes Point and Wentworth Point.	
Iron Cove – Net and trap closure By means of nets and traps of every description, except the hoop or lift net, the hand-hauled prawn net, the push or scissors net, the dip or scoop net, the landing net, the otter trawl net (prawns), the pilchard, anchovy and bait net (hauling) (when used to take Krill only), the crab trap and the bait trap, as prescribed by Regulation.	The whole of the tidal waters of Iron Cove and its creeks and tributaries upstream of the Iron Cove Bridge.	Finfish must not be retained by otter trawl net. Finfish must not be taken for sale by any method in Iron Cove.
Pilchard, anchovy and bait net By means of a pilchard, anchovy and bait net (hauling), as prescribed by Regulation, only when the net is used as a floating net and landed on to the tray of a boat.	The whole of the waters of Port Jackson, together with its bays and tributaries, which are not closed to netting.	The net may only be used from 5am Monday to 8am Saturday in each week (excluding Public Holidays).
Shellfish closure - Port Jackson and tributaries All methods.	The whole of the tidal waters of Port Jackson and its tributaries, upstream of a line drawn from the northern extremity of South Head, to the southern extremity of North Head.	

Whilst a ban has been placed on all commercial fishing, recreational fishing has not been banned. However, fishers are urged to follow dietary advice on the consumption of seafood from the Sydney Harbour, Parramatta River and other connected tidal waterways. Fishers can also continue to practise catch and release. Based on advice from an expert panel, NSW DPI - Fisheries (2005) reports that the Government is recommending that:

- No fish or crustaceans caught west of the Sydney Harbour Bridge should be eaten.
- You should release your catch.
- For fish caught east of the Sydney Harbour Bridge generally no more than 150 grams per month should be consumed.

DPI NSW - Fisheries also provides additional and ongoing advice regarding this matter.

In November 2006, a Section 8 notification was issued under the *Fisheries Management Act 1994* prohibited the taking of the tunicate 'cunjevoi' (*Pyura* spp.) and all invertebrates, except abalone (*Haliotis ruber*), eastern rock lobster (*Jasus verreauxi*) and southern rock lobster (*Jasus novaehollandiae*), by all methods of fishing from the whole of the foreshores of Sydney Harbour and all its tributaries, west (upstream) of a line from the southern extremity of North Head to the northern extremity of South Head, but excluding those waters of North Harbour which are north of a line from Manly Point to the south end of Forty Baskets Beach (DPI Fisheries, 2006b).

In addition, there are a number of Intertidal Protected Areas located within the study area. These are discussed in **Section 10.3**.

11.5 Social Factors

The Bureau of Statistics defines data for the study area into six sub-areas. Key social data has been provided in **Table 11.4 to Table 11.6** for those areas. A summary of the demographic data for the whole study area is shown in **Figure 11.6**.

Table 11.4 Demographics (ABS, 2004 Census)

Demographics (years)	Area					
	Hunters Hill	Ryde	Parramatta	Auburn	Canada Bay to Concord	Canada Bay to Drummoyne
0 to 4	753	5,676	9,910	4,614	1,857	1,995
5 to 9	774	5,215	9,607	4,092	1,698	1,741
10 to 14	1,009	5,206	9,322	3,899	1,679	1,581
15 to 19	1,499	5,628	9,694	4,459	1,846	1,561
20 to 24	775	8,041	11,832	5,427	2,145	2,061
25 to 29	637	8,093	12,374	5,189	2,476	3,083
30 to 34	829	8,700	13,028	5,507	2,575	3,686
35 to 39	861	7,787	11,738	5,034	2,431	3,135
40 to 44	982	7,853	11,901	5,109	2,440	2,762
45 to 49	968	6,821	9,827	4,396	2,186	2,405
50 to 54	967	6,306	8,782	3,545	1,971	2,343
55 to 59	888	5,523	7,856	2,943	1,779	2,160
60 to 64	685	4,055	5,990	2,072	1,326	1,573
65 to 69	491	3,606	5,076	1,745	1,099	1,423
70 to 74	414	3,345	4,302	1,540	943	1,362
75 to 79	443	3,205	4,112	1,361	834	1,177
80 to 84	399	2,414	3,028	986	590	875
85 and over	515	2,032	2,406	758	504	718
Total	**13,889**	**99,506**	**150,785**	**62,676**	**30,379**	**35,641**

Table 11.5 Overseas Born Population (ABS, 2001 Census)

Overseas Born Population : Percentage of Total Population	Area					
	Hunters Hill	Ryde	Parramatta	Auburn	Canada Bay to Concord	Canada Bay to Drummoyne
Total Born overseas	24.7	35.4	36.6	52.2	33.8	27.5
Born in Oceania and Antarctica (excluding Australia)	2.5	2.5	3.4	3.6	2.2	2.6
Born in North-West Europe	7.7	5.1	4.3	1.8	4.7	5.8
Born in Southern and Eastern Europe	5.5	5.1	3.8	5.0	10.6	11.3
Born in North Africa and the Middle East	1.3	3.3	6.8	12.2	2.2	1.3
Born in South-East Asia	1.8	4.3	4.1	10.8	3.0	1.8
Born in North-East Asia	2.9	9.5	7.8	11.2	7.3	2.5
Born in Southern and Central Asia	0.7	3.3	4.7	5.9	1.7	0.5
Born in Americas	1.5	1.3	1.2	1.1	1.3	1.1
Born in Sub-Saharan Africa	0.9	0.8	0.7	0.8	0.7	0.7

Table 11.6 Language Spoken at Home (ABS, 2001 Census)

	Area					
	Hunters Hill	**Ryde**	**Parramatta**	**Auburn**	**Canada Bay to Concord**	**Canada Bay to Drummoyne**
Speaks a Language other than English at Home : Percentage Of Total Population	16.6	32.5	38.5	65.0	35.4	25.9

There are numerous studies which look at community values and expectations for the study area. However, very few of them look at the study area as a whole and tend to be related to particular areas. A recent survey was undertaken of residents who use Callan Park, Rozelle (Menzies, 2007). The study looked at where people where coming from, why they were using Callan Park and what they valued about the park. This information could be used to gain an understanding of people's attitudes towards large open space areas within the study area.

11.6 Economic Factors

11.6.1 Employment

The Bureau of Statistics defines data for the study area into six sub-areas. Key employment data for 2001 has been provided in **Table 11.7** for those areas.

Table 11.7 Employment Statistics (ABS, 2001)

	Area (%)					
	Hunters Hill	**Ryde**	**Parramatta**	**Auburn**	**Canada Bay to Concord**	**Canada Bay to Drummoyne**
Managers and Administrators	19.0	9.6	6.9	4.4	10.3	14.0
Professionals	32.2	26.5	20.9	14.6	23.9	28.4
Associate Professionals	13.2	12.6	11.1	9.5	13.2	14.5
Tradespersons and Related Workers	5.1	9.2	11.3	12.7	9.8	7.4
Advanced Clerical and Service Workers	4.5	4.5	4.1	2.7	5.2	5.3
Intermediate Clerical, Sales and Service Workers	13.4	17.2	18.4	16.7	16.6	15.6
Intermediate Production and Transport Workers	1.9	4.6	8.1	12.7	5.0	3.4
Elementary Clerical, Sales and Service Workers	5.6	9.0	9.5	10.4	8.6	6.5
Labourers and Related Workers	3.0	5.2	7.4	12.8	5.2	3.2
Inadequately described or Not stated	2.0	1.7	2.2	3.4	2.1	1.7

This data shows that a high percentage of the employed people in the study area are professionals. This could be equated to an above-average income base in the study area.

11.6.2 Tourism and Events

In NSW, tourism is larger than the following industries; Agriculture, Forestry and Fishing, Mining, Communication Services, Personal and Other Services, Electricity, Gas and Water

Supply, Accommodation, Cafes and Restaurants, Government Administration and Defence, and Cultural and Recreational Services (Tourism NSW, 2008).

Tourism NSW provides tourism data for Sydney. However, there is very little data available relating to tourism visitation or expenditure specifically within the study area.

Sydney received nearly 7.4 million domestic overnight visitors, received nearly 2.7 million international overnight visitors and 17.1 million domestic daytrip visitors in 2007. 'Holiday or leisure' was the primary purpose of the visits for those coming from overseas and domestic day trips. Other reasons for visiting including 'visiting friends or relatives' and 'business'. The average daily expenditure for those travelling domestically for the day was $101 (Tourism NSW, 2008).

A Tourism Issues Paper (Pac Rim Planning, 1994) was undertaken for the recreational spaces with direct river frontage to the Parramatta River, between Parramatta Park and Ermington Park. This paper looks at limitations and potential for tourism to these areas.

It is understood that Parramatta City Council is currently collecting data on tourism within the LGA (Pers. comm. Parramatta City Council Officer, 14 February 2008). This data should be incorporated into the Estuary Management Process at a later date.

There are also a number of events that attract visitors to the Parramatta River estuary. Riverbeats is a popular annual celebration of the river and includes the Thai Water Festival (Loy Krathong). In addition, numerous events are hosted by Sydney Olympic Park each year, the details of which can be found on the Sydney Olympic Park website at: http://www.sydneyolympicpark.com.au/Visiting/Whats_on.

11.7 Management Issues

As part of the Parramatta River Foreshore Management Strategy (Clouston, 1994a) a range of focus group meetings were held to identify the community's major issues and concerns. The following issues and concerns were identified (Clouston, 1994a 1994b, 1994c and 1994d):

- No signage on Victoria Road announcing George Kendall Reserve;
- Problems with graffiti on existing signage;
- Private land use inhibits public access to the foreshore;
- Tall buildings impact on the visual amenity;
- Riverside Theatres are an example of poor orientation;
- Tables and seating should cater for different sized groups;
- Mosquitos are a problem around George Kendall Reserve and Meadowbank Park;
- The RiverCat bow wave is quite alarming in terms of its effects on bank stability and turbidity has increased notably;
- Lack of continuity of walking tracks and open space along the foreshore;
- Some areas utilise boardwalks, other areas could benefit from this;
- Better pedestrian links are required on the south side of the River across Duck River, connecting Parramatta with Homebush Bay; and
- There is a need to balance the demand for RiverCat services against the environmental capacity or costs.

The *Regional Recreational Demand and Opportunity Assessment* (Suter and Assoc. Leisure & Tourism Planners, 2003) was undertaken for western Sydney, two of the foreshore LGAs were included in this study (Auburn and Parramatta). The following management issues were identified in this study:

Auburn

- High level of cultural diversity and lower income creates constraints to demand, i.e. language, cultural and affordability issues;
- Poor transport is a key constraint to accessing the estuary, made worse by the lower income character of the area;
- The need for informal recreation areas that cater for families and larger groups.
- Increase in demand for sports by 'second generation immigrants'.
- There is a high demand for dedicated sports facilities by cultural groups.
- There is increasing demand for golf by residents of Asian background.
- There is a demand for soccer fields.
- Need to cater for young people, including entertainment facilities and informal recreation for girls.
- Housing developments (medium density) around Homebush Bay will increase demand for public spaces and facilities, although Sydney Olympic Park may be able to meet this need.

Parramatta

- There is a demand for parks and built recreation facilities by large working population (60,000-90,000 people).
- There is a demand for larger informal spaces that cater for large groups, eg grassed landscaped areas and picnic and barbecue settings catering for Arabic speaking groups and other cultural groups.
- There is a demand for water attractions, *e.g.* Lake Parramatta Reserve.
- There is a demand for soccer fields.
- There is a high use of sporting grounds by schools (38 schools in the LGA and a further 43 within 1km).

Other management Issues identified through the literature review are:

- Some foreshore locations are affected by foreshore inundation and there are concerns that projected sea level rises will lead to significant losses of foreshore open spaces. These foreshore areas are often the key recreational sites supporting a large number of users.
- Conflict between waterway users, in particular the RiverCat and rowing sculls;
- Erosion of the foreshore and undermining of the mangrove by the RiverCat wash;
- There is a need to rationalise boat ramps and associated facilities (such as car parks);
- Impacts of car parking on the foreshore;
- Lack of appropriate signage (in some areas) to direct the public to foreshore areas and facilities.
- Lack of formalised access points to the waterway, bank erosion and impacts to vegetation due to informal access point being created at multiple locations.
- Lack of appropriate lighting along foreshore areas.

11.8 Data Gaps

Data gaps identified include:

- There is no tourism data relating specifically to the study area or the immediate region.
- There is limited information on the community values of the estuary. However, it is understood that this type of information has been collected for the Upper Parramatta River Estuary as part of the Parramatta River Foreshore Plan Review (Pers. comm, A. Collins, Parramatta City Council, 24 April 2008).

11.9 Further Studies

Further studies identified include:

- In order to rationalise the boat ramps and associated facilities, it must first be determined which facilities are the most popular and what their capacity is.
- Tourism Data Collection: if possible it would be useful to collect data relating to how many people are visiting the estuary, where they are coming from and the purpose for their visit.
- It may be useful to undertake an economic assessment of the values of the estuary. That is to undertake an assessment which determines an economic value for the various aspects on the estuary. This is usually done based on how much people are willing to pay to visit the estuary or protect features of the estuary. It may be necessary to undertake a survey of the community to undertake this assessment. This could be done in conjunction with the collection of tourism data.
- Incorporation of the Community Values data from the Parramatta River Foreshore Plan Review and the Community Survey.

12. CULTURAL HERITAGE, VALUES AND SIGNIFICANCE

12.1 Data Sources

The following databases were searched for information on the occurrence of heritage sites or items located within the study area:

- Aboriginal Heritage Information Management System (AHIMS)
- Maritime Heritage Online (http://maritime.heritage.nsw.gov.au/public/welcome.cfm)
- National Shipwreck Database (http://www.environment.gov.au/heritage/shipwrecks/shipdata.html)
- Register of the National Estate (http://www.environment.gov.au/cgi-bin/ahdb/search.pl)
- State Heritage Inventory Database (http://www.heritage.nsw.gov.au/07_subnav_01.cfm)

The following data sources relating to *cultural heritage* have been used herein:

- Anon. (2007a)
- A.&H. Bonanno Consultants (1993)
- Arundel (1918)
- Ashfield Municipal Council (1985)
- Attenbrow (1991)
- Attenbrow and Steele (1995)
- Attenbrow (2001)
- Auburn Council (2000a)
- Auburn Council (2007)
- Barratt (1981)
- Blaxell (2004)
- Britton (2004)
- Brook and Kohen (1991)
- CCBC (2008)
- Chambers (2000)
- Clouston (1994a)
- Cole (1983)
- CoR (2003)
- Cumberland County Council (1961)
- Dallas (2003)
- DEAP (1986e)
- DoP (1993)
- Environmental Partnership (2008)
- Flynn (1995)
- Fox & Associates (1986)
- Freame (1918)
- Hawkless Consulting (2006)
- Hawthorne (1982)
- HHC (2008f)
- HHC (2008g)
- Howlett (2008a)
- Irish (2004)
- Jervis (1920)
- Lee and Darwala-Lia (1998)
- Little (1918)
- LMC (2000)
- LMC (2008c)
- McLoughlin (2000b)
- Mills (2008)
- NSW Government (2005b)
- NT (1976)
- O'Dwyer and Anderson (2007)
- O'Brien (2004a)
- Parker (1977)
- PCC (2001)
- PCC (2007d)
- Pollon (1983)
- Proudfoot (1971)
- RTA (2008a)
- RTA (2008b)
- SHFT (2004a)
- SHFT (2007a)
- SHFT (2007b)
- SHFT (2008a)
- SHFT (2008b)
- SKM (2005a)
- SMC (2008d)
- SMEC (2006)
- SOPA (2002b)
- SOPA (2008d)
- SOPA (2008j)
- Stedinger Assoc. (2003)
- Strathfield Council (2003)
- Suter Architects Snell (1996)
- Swann (1918)
- West (1990)
- Wolfe (1990)

12.2 Historical Accounts

The Parramatta River estuary was first visited by Europeans in 1788 and was settled for agriculture shortly thereafter. Over the years, the estuary has been subject to significant development pressures relating to industrial and residential development. The long history of European settlement and usage has led to the estuary being significantly modified. The Parramatta River was the first Australian estuary to be subjected to impacts by Europeans and continues to be impacted today.

There is a sizeable volume of literature relating to the heritage and cultural values of the Parramatta River and its foreshores. A large number of historical accounts and analyses are given in a range of literature (e.g. Arundel, 1918; Freame, 1918; Swann 1918; Proudfoot, 1971; Barratt, 1981; Pollon, 1983; Brook and Kohen, 1991; Flynn, 1995; McLoughlin, 2000b; Blaxell, 2004). These histories account for, in many instances, post-European settlement only, and are presented from a predominantly non-Indigenous perspective.

This literature often includes excerpts of manuscripts of European settlers such as Governor Arthur Phillip (Flynn, 1995; Fox & Associates, 1986; Freame, 1918; McLoughlin, 2000b; Proudfoot, 1971; Pollon, 1982; West, 1990), Governor Macquarie (Proudfoot, 1971; West, 1990) and Lieutenant Dawes (Flynn, 1995).

It is understood that PCC are currently working on developing a program called 'Parramatta Stories', which intends to transform Parrramatta, including the Parramatta River foreshore, into a 'outdoor living museum' (pers. comm, A. Collins, PCC, 20 June 2008). This will be achieved through promotion of the Aboriginal and European history of the area through public art, interpretive signage, storytelling, digital media, theatre, performance art or new technologies.

Indigenous Historical Accounts

There are some instances of resources that give accounts of Aboriginal history, with varying degrees of accuracy (Attenbrow and Steele, 1995; Brooke and Kohen, 1991; Flynn, 1995; Hawthorne, 1982; SMC, 2008d; SOPA, 2008d; West, 1990). However, these descriptions tend to be fairly limited in scope, encompass only the time period following European settlement and generally present Indigenous culture and society from a European perspective.

It is understood that both Parramatta and Strathfield Councils have prepared Aboriginal cultural heritage studies (Auburn Council, 2007 and Dallas, 2003).

Flynn (1995) provides an overview of the early history of contact between the Europeans and the Aboriginal clans of Sydney with a focus on Parramatta. Some features of pre-1788 Aboriginal society are also discussed, such as the cultural divide between the *paiendra* (or "tomahawk") people, who hunted game, and the *katungal* (or "sea") people, who were oriented towards resources provided by the ocean and estuaries (Flynn, 1995).

Accounts of Aboriginal culture associated with Homebush Bay can be found in Lee and Darwala-lia (1998) and Lee and Lennis (2000). Lee and Darwala-lia (1998) compiled oral histories from both the Darug and Dharawal people. These oral histories revealed that Homebush Bay was shared between the coastal Dharawal and inland Darug people, and that location is remembered as meeting place, or special, where these two groups came together and met, or as a place of Law (Lee and Darwala-lia, 1998). It is understood that the information in that study has been made available to the public by SOPA (2008d).

Lee and Lennis (2000) expand upon that document by providing further background to the Aboriginal ownership of the country, the type of bush foods consumed and who collected them, how people moved through the Homebush area and an overview of the activities undertaken by men, women and children.

Apart from these two detailed historical accounts of Aboriginal use and occupation of the study area, little information was identified during the literature search undertaken as part of this study.

Other accounts of Aboriginal culture are provided from a European perspective (e.g. Barratt, 1981).

European Historical Accounts

In addition to those previously discussed, there are a number of historical accounts from a European perspective that relate to a specific location or have a particular focus. These have been discussed below.

The Upper Parramatta River Estuary

Historical accounts of present-day heritage items or sites are given in a range of literature, particularly in the context of heritage assessment.

Cumberland County Council (1961) describes the history associated with a range of historic buildings which have heritage significance, whilst the history of four weirs in the Upper Parramatta River Estuary is given in a heritage assessment by Stedinger & Associates (2003). An oral history example is given by Little (1918), whereby the historical context of the Parramatta District Hospital is presented in the format of a transcribed speech.

The Mid Parramatta River Estuary

SOPA (2008a-c) have produced summary pamphlets of histories associated with Homebush Bay.

Fox & Associates (1986) gives a detailed history of the Homebush Bay area using a time-line format to convey a logical progression. In particular, the history of modern-day heritage sites such as the Newington Armament Depot is provided so as to validate the cultural and historical significance of these heritage sites.

The Lower Parramatta River Estuary

Cockatoo Island is one location within the Lower Parramatta River Estuary that is the basis of a several pieces of literature (Anon., 2007a; Chambers, 2000; Parker, 1977 and SHFT, 2004a). These references give historical accounts of the island, especially relating to its maritime heritage and history (See **Section 12.4.2** for additional information). SMC (2008d) gives a general history of the Strathfield area, but this document is only very brief and goes into little detail or in-depth discussion.

With respect to other parts of the Lower Parramatta River Estuary, Cole (1983) provides excerpts of a speech given to the Royal Australian Historical Society in 1919. The speaker recalled transport options in the area during the mid 1800s, such as usage of the Bedlam Punt Ferry to cross the River. The linkage that this ferry once created has been superseded by the Gladesville Bridge.

12.3 Indigenous Heritage

A search of the AHIMS database conducted on 25 March 2008 revealed 250 records of Aboriginal places or objects recorded in or near the study area. The large number of listings recorded for the area highlights the importance of the study area for Aboriginal people. A summary of the types of sites recorded is provided in **Table 12.1**. More than one of these types of sites/items may occur in a single location. The full list of items is provided in **Attachment 9**.

Table 12.1 Summary of General Features of Aboriginal Sites Recorded in the Study Area

Site Features	Code	Description (after AHIMS)	No. of Records
Artefacts	AFT	Objects such as stone tools, spears, manuports, grindstones, discarded stone flakes, modified glass or shell demonstrating evidence of use of the area by Aboriginal people.	208
Shell	SHL	An accumulation of shell from beach or estuarine crustacean species resulting from Aboriginal gathering and consumption, usually found in deposits previously referred to as shell middens in association with other objects like stone tools, fish bones, and burials. Will vary greatly in size and components.	173
Earth mound	ETM	A mound of earth which may be associated with ceremonial activities, e.g. bora grounds, or may be a by-product of continued traditional and contemporary use of an area, e.g. shell midden.	172
Art	ART	Art surfaces which may be painted, abraded, pitted or engraved for the purpose of ceremony and/or self expression on the part of the artist.	41
Grinding Grooves	GDG	A groove in a rock surface resulting from manufacture of stone tools such as ground edge axes and spears may also include rounded depressions resulting from grinding of seeds and grains.	8
Potential Archaeological Deposit	PAD	Areas where artefacts may or may not have been identified where further subsurface artefacts and/or other cultural materials are thought likely to occur.	7
Burials	BUR	A traditional or contemporary burial of an Aboriginal person which may occur outside designated cemeteries and may not be marked, e.g. in caves, marked by stone cairns, in sand areas, along creek banks etc.	5
Habitation Structure	HAB	Structures produced by, or for, Aboriginal people for short or long term shelter. More ephemeral structures are commonly preserved away from the NSW coastline, may include historic camps of contemporary significance such as Aboriginal mission and reserves. Smaller structures may make use of natural materials such as branches, logs and bark sheets or manufactured materials such as corrugated iron to form shelters.	1
Modified Tree	TRE	Mature tree species which show the marks of modification as a result of cutting of bark from the trunk for use in the production of shields, canoes, boomerangs, burials shrouds, for medicinal purposes, foot holds etc., or alternately intentional carving of the heartwood of the tree to form a permanent marker to indicate ceremonial use/significance of a nearby area, again these carvings may also act as territorial or burial markers.	1
Waterhole	WTR	A source of water for Aboriginal groups which may have traditional ceremonial or dreaming significance and/or may also be used to the present day as a rich resource gathering area (e.g. waterbirds, eels, clays, reeds etc)	1

The following qualifications apply to an AHIMS search:

- AHIMS only includes information on Aboriginal objects and Aboriginal places that have been provided to DECC,
- Large areas of NSW have not been the subject of a systematic survey or recording of Aboriginal history. These areas may contain Aboriginal objects and heritage values which are not recorded on AHIMS,
- Recordings are provided from a variety of sources and may be variable in their accuracy. When an AHIMS search identifies Aboriginal objects in or near the area it is recommended that the exact location of the Aboriginal object be determined by location on the ground, and
- The criteria used to search AHIMS are derived from the information provided by the client and DECC assumes that this information is accurate.

Data on the location of these sites has not been provided due to the sensitive nature of Aboriginal heritage sites and objects. It is recommended that the potential for Aboriginal sites to be affected by any future management actions be considered. Where any activities are planned within the study area or the larger catchment, a location specific assessment of the potential occurrence and/or significance of any heritage items will be required. This is particularly important given the potential for previously un-recorded items to occur within the study area. It is understood that staff from Parramatta City Council have recently observed what may be a midden in George Kendall Riverside Park, as shown in **Figure 12.1** (pers. comm, C. Jeffers, 14 February 2008).

It is understood that Parramatta City Council is currently preparing to undertake a heritage assessment of a sand sheet (levee) located in the Parramatta River Estuary near the CBD. This sand sheet is known to contain highly significant evidence of Aboriginal occupation.

A number of literature sources provide information on the Aboriginal heritage sites and items within the study area.

Attenbrow (2001) presents a collection of Indigenous place names that were recorded by European settlers in the 18th and 19th Centuries. At that time, place names were phonetically transcribed into English, and some are today considered as the formal and accepted place names for areas, such as Parramatta and Toongabbie. Jervis (1920) also presents a history of place names but includes a mixture of Indigenous and non-Indigenous names and their origins.

Aboriginal place names are also mentioned in Cole (1983) and O'Dwyer and Anderson (2007).

Aboriginal sites were recorded and assessed for Port Jackson by Attenbrow (1991). The patterns of distribution of these recorded sites is thought to have been impacted by urban development (Attenbrow, 1991), a process which is likely to have resulted in the loss of a number of items and sites of Aboriginal significance within the Parramatta River Estuary Study area. Further, it is noted that sea level rose approximately 6,000 years ago, inundating parts of Port Jackson and the Parramatta River Estuary (which is a drowned river valley, see **Section 4.2**) which would have dramatically changed patterns of resource use. In any case, few sites are recorded by Attenbrow (1991) for the study area.

A locational analysis of Aboriginal sites in Port Jackson was also undertaken by Hawthorne (1982) who correlated the spatial distribution of sites with patterns of resource use.

Irish (2004) presents the findings of a survey of scarred trees in Sydney Olympic Park in order to relocate and reassess those scarred trees previously identified in other surveys. It is understood that a number of stone artefacts were also found. Further information on the identification of trees that have been scarred as a result of use by Aboriginal people is also given in Irish (2004).

Some literature makes reference to the number and locations of various sites that are of Indigenous significance without going into extensive detail (A&H Bonanno Consultants, 1977; DEAP, 1986e; Fox & Associates, 1986; Attenbrow, 1991; Attenbrow, 1995; SKM, 2005a).

More comprehensive information on Indigenous heritage sites is presented by Hawthorne (1982) and Dallas (2003). The latter describes a range of surveys that have been undertaken in recent times with the specific aim of regaining significant heritage artefacts for future protection under legislative agreements. Sensitivity Mapping is one technique that has been undertaken in order to determine the likelihood of an area or zone to contain undocumented Indigenous heritage sites. Zones that are considered as having "high sensitivity" (i.e. high potential of containing heritage items) include areas of undisturbed natural landscape, areas with known Indigenous heritage sites within a 50m radius and sites with high archaeological potential (Dallas, 2003). The promotion of Indigenous culture and heritage within Parramatta City LGA is also mentioned by Dallas (2003). The commemorative Riverside Walk, Parramatta Heritage Centre's People and Place Exhibition and Indigenous Welcome sculptures at Ferry Wharf are all examples of interpretation of Indigenous heritage in the Parramatta River foreshore area.

The literature review undertaken for this study indicates that there is lack of Aboriginal perspectives on Aboriginal heritage.

12.4 Non-Indigenous Heritage

The Parramatta River Estuary is significant as being the birthplace of Australia's non-Indigenous heritage. The port and river were the genesis of European settlement, and the Parramatta River Estuary was the essential link between Sydney Town and Parramatta in the early colony of New South Wales (National Trust, 1976).

A large number of references relating to non-Indigenous or European heritage were identified during the literature review process. Some literature gives a simplified outline of heritage or makes reference to the number and locations of various sites that are of heritage significance (A&H Bonanno Consultants, 1977; Fox & Associates, 1986; DoP, 1993).

A more thorough indication of non-Indigenous heritage items and their significance is given by DEAP (1986e) and Clouston (1994a), in the context of a *Heritage Assessment* and a *Foreshore Management Strategy* respectively. The latter of the two is more comprehensive because heritage items and there locations are described and their legislative status and physical condition is discussed in detail. Recommendations for improvements are also given.

12.4.1 Terrestrial Heritage

Table 12.2 provides a summary of the number of heritage listings recorded for each of the LGAs with foreshore frontage. The full list of heritage item records returned from a search of those three databases is reported in **Attachment 10**.

Items of Natural Heritage under the *EPBC Act* as identified through the Protected Matters Search Tool are listed in **Section 10.5.4.**

Table 12.2 Summary of Heritage Listings by LGA for the Study Area

LGA	Australian Heritage Database*	Protected Matters Report (EPBC Act)	NSW Heritage Act
Ashfield	27	19	9
Auburn	8	13	8
City of Canada Bay	32	17	7
City of Ryde	23	11	10
Hunters Hill	225	211	8
Leichhardt	75	63	23
Parramatta	105	75	63
Strathfield	9	5	5

*Register of the National Estate and/or Commonwealth Heritage List

Heritage items of local significance are also listed in the respective LEPs for each of the relevant Councils:

- Auburn Council (Auburn Council, 2000a)
- Ashfield Municipal Council (Ashfield Municipal Council, 1985)
- City of Canada Bay Council (CCBC, 2008)
- City of Ryde (CoR, 2003)
- Hunters Hill (HHC, 2006; 2008h)
- Leichhardt Municipal Council (LMC, 2000)
- Parramatta City Council (PCC, 2001 and 2007d)
- Strathfield Council (Strathfield Council, 2003).

Heritage mapping (orthorectified) for the respective LGAs has been obtained from four foreshore Councils. **Figures 12.2 to 12.5** show the location of heritage items and/or conservation areas in the Parramatta, Ryde, Ashfield and Leichhardt LGAs.

There is a large volume of literature that refers to the significance of terrestrial heritage along the Parramatta foreshore area (Blaxell, 2004; Cumberland County Council; 1961; Fox & Associates, 1986; Clouston, 1994a; Suter Architects Snell, 1996; Britton, 2004; RTA, 2008).

For the majority of terrestrial heritage features, namely those of visual significance (including colonial cottages and bridges), see **Section 12.5**.

Other than the visually significant heritage outlined in **Section 12.5**, there are also a number of less obvious heritage items. Examples include those outlined by Clouston (1994a) and include items such as a boundary stone (delineating the border of the Parramatta area), a stern section of a British Warship existing as part of a Navy memorial, and the grave of a woman and child who drowned in 1793. These types of heritage items can become susceptible to vandalism and weathering if not monitored and managed accordingly.

A brief overview of some of the key heritage sites situated along the Parramatta River Estuary is provided below to place in context the importance of the study area to the historic development of Sydney and the Colonies.

Lower Parramatta River Estuary

<u>Cockatoo Island</u>

Cockatoo Island represents a highly significant heritage site and also contributes to the visual character of the lower estuary. Both Cockatoo Island itself and a number of features located on the Island are protected under the *EPBC Act* as Commonwealth Heritage Listed sites. These listings are provided below and are also included in **Attachment 10**:

- Cockatoo Island Industrial Conservation Area,
- Barracks Block,
- Biloela Group,
- Blacksmith and Machine Shop,
- Cockatoo Island,
- Fitzroy Dock,
- Mess Hall,
- Military Guard Room,
- Power House / Pump House,
- Prison Barracks Precinct,
- Sutherland Dock, and
- Underground Grain Silos.

Cockatoo Island was originally established in 1839 as a penal settlement for convicts who re-offended in the colonies, and operated as such until 1869. Living conditions for the convicts were harsh and hard labour was the primary form of punishment, with convicts involved in quarrying, labouring and construction. A large volume of sandstone was quarried from the Island, which is evident in the buildings remaining on site.

Cockatoo Island also has enormous heritage significance as a shipbuilding facility, operating for 134 years between 1857 and 1991, during which time it was the nation's primary shipbuilding facility. As such, it has contributed to Australia's naval and maritime history.

Further information on Cockatoo Island is available in a number of publications (e.g. Anon., 2007a; Chambers, 2000; O'Brien, 2004a; Parker, 1977 and SHFT, 2004a and 2007b).

A Management Plan has been prepared for Cockatoo Island by the Sydney Harbour Federation Trust (SHFT, 2007b).

Cockatoo Island has been open to the public for casual visitation since April 2007. Visitors may either join a guided tour (SHFT, 2008a), or alternatively take themselves on a self-guided tour for which maps are available (SHFT, 2007a), and it is understood that the public may also stay overnight at either the camping grounds or formal facilities. Between February 2007 and February 2008, around 8,700 people visited the Island (pers. comm., R. Sutcliffe, Sydney Harbour Federation Trust, 26 February 2008).

It is understood that Cockatoo Island has been nominated for World Heritage listing with the United Nations Educational, Scientific and Cultural Organisation (UNESCO).

Spectacle Island

Spectacle Island was so named because it was originally two islands joined by an intertidal rocky island resembling a pair of spectacles. However, it was originally named Dawes Island by Captain Hunter, who took shelter on the Island overnight, fearing the local Aboriginals, during his first journey up the Parramatta River in 1788 (Blaxell, 2004). In 1863-65 a powder magazine, residence, guard room, barracks and cooperage were built on the Island, followed in 1878 by a laboratory and labourer's quarters, with all buildings sited on the eastern islet closest to Cockatoo Island (Blaxell, 2004). After 1888, reclamation of the land between the two islands was undertaken and further construction took place. It is understood that the reclamation works nearly doubled the size of Spectacle Island to 2 ha (Blaxell, 2004).

Spectacle Island was used to produce munitions during times of war and was used as an arsenal for its storage. According to Blaxell (2004), during World War II up to 600 people worked on the Island to produce munitions. In the 1960's the armaments were transferred to the Newington depot and Spectacle Island became the home of the Naval Historical Collection. Today the site is used as the Naval Reserve Cadets headquarters (Blaxell, 2004).

Mid Parramatta River Estuary

<u>Callan Park</u>

Callan Park originally consisted of two land grants which, through a series of transactions, were merged into the one land holding and sold to the government for £12,000 in 1873 with the intention of developing a modern hospital for the mentally ill (Blaxell, 2004). In the years leading up to the purchase of Callan Park, there had been substantial criticism of the conditions of the asylums of Parramatta and Tarban Creek. At that time people suffering from mental illnesses were not distinguished from criminals and were often incarcerated in gaols or asylums.

Legislation was passed in 1878 establishing Callan Park as an asylum. At this time, the original Callan Park House and new buildings accommodated 114 patients (Blaxell, 2004). The Callan Park Hospital complex was completed in 1885, constructed from locally quarried sandstone. This sandstone was obtained largely from the excavation of two large underground tanks (5,000kL capacity) which collected water from roofs of the buildings (Blaxell, 2004). The water was used for fire fighting and for use by the patients.

By 1900 the hospital was known as one of the finest institutions for the treatment of the mentally ill in the Commonwealth. Later, in 1976, Rozelle Hospital was formed from the amalgamation of Callan Park Hospital and the Broughton Hall Psychiatric Clinic. The progressive changes between the 1870's and the present day show the progression of the changes in the approach to the treatment of the mentally ill.

These days the Kirkbridge complex within Callan Park is used by the Sydney College of the Arts. Callan Park is an important focus for recreation, representing a sizable portion of land available for recreation in the Leichhardt LGA. The Bay Run follows the shoreline through Callan Park and the sporting fields also provide an important resource.

In recent years there has been substantial controversy over the future management of Callan Park. In 2001 the State Government announced plans to sell the land for redevelopment. However, the local community mounted a successful campaign against these plans, resulting in the passing of the *Callan Park (Special Provisions) Act 2002*, which provided some protection for the site from redevelopment (LMC, 2008c). More recently, in February 2007, the Sydney Harbour Federation Trust released a draft land use plan for the Park which proposes upgrade to the sporting facilities, greater usage of the site by Sydney University and a continuing health presence on the site (SHFT, 2008b). It is understood that, in addition to renewed community opposition to the redevelopment, Leichhardt Council also opposes the plans for the site on the basis of the following concerns:

- There will be fewer mental health services and facilities;
- Fewer recreational facilities and sporting grounds, which is of particular concern in Leichhardt LGA, for which Callan Park is the biggest remaining open space;
- Loss of local control of and access to recreational facilities and sporting grounds;
- Over-development and loss of heritage features; and
- A lack of overall long-term planning for the site (LMC, 2008c).

The Thomas Walker Convalescent Hospital

Thomas Walker, originally from Scotland, arrived in the Colony in 1822. He was a successful businessman and became a director of the new Bank of Australia in 1826 (Blaxell, 2004). It was through this role that he acquired an estate in Concord, upon which he built a family home called Yarralla. Both Thomas Walker and his daughter Eadith Campbell Walker were benevolent donors, supporting a number of Anglican churches, sporting clubs, arts groups and other organisations (Blaxell, 2004).

Before he died, Thomas Walker set aside a part of his estate for the building of a convalescent hospital at Rocky Point (Blaxell, 2004). The construction of the hospital began in 1891 and was completed in 1893. The hospital was intended as a place where convalescent patients could recuperate in peaceful surroundings and provided medical care and accommodation for four weeks for each patient (Blaxell, 2004). In 1884, the Joanna Walker Memorial Children's Hospital was built.

The Thomas Walker Convalescent Hospital functioned until 1979, at which point it was taken over by the Health Commission of NSW and established as the Rivendell Adolescent Unit for the care and treatment of emotionally disturbed adolescents (Blaxell, 2004).

Queens Wharf

Historically, Queens Wharf was a focal point for commercial activity on the Parramatta River. Queens Wharf was located to the east of what is now known as the Gasworks Bridge, on the site of the existing Queens Wharf Reserve.

Recently, Parramatta City Council staff constructing a walking path unearthed a historic seawall dating back to the 1790's that was formerly part of Queens Wharf, east of Gasworks Bridge (Howlett, 2008a; Mills, 2008). The seawall provided off-channel mooring places for vessels through the use of berthing bays and represents the last remnants of the Byrnes Mill complex (Howlett, 2008a). It is understood that the seawall is to be restored (Howlett, 2008a).

The Bynes' Mill was a steam-driven four mill constructed to the east of Queen's Wharf (Blaxell, 2004). In 1844, an additional five-storey brick building was constructed for cloth making. The machinery used was imported from England and was also stream-driven. The wool used in the mill was prepared at a site upstream near Toongabbie Creek (Blaxell, 2004).

With the construction of roads for transport to Parramatta in 1794, the importance of the River for transport began to decline (Blaxell, 2004). In addition, the railway between Sydney and Parramatta was completed in 1855.

Newington Armoury

The Newington Armoury at Sydney Olympic Park (and elements thereof) is protected under the *EPBC Act*. The significance of the Newington Arms Depot Conservation Area relates to the sequence of design philosophies for explosives handling throughout the twentieth century, examples of which are evident on the site. It also provides an insight into the development of the Australian Navy from when it was still a member of the Royal Navy.

The Conservation Area comprises 80ha of land fronting the Parramatta River and includes the Arms Depot and its associated wharf, cranes, roads and tramway. The wharf is also listed under the State Heritage Register. There are also over 100 historic buildings and structures scattered throughout the site, including the 1897 gate house.

The Newington Armoury is now a restricted area with limited public access. Parts of the precinct are now being used as a visual and performing arts venue, with an amphitheatre,

theatre and gallery. Some of these venues may be hired and there is also accommodation provided for visitors within the Armoury precinct.

Homebush Bay

Blaxell (2004) provides an excellent history of the European settlement of Homebush Bay by the Wentworth family. That document also goes on to discuss the development of the estate and the subsequent industrial development of Homebush Bay between 1891 and 1974, including discussion relating to the construction of foreshore protection works and reclamation works.

Upper Parramatta River Estuary

Breakfast Point

Breakfast Point was so named because it was at this location that Captain John Hunter stopped to have breakfast on his first journey up the Parramatta River on 5 February 1788 (Blaxell, 2004). When Governor Phillip came to inspect ten days later, the party stopped at the same place, again for breakfast.

From 1886 the Australian Gas Light Company occupied Breakfast Point (Blaxell, 2004). Few buildings survive today and the areas has been redeveloped for residential housing.

12.4.2 Maritime Heritage

In addition to items of heritage significance located on land, heritage items such as shipwrecks or the remains of wharves may also occur in the estuary itself. Given the history of boating in the area, it is reasonable to suggest that there are a number of maritime heritage items located within the study area.

In reviewing the literature, a collection of sources were found to provide significant detail on various aspects of maritime heritage (Wolfe, 1990; Clousten, 1994a; Chambers, 2000; Stedinger & Associates, 2003; Hawkless Consulting, 2006; SMEC, 2006).

The Harbour REP (NSW Government, 2005b) lists those heritage items that are listed on the State Heritage Register and any item assessed as being of state heritage significance in a relevant heritage study or listed on the Heritage Act 1977 Section 170 register. Schedule 4 lists a total of 52 heritage items, that are either in the waterway, at the land–water interface, or that have a historic relationship with the waterway. They include navigation structures, wharves, shipwrecks and the Harbour islands. Most of these items were identified as heritage items in the Sydney Regional Environmental Plan No. 23 – Sydney and Middle Harbours (SREP 23). Others are water-related items that were identified either in the Parramatta River Heritage Study or the Lane Cove and Inner Harbour Regional Environmental Study. Any item listed in a council planning instrument has been excluded from the Harbour REP to avoid duplication. The locations of these items are shown in **Figure 12.2**.

The Harbour REP (NSW Government, 2005b) includes a series of provisions to be taken into consideration by consent authorities before granting development consent and public authorities before carrying out activities within the Parramatta River Estuary. The Heritage provisions generally reflect the current model heritage provisions prepared by the Heritage Office and aim to protect places and items of Aboriginal and non-Aboriginal heritage significance and views associated with the heritage significance of heritage items.

Hawkless Consulting (2006) examines the maritime heritage context of the whole of NSW. However, within this large document there are areas of relevance to the Parramatta River, including references to the White Bay Power Station Canal at Rozelle.

A more comprehensive indication of the location and heritage value of sites specific to the Parramatta River foreshore is given by Wolfe (1990). Each site in the report has been given an excavation priority value of 1-9 in terms of maritime archaeological significance (9 indicates high priority whilst 1 indicates a low priority). The resulting priorities demonstrate that, in general, sites along the upper reaches of the river are considered to have a higher probability of containing artefacts than those in the lower reaches. Recommendations are given to promote the preservation of heritage artefacts during any excavation that might take place.

Both the National Shipwreck Database and Maritime Heritage Online (NSW Heritage Office) were searched on the 12 February 2008. A total of 11 shipwrecks are recorded for the Parramatta River, with several located in Homebush Bay (**Table 12.3**). The former Homebush Bay scuttling yard is also listed as a conservation area relating to maritime heritage.

Further, it is understood that there is significant potential for previously un-recorded heritage items. This relates primarily to foreshore structures such as jetties and wharves associated with both former ferry services and the historic houses located along the river foreshores. Where these structures were located, it is reasonable to anticipate that there will also be items located on the riverbed where they have been dropped by disembarking passengers. It is understood that staff from Parramatta City Council recently observed what appears to be as yet un-recorded heritage pylons (remains of a pier or wharf), as shown in **Figure 12.1** (pers. comm, C. Jeffers, 14 February 2008).

The Upper Parramatta River Estuary

Stedinger & Associates (2003) and SMEC (2006) outline the heritage significance of four weirs in the upper Parramatta River Estuary, particularly in relation to the proposed development of fish ladders and their associated impact upon heritage. These assessments give an indication of how to maintain a balance between the preservation of anthropological heritage features and the conservation of natural heritage. Clouston (1994a) also makes reference to these four weirs in the context of a Foreshore Management Plan.

The Mid Parramatta River Estuary

Blaxell (2004) provides details on the shipwrecks of Homebush Bay, including the SS Ayrfield, SS Heroic and HMAS Karangi.

The Lower Parramatta River Estuary

Chambers (2000) discusses the Cockatoo Island Dockyard and its significance as a heritage area on a state level and national level. Sutherland Dock, one of two main docks located at Cockatoo Island, was the largest in the world at the time of its construction.

Table 12.3 Maritime Heritage Records for the Parramatta River Estuary

Shipwrecks					
Shipwreck ID	**Name**	**Type**	**Date Wrecked**	**Where Wrecked**	**Short Description**
550	Ayrfield	Steamer screw	1972	Homebush Bay	The Ayrfield was a steel single screw steam collier, 1,140 tonnes.
1208	Kaludah	Steamer screw	22 March 1911	Near the head of Tarban Creek	The Kaludah burnt and was wrecked in Tarban Creek, near the head of Parramatta River, Sydney.
1211	Karangi H.M.A.S.	Motor Vessel	1970c	Homebush Bay	A steel boom defence vessel of 971 tonnes, 54.
733	Lady Edeline	Screw Steamer		Parramatta River	The Lady Edeline was one of five double-ended wooden ferries built to a design created by Water Reeks.
977	Little Violet	Steamer screw	1888	Parramatta River, off 'the Brothers'	The 37 tonne screw steamer Little Violet sank in 1888 during a trip from Sydney Harbour to Parramatta River, Mortlake, after it collided with the Undine off 'The Brothers' Parramatta River, Sydney.
879	Maria Prudence	Schooner	July 1853	Parramatta River, down stream	The wooden schooner Maria Prudence capsized in a strong wind in the Parramatta River in July 1853.
785	Mortlake Bank	Steamer screw	1972	Homebush Bay	The Mortlake Bank rests today in the shallow waters of Homebush Bay, off the Parramatta River.
1560	Parramatta Ex H.M.A.S.	Hulk	8 December 1834	Hawkesbury River	HMAS Parramatta was one of a number of vessels ordered for the Commonwealth's new naval forces in 1909, following the assimilation of the various colonial fleets' post Federation in 1901. The bow is now mounted ashore at Garden Island and the *stern imbedded into a monument at Queens Park, Parramatta.* The remainder of the wreck site remains on the riverbank of the Hawkesbury River.
1267	Police Launch	Launch	16 January 1938	Parramatta River	This wooden police launch caught fire in Parramatta River, Sydney, on the 16th of

Shipwrecks					
Shipwreck ID	**Name**	**Type**	**Date Wrecked**	**Where Wrecked**	**Short Description**
					January 1938.
737	Heroic	Steamer screw	1973c	Homebush Bay	A steel tugboat built at South Shields, United Kingdom in 1909.
1947	Una	Steamer screw	4 April 1927	Five Dock Bay	On the 4th of April 1927 the wooden screw steam ferry Una caught fire and wrecked in Five Dock Bay, Sydney Harbour.
Ports and Harbours					
Type	**Name**	**Type**	**Date Built**	**Where Located**	**Short Description**
Archaeological -Terrestrial	Homebush Bay Scuttling Yard	Scuttling Yard		Homebush Bay	Until 1990, used as the scuttling yard for the Port of Sydney. Years of spoil and maritime debris are deposited on the floor of the bay. The site is of interpretative significance for its potential to yield artefacts of maritime archaeological interest.

12.5 Visually Significant Features

There are a multitude of visually significant heritage features along the Parramatta River Estuary foreshores, however they are predominantly originate from post-European settlement. Several colonial cottages of visual significance exist, such as Brush Farm Estate in Eastwood (Britton, 2004), Experiment Farm Cottage (Cumberland County Council; 1961; Suter Architects Snell, 1996), Elizabeth Farm Cottage, and Hambledon Cottage (Suter Architects Snell, 1996). The latter three sites are part of the *Harris Park Heritage Precinct.* Discussion is given in these references, not only of the visual significance of the houses themselves, but also of the surrounding estates. The four cottages hold similar, but unique, visually significant features such as remnant gardens, potentially significant archaeological sites, remnant view connections to other areas of the foreshores, and independently significant structures (such as courtyard walling) (Suter Architects Snell, 1996; Britton, 2004).

Bridges and maritime structural remnants can also maintain visual significance. The Lennox Bridge, for example, is a heritage item that can be considered as being visually significant in the Parramatta area. Literature (Clouston, 1994a; RTA, 2008) highlight that this bridge as a prominent feature within its environment and despite the intrusion of later alterations to the structure, its iconic visual significance remains. Other bridges are also given as examples of visual significance by Clouston (1994a). Iron Cove Bridge in the Lower Parramatta River Estuary, for example, is listed under State heritage legislation. RTA (2008) details the characteristics of this bridge and describes its aesthetic and visual significance, namely due to its landmark size and also its distinctive piers and abutments.

The site of Queens Wharf Reserve is mentioned as having some visual significance (Suter Architects Snell, 1996; Clouston, 1994). This site consists of one remaining sandstone wall designed by David Lennox and related fixtures and fittings associated with the original Queens Wharf that existed in the 19th century. Clouston (1994) and SOPA (2002b) also refer to Naval Stores in Ermington as being of visual significance due to the large buildings being prominent in views to the River from parkland and slopes to the north.

Clouston (1994a) raises the issue that the heritage significance of the River itself should not be overlooked because emphasis is placed on individual items along its course. The River is certainly a visually significant feature of the landscape in its own right.

12.6 Community Values

A newsletter was sent out to local residents to gauge their feedback with respect to how they value the Parramatta River Estuary and what estuarine attributes are particularly important to them. A copy of the community newsletter and survey is provided in **Appendix D**. Unfortunately no responses were received and so this section of the report has been based on the consultation undertaken by PCC for the *Draft Parramatta River Foreshore Plan* (Environmental Partnership, 2008). A comprehensive program of community consultation was undertaken as part of that study, including a survey, stakeholder workshop and focus groups.

The results have been summarised below (after Environmental Partnership, 2008):

- 39.1% of visitors to the Parramatta River foreshore visit for walking, while 29.5% visit for relaxation.
- Visitors to foreshore areas focussed on the need to increase maintenance of parks and public facilities, and also identified a lack of facilities (e.g. BBQs).
- The best things about the foreshore were:
    - Natural views of water and bushland,
    - Accessible,
    - Public art,
    - RiverCat,
    - Sporting facilities,

- Walking and cycling, and
- History and recognition of cultural heritage.

- The worst things about the foreshore were:
  - Lack of seating, shelter and shade,
  - Water pollution,
  - Availability of parking,
  - Untidiness and proximity of industrial areas,
  - Trolley dumping,
  - Vandalism and graffiti, and
  - Bland character of many parks.
- The foreshore areas were used for jogging, walking, picnics, events (e.g. Australia Day), ferries, cafes, to take visitors, view sports and to have contact with the water.
- The foreshore areas were not used due to a lack of parking, don't ride a bike, safety concerns, lack of seating and shelter, lack of public transport and lack of awareness.
- The respondent's vision for the Parramatta River foreshore, included:
  - Healthy,
  - Beautiful views,
  - Accessible (along as well as to the river),
  - Clean,
  - Green,
  - Enjoyable,
  - Inviting,
  - Calm and relaxing,
  - Meeting and Gathering,
  - Safe,
  - Constant carnival of activity,
  - Habitat, and
  - Family oriented.

A series of values for the Parramatta River foreshore were developed in response to the feedback gained through consultation. These are presented in Environmental Partnership (2008).

12.7 Management Issues

Based on the review of the data compiled herein, a preliminary list of management issues has been compiled:

- **Integration of data on heritage items** is lacking. This a particular issue given the number of agencies that are responsible for management of various parts/aspects of the study area.
- **Loss of heritage items** is thought to be a significant issue in the study area. While it is anticipated that a number of items have been lost during the process of urbanisation of the catchment, there are ongoing impacts as well. One aspect of this relates to the high potential for the occurrence of previously unidentified heritage sites and items, both European and Aboriginal. It is understood that items are also being impacted upon by the failure of seawalls and other foreshore infrastructure, as discussed in **Section 7.6**. In addition, it is anticipated that there are a number of items on the estuary bed, particularly in association with old jetties and wharves.
- **Promotion of cultural heritage** has been identified as a major issue. In preparing this study, a number of individuals and organisations indicated that they felt that the cultural heritage of the Parramatta River Estuary was inadequately promoted, particularly with respect to Aboriginal cultural heritage.
- **Lack of linkages** between open space areas and heritage items.

12.8 Data Gaps

The following data gaps have been identified with respect to the cultural heritage of the study area:

General:

- Potential for previously unidentified heritage sites and items.
- Loss of heritage items due to urbanisation of the catchment.
- Assessments of heritage in the study area as a whole are generally lacking.

Aboriginal Heritage:

- Relatively poor appreciation of the Indigenous heritage of the study area, particularly in the context of the study area as a whole.
- Much of the information available is from an archaeological perspective, as opposed to an anthropological perspective.
- An Aboriginal perspective on the Indigenous heritage sites and their cultural associations with the study area is lacking.

European Heritage:

- There is a great deal of European heritage information available, however much of it relates to particular locations or events. A broad overview relating to the entire study area is lacking.

Visually Significant Features:

- There are a very limited number of studies that explicitly address the visual landscape and landscape character.

12.9 Further Studies

Based on the identified data gaps, the following further studies are recommended:

- Integrate all existing information (including locational details) on a centralised database that may be accessed by all relevant agencies and organisations (as is appropriate).
- Undertake an Aboriginal cultural heritage assessment for the entire study area, to incorporate consideration of culturally important sites that may not otherwise be accounted for.
- Undertake a comprehensive survey of European heritage items in the study area in an attempt to identify any previously unrecorded sites. To narrow down the search area, sites considered to have a high potential of containing heritage items may be targeted.
- Undertake targeted maritime heritage surveys in association with locations thought to have a high potential for the occurrence of important archaeological items (e.g. Queens Wharf).
- Documentation of Indigenous oral history and personal accounts.

13. MANAGEMENT ISSUES, DATA GAPS AND FURTHER STUDIES

All management issues, data gaps and further studies listed in each chapter of this report have been summarised in **Table ES1** (in the executive summary). This summary provides a provisional indication of the range of issues identified for the estuary. A more comprehensive understanding of the issues will be obtained through the Estuary Processes Study (the next stage of the Estuary Management Process).

A provisional indication of priority has been allocated to each of the management issues. This has been done with regard to significance and magnitude. Data gaps have been identified where there is insufficient information to adequately address the management issues. Further studies have been proposed for each of the data gaps identified (in some cases one further study fulfils more than one data gap).

The further studies have been prioritised using a multi-criteria matrix assessment. For each further study, an indicative capital and recurring cost has been estimated. This has then been calculated as a Net Present Value (NPV) based on a 30 year period. Each further study has then been allocated a score for the potential benefit it may have on the following management aspects of the estuary:

- Economy;
- Public health and Safety;
- Human Usage and Recreation;
- Water Quality;
- Hydrology and Hydraulics;
- Sediment Quality;
- Ecology; and
- Cultural Heritage.

Each further study was also allocated a score with regard to the community support it would be likely to receive. This score is based on the information gathered as part of the *Parramatta River Foreshore Plan Review 2008* (Environmental Partnership, 2008).

A benefit index was calculated based on the sum of the benefit scores and then an overall index was calculated by dividing the benefit index by the NPV. The further studies were then ranked based on this number. To assist in the inclusion of further studies in the Estuary Process Study, an additional column was included which denotes whether the identified further study is appropriate for inclusion in the processes study.

The outcome of the assessment is shown below in **Table 13.1**.

A subset of further studies was identified as being recommended for inclusion in the next stage of the management process, the Estuary Processes Study. These studies were selected based on their value with respect to gaining a comprehensive understanding of the physical, chemical and ecological processes governing the functioning of the Parramatta River Estuary. For example, three dimensional hydrodynamic modelling of the estuary will assist in developing an appreciation of ecological gradients, mixing and flushing of estuarine waters, sediment transport and water quality processes. The top 10 highest ranking further studies recommended for inclusion in the Estuary Processes Study sum to a total of approximately $400,000. However, there may be an opportunity to include other studies that have been allocated a lower ranking or priority, but also have a lower cost (e.g. Further Studies 1.02, 5.06, 6.13 and/or 8.01).

Table 13.1 Multi-Criteria Matrix Assessment of Further Studies

	No.	FURTHER STUDIES	Indicative Cost	Economic Benefit	Public Health And Safety	Human Usage	Water Quality	Hydrology And Hydraulics	Sediment Quality	Ecology	Cultural Heritage	Likely Community Support	Benefit Index	Benefit Index / log Cost	RANK	RECOMMENDED FOR INCL. IN ESTUARY PROCESSES STUDY?
Catchment Processes	1.01	Compile a history of land use within the Parramatta River Estuary catchment area using current and historical aerial photography, assessing both local areas which have undergone dramatic changes and the catchment area as a whole.	$15,000	0	0	1	1	0	1	0	1	0	4	1.0	**45**	N
Catchment Processes	1.02	Assess the distribution of public and privately owned land within the catchment, including the associated environmental impacts.	$15,000	1	0	2	1	0	1	0	1	1	7	1.7	**26**	N
Catchment Processes	1.03	Update the Local Government LEP boundaries and zoning within the catchment in conformance with changes to State planning policy.	Part of other budget	1	0	3	0	0	0	0	1	1	6	N/A	**N/A**	Y
Catchment Processes	1.04	Obtaining the LEP mapping for all councils within the catchment.	$1,000	0	0	1	1	1	1	1	1	0	7	2.3	**15**	Y
Catchment Processes	1.05	Assess the nature and condition of tributaries which flow into Parramatta River Estuary.	$100,000	0	1	1	1	2	1	1	0	1	8	1.6	**29**	N
Catchment Processes	1.06	Compile an up to date database of known sewer overflow points within the catchment.	$5,000	0	3	3	2	0	0	0	0	2	10	2.7	**8**	N
Urban Stormwater, Hydrology and Flood Behaviour	2.01	Stormwater data compilation or modelling of key catchments and key locations with the aim of determining the likely sources of poor stormwater quality.	$50,000	0	2	2	3	0	2	2	0	1	12	2.6	**11**	Y
Urban Stormwater, Hydrology and Flood Behaviour	2.02	Hydraulic modelling of the catchments to quantify stormwater flow velocities and identify potential erosion "hot spots" based on high velocities.	$100,000	0	3	0	3	2	1	1	0	2	121	2.4	**13**	Y
Urban Stormwater, Hydrology and Flood Behaviour	2.03	Where sensitive locations are identified through hydraulic modelling of the catchments (see above), targeted field inspections of the creeks may be undertaken to identify any erosion issues.	$25,000	0	1	0	2	2	1	1	0	0	7	1.6	**30**	N
Urban Stormwater, Hydrology and Flood Behaviour	2.04	Program of groundwater sampling to characterise groundwater quality.	$150,000	0	1	0	3	0	0	0	0	0	4	0.8	**46**	Y
Urban Stormwater, Hydrology and Flood Behaviour	2.05	Groundwater modelling to identify transport paths, contaminant plumes and transport rates.	$100,000	0	1	0	3	2	1	1	0	1	9	1.8	**22**	Y
Urban Stormwater, Hydrology and Flood Behaviour	2.06	Compile all flood management actions listed in the relevant Floodplain Risk Management Plans should be compiled and mapped as part of the Estuary Management Study.	$5,000	0	3	0	0	3	0	0	0	0	6	1.6	**28**	N
Urban Stormwater, Hydrology and Flood Behaviour	2.07	Information on water access licence titles should be obtained from the Department of Water and Energy (DWE). This information should be assessed against environmental flows for the Parramatta River and it's tributaries to gain an understanding of the impacts of water extraction on ecosystem health.	$30,000	0	0	1	0	0	0	2	0	0	3	0.7	**49**	Y
Urban Stormwater, Hydrology and Flood Behaviour	2.08	Identification of GPTs in the study area (location, type and volume of material collected).	$10,000	0	2	1	2	1	1	1	0	1	9	2.3	**16**	Y

	No.	FURTHER STUDIES	Indicative Cost	Economic Benefit	Public Health And Safety	Human Usage	Water Quality	Hydrology And Hydraulics	Sediment Quality	Ecology	Cultural Heritage	Likely Community Support	Benefit Index	Benefit Index / log Cost	RANK	RECOMMENDED FOR INCL. IN ESTUARY PROCESSES STUDY?
Bathymetry and Estuary Sediments	3.01	Compile a database on existing sediment grain size analyses and assess the need for additional sampling.	$5,000	0	0	0	0	0	1	0	0	0	1	0.3	**50**	Y
Bathymetry and Estuary Sediments	3.02	Characterise estuarine sediments in terms of grain size, geochemistry and susceptibility to bioturbation.	$75,000	0	0	1	1	0	3	1	0	0	6	1.2	**39**	Y
Bathymetry and Estuary Sediments	3.03	Assess sediment transport throughout the estuary.	$80,000	0	0	1	0	1	3	0	1	1	7	1.4	**36**	Y
Bathymetry and Estuary Sediments	3.04	Compile a centralised database, to include geo-referenced data, on historic dredging and reclamation activities.	$10,000	0	0	0	0	3	3	0	1	0	7	1.8	**24**	N
Bathymetry and Estuary Sediments	3.05	Quantification of catchment inputs of pollutants including total nitrogen, total phosphorous, heavy metals and total suspended solids (see 2.1).	See 2a above	0	2	1	3	0	3	3	0	1	13	N/A	**N/A**	Y
Bathymetry and Estuary Sediments	3.06	Compile a centralised database of all existing studies on sediment quality, to include integration with GIS software.	$5,000	0	2	1	1	0	3	2	0	1	10	2.7	**8**	N
Bathymetry and Estuary Sediments	3.07	Assess partitioning of contaminants between estuarine sediments and the overlying water column for a range of environments found within the estuary.	$40,000	0	2	1	2	0	3	2	0	1	11	2.4	**14**	N
Bathymetry and Estuary Sediments	3.08	Assess nutrient flux in benthic sediments.	$25,000	0	0	0	2	0	3	3	0	0	8	1.8	**21**	N
Bathymetry and Estuary Sediments	3.09	More detailed information on the extent of ASS will be required where works that disturb the soils are to be undertaken.	To be undertaken on a needs basis.	0	0	0	2	0	2	1	0	0	5	N/A	**N/A**	N
Bathymetry and Estuary Sediments	3.10	Bank erosion assessments should be undertaken in high risk areas (i.e. areas with high velocities, erodible soils or previously identified erosion).	$60,000	0	1	1	2	0	0	2	1	1	8	1.7	**27**	N
Hydrodynamics	4.01	Develop a 3D hydrodynamic model of the estuary that may be used to assess water quality and sediment transport in the estuary. As part of the hydrodynamic modelling, tidal limits should be established for Charity Creek, Archer Creek, Clay Cliff Creek and Saltwater Creek	$50,000	0	0	1	2	3	3	2	0	1	12	2.6	**11**	Y
Water Quality	5.01	An analysis of the effects of anthropogenic influences on tidal mixing within the estuary is required.	See 4.01 above.	0	0	0	1	1	1	2	0	0	5	N/A	**N/A**	Y
Water Quality	5.02	There is limited information addressing the extent of impacts associated with oils and scums within the Parramatta River Estuary. Further assessment is needed to identify the significant sources and the effect of these pollutants on water quality.	$15,000	0	3	2	3	0	2	3	0	2	15	3.6	**1**	N
Water Quality	5.03	The existing quantitative data on gross pollutants within the Parramatta River estuary should be incorporated into a centralized database (where available). This should include the numbers, types and locations of GPTs within the catchment, along with quantity and type of material removed, as well as other incidental litter collection, such as that undertaken by NSW Maritime and on Clean Up Australia Day. This would facilitate a more coordinated approach to the management of catchment-based controls on gross pollutants.	$10,000	0	3	3	3	0	0	2	0	2	13	3.3	**3**	N

	No.	FURTHER STUDIES	Indicative Cost	Economic Benefit	Public Health And Safety	Human Usage	Water Quality	Hydrology And Hydraulics	Sediment Quality	Ecology	Cultural Heritage	Likely Community Support	Benefit Index	Benefit Index / log Cost	RANK	RECOMMENDED FOR INCL. IN ESTUARY PROCESSES STUDY?
Water Quality	5.04	Assess impacts of human activities on water temperatures within the estuary.	$15,000	0	0	0	1	1	1	2	0	0	5	1.2	**41**	N
Water Quality	5.05	Quantification of organic and inorganic chemical influx into the estuarine system is required. Whilst there is limited information outlining the inputs as a response of sedimentation, such studies need to be expanded upon in order to account for the transition of chemicals and heavy metals into the water column.	$25,000	0	2	2	3	0	2	2	0	1	12	2.7	**7**	Y
Water Quality	5.06	Calculation of a nutrient budget for the estuary and determination of the potential for eutrophication (see also 3.8).	$10,000	0	1	0	3	0	2	3	0	2	11	2.8	**6**	N
Water Quality	5.07	Characterisation of estuarine water quality for a series of conditions (e.g. dry and wet weather, over a tidal cycle) and on a variety of temporal scales (e.g. seasonal).	$120,000	0	3	3	3	0	2	2	0	3	16	3.2	**5**	Y
Water Quality	5.08	The extent and sources of faecal contamination within the Parramatta River estuary needs to be assessed with regards to both primary and secondary contact. Outlining potential hotspots and local catchment areas which may require further attention is a priority. An up to date catalogue of sewer overflow points is also required.	$20,000	0	3	2	2	0	0	0	0	2	9	2.1	**17**	N
Ecology	6.01	Assess the riparian vegetation of the study area as a whole and prioritise stretches of the foreshore for re-vegetation. Considerations of the site constraints and fauna communities present should be incorporated into the prioritisation process.	$40,000	0	0	2	1	0	1	3	1	1	9	2.0	**20**	Y
Ecology	6.02	Condition assessment of aquatic vegetation to facilitate prioritisation of rehabilitation works. As mentioned above, key considerations for prioritisation should include site constraints (e.g. relating to human usage and tidal inundation) and fauna communities present.	$50,000	0	0	1	1	0	1	2	1	1	7	1.5	**35**	Y
Ecology	6.03	Explicit assessment of the potential impacts of climate change and ongoing human usage on the estuarine flora and fauna. To incorporate as a priority an assessment of the potential impacts of sea level rise on estuarine flora.	$30,000	0	0	2	2	1	1	2	0	2	7	1.6	**31**	Y
Ecology	6.04	An assessment of the success of programs to re-establish aquatic vegetation.	$10,000	0	0	0	0	0	1	2	0	0	3	0.8	**47**	N
Ecology	6.05	Identification of those natural areas most heavily impacted by human usage. Once identified, the types of impact can be assessed in order to develop methods to reduce these impacts.	$10,000	0	0	1	1	0	1	3	0	2	8	2.0	**18**	Y
Ecology	6.06	Develop an understanding of primary production in the aquatic environment.	$20,000	0	0	0	1	0	0	2	0	0	3	0.7	**48**	N
Ecology	6.07	Ongoing monitoring of key ecological indicators of both ecological integrity and biodiversity. This monitoring should aim to facilitate identification of patterns and directions of change.	$50,000	0	0	0	0	0	1	3	0	2	6	1.3	**38**	N
Ecology	6.08	Identify locations in which mangroves are becoming established to the detriment of other estuarine habitats, or in otherwise inappropriate locations, and assess the need for management.	$35,000	0	0	0	0	0	1	3	0	1	5	1.1	**42**	Y

	No.	FURTHER STUDIES	Indicative Cost	Economic Benefit	Public Health And Safety	Human Usage	Water Quality	Hydrology And Hydraulics	Sediment Quality	Ecology	Cultural Heritage	Likely Community Support	Benefit Index	Benefit Index / log Cost	RANK	RECOMMENDED FOR INCL. IN ESTUARY PROCESSES STUDY?
Ecology	6.09	Identify portions of the river bank affected by scour, recommend appropriate ameliorative actions and prioritise for works based on habitat values.	See 3.1 above.	0	1	1	2	0	0	2	1	2	9	N/A	**N/A**	Y
Ecology	6.10	The undertaking of an assessment of the impacts of RiverCat boat wake on foreshore stability may be included in the Estuary Processes Study. However, this may be considered a low priority given that the existing evidence reasonably implicates the RiverCat boat wake as being the chief cause of bank undermining and mangrove collapse in the upper portion of the estuary, coincident with locations in which the RiverCat is the primary form of boat traffic and private vessels are banned.	$30,000	0	0	0	1	1	2	2	1	2	8	1.8	**23**	Y
Ecology	6.11	Undertake a study of the plankton of the Parramatta River Estuary.	$50,000	0	0	0	2	0	0	3	0	0	5	1.1	**43**	Y
Ecology	6.12	Undertake a survey of the fish fauna of the estuary.	$100,000	1	0	1	0	0	0	3	0	1	6	1.2	**40**	Y
Ecology	6.13	Examine the existing data set on avifauna to assess any trends in birds populations associated with the estuary. This may be correlated with any changes in the available habitat or major land use changes.	$10,000	1	0	1	0	0	0	3	0	1	6	1.5	**34**	Y
Ecology	6.14	Compile a database of the existing data on terrestrial fauna within the study area and assess the need for further studies.	$10,000	0	0	0	0	0	0	3	0	1	4	1.0	**44**	Y
Human Usage and Recreation	7.01	In order to rationalise the boat ramps and associated facilities, it must first be determined which facilities are the most popular and what their capacity is.	$50,000	0	3	3	1	1	1	0	1	3	13	3.3	**3**	Y
Human Usage and Recreation	7.02	Tourism Data Collection: if possible it would be useful to collect data relating to how many people are visiting the estuary, where they are coming from and the purpose for their visit.	$100,000	3	2	3	1	0	0	0	2	3	14	3.3	**2**	Y
Human Usage and Recreation	7.03	It may be useful to undertake an economic assessment of the values of the estuary. That is to undertake an assessment which determines an economic value for the various aspects on the estuary. This is usually done based on how much people are willing to pay to visit the estuary or protect features of the estuary. It may be necessary to conduct a community survey as part of this assessment. This may be done in conjunction with the collection of tourism data.	$10,000	3	0	3	1	0	0	1	1	3	12	2.7	**10**	Y
Cultural Heritage, Values and Significance	8.01	Integrate all existing information (including locational details) on a centralised database that may be accessed by all relevant agencies and organisations (as is appropriate).	$10,000	0	0	3	0	0	0	0	3	2	8	2.0	**18**	Y
Cultural Heritage, Values and Significance	8.02	Undertake an Aboriginal cultural heritage assessment for the entire study area, to incorporate consideration of cultural important sites that may not otherwise be accounted for.	$10,000	0	0	2	0	0	0	0	3	2	7	1.2	**31**	Y
Cultural Heritage, Values and Significance	8.03	Undertake a comprehensive survey of European heritage items in the study area in an attempt to identify any previously unrecorded sites. The narrow down the search area, sites considered to have a high potential of containing heritage items may be targeted.	$20,000	0	0	2	0	0	0	0	3	3	8	1.7	**25**	N

	No.	FURTHER STUDIES	Indicative Cost	Economic Benefit	Public Health And Safety	Human Usage	Water Quality	Hydrology And Hydraulics	Sediment Quality	Ecology	Cultural Heritage	Likely Community Support	Benefit Index	Benefit Index / log Cost	RANK	RECOMMENDED FOR INCL. IN ESTUARY PROCESSES STUDY?
Cultural Heritage, Values and Significance	8.04	Undertake targeted maritime heritage surveys in association with locations thought to have a high potential for the occurrence of important archaeological items (e.g. Queens Wharf).	$30,000	0	0	2	0	0	0	0	3	1	6	1.3	**37**	N
Cultural Heritage, Values and Significance	8.05	Documentation of Indigenous oral history and personal accounts.	$10,000	0	0	2	0	0	0	0	3	2	7	1.6	**31**	N

14. CONCEPTUAL MODEL OF THE ESTUARY

A conceptual model is a diagrammatic representation of the key characteristics and processes occurring within the estuary. A conceptual model has been prepared for the Parramatta River Estuary. The conceptual model is shown in **Figure 14.1**. The following processes have been included in the model:

- Depth variations along the Parramatta River;
- Land contamination;
- Flora and fauna;
- Tidal exchange with the ocean;
- Tidal range;
- Recreation;
- Sediment transport;
- Dredging;
- Nitrogen and Carbon exchange with the atmosphere;
- Wind mixing;
- Rainfall; and
- Freshwater inflows.

15. RECOMMENDATIONS

A number of data gaps and uncertainties have been identified as part of the data compilation and review process. Generally these data gaps and uncertainties relate to issues in the estuary. Where possible these data gaps and uncertainties should be addressed through further studies as part of the Estuary Processes Study.

The preliminary list of issues compiled at the conclusion of each chapter sum to a total of 80 management issues. These management issues may be expanded upon and clarified based on additional information gathered during the Estuary Processes Study.

The prioritisation of these issues will be a key step when progressing further along the Estuary Management Process. The management issues effectively drive the rest of the Management Process – the management goals, objectives and actions are derived from this basis. Given the large number of stakeholders and estuary users, it is critical that this prioritisation process be undertaken as part of a transparent consultative and whole-of-estuary approach.

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  - Strathfield Municipal Council
  - Sydney Ferries Corporation,
  - Ryde-Hunters Hill Flora and Fauna Preservation Society,
  - City of Canada Bay Council,
  - Darug Tribal Aboriginal Corporation,
  - Deerubbin Local Aboriginal Land Council,
  - Friends of Duck River,
  - Hunters Hill Council,
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  - Sydney Harbour Federation Trust,
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- Bankstown City Council;
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- DoP;
- DoL;
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- Friends of Duck River;
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17. REFERENCES

NB - This section lists those references that were used in the preparation of this report. However, the full list of references compiled during the undertaking of this study are available in **Appendix B**.

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FIGURES

APPENDIX A

Site Photolog

APPENDIX B

All Data Sources

APPENDIX C

Key References

APPENDIX D

Community Newsletter and Survey

ATTACHMENT 1

Rainfall Gauges in the Parramatta River Estuary Catchment

ATTACHMENT 2

Protection of Environment Operations Act Register of Licences

ATTACHMENT 3

Contaminated Lands Management Act Register of Notices

ATTACHMENT 4

Flora Species List by LGA

ATTACHMENT 5

Fauna Species List by LGA

ATTACHMENT 6

Threatened and Protected Flora Species

ATTACHMENT 7

Threatened and Protected Fauna Species

ATTACHMENT 8

Protected Matters

ATTACHMENT 9

Indigenous Heritage Sites

ATTACHMENT 10

European Heritage Listings