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Wollongong City Council

Estuary Management Plan for Several Wollongong Creeks and Lagoons

Estuary Processes Study

December 2007

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

Executive Summary

GHD was commissioned by Wollongong City Council to complete an Estuary Processes Study for ten creeks and lagoons in the Wollongong local government area (LGA). The study area comprised the tidal waterways, foreshores, surrounding open space and adjacent lands of the following estuaries:

» Tom Thumb Lagoon (including Springhill and J.J. Kelly catchments);

» Bellambi Lagoon;

» Bellambi Gully (including Farrahars Creek catchment);

» Collins Creek;

» Whartons Creek;

» Slacky Creek;

» Flanagans Creek (including Thomas Gibson Creek);

» Stoney Creek;

» Stanwell Creek; and

» Hargraves Creek.

The Processes Study incorporated investigations into the aquatic and riparian flora, an assessment of fauna habitat values, a fishery and macroinvertebrate study, and an assessment of estuary geomorphology and bank erosion, together with a review of relevant literature and water quality data. The key findings of the processes studies are summarised below.

Water Quality

The review of available water quality data identified that the majority of the estuaries had low dissolved oxygen saturation values, high nutrient concentrations and high faecal coliform counts, making the waters unsuitable for primary, and in some cases, secondary recreational activities. Some waterways failed to meet the appropriate ANZECC guideline values on much more than 50% of the occasions. Copper and zinc concentrations were also higher than guideline values at many of the sites.

As expected, the less urbanised catchments in the north appear to have better water quality than more urbanised catchments in the central areas of Wollongong. Elevated nutrient levels and faecal coliforms are likely to be associated with rainfall events, but further monitoring is required to quantify the effects of season and rainfall.

Water quality data for the northern catchments of Hargraves, Stanwell and Stoney Creeks (collected up to 1999) identified elevated faecal coliform levels in the three creeks that exceeded the secondary recreational contact guideline. Since this data was collected, Sydney Water has constructed the Coalcliff, Stanwell Park, Stanwell Tops and Otford Sewerage Scheme and approximately 75% of residences in the catchments of Hargraves, Stanwell and Stoney Creeks have been connected to the system. Consequently, it is likely that water quality in these creeks has improved in comparison to water quality data obtained prior to scheme commissioning, although the remaining unconnected residences still pose a risk of faecal contamination.

Ecological Assessment

Several areas of ecological significance were identified in the estuaries, including:

» Areas of Coastal Saltmarsh EEC at Hargraves Creek, Stanwell Creek, Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon;

» Areas of remnant Swamp Oak Floodplain EEC at Stanwell Creek and Bellambi Lagoon, and recreated Swamp Oak Floodplain EEC at Tom Thumb Lagoon;

» An area of Bangalay Sand Forest EEC recorded at Bellambi Lagoon;

» Mangroves recorded at Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon;

» Seagrasses recorded at Bellambi Lagoon;

» Estuarine areas of potential habitat for the threatened Green and Golden Bell Frog at Hargraves Creek, Stanwell Park, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon;

» Estuarine areas of potential habitat for the threatened Sooty Oystercatcher at Stanwell Creek;

» Estuarine areas of potential habitat for the threatened Swift Parrot at Bellambi Lagoon;

» Estuarine areas of potential habitat for the threatened Australasian Bittern and Black Bittern at Bellambi Gully;

» Swamp Oak Forest and Bangalay Sand Forest at Bellambi Lagoon that contain hollow-bearing trees, providing potential nesting habitat for birds, bats and mammals;

» Bangalay Sand Forest (which includes flowering eucalypts) that would provide potential foraging habitat for a variety of birds, bats and mammals;

» Swamp Oak Forest at Stanwell Creek, Bellambi Lagoon and Tom Thumb Lagoon that would provide potential foraging habitat for a variety of birds and mammals;

» Potential foraging habitat for a range of owls and birds of prey was identified within the catchments of all estuaries surveyed; and

» Lagoons with dense riparian vegetation that would provide important fauna foraging habitat for a range of amphibians, bats, reptiles and birds at Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon.

Conservation efforts should initially be focused on the larger areas of EECs at Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon, areas of seagrass and mangroves, and areas of higher fauna habitat value. Conservation efforts could include research and monitoring of EECs, investigation into the effect of anthropogenic impacts, and the monitoring and management of sites for invasion of exotic species.

Potential threats to the flora and fauna values of the lagoons include: the decline and/or weed invasion of riparian vegetation and EECs; loss of fauna and riparian habitat through urban development; inappropriate levels of, or impacts from, recreational use (particularly at Bellambi Lagoon); introduced fauna preying on native fauna; urban runoff containing high levels of nutrients, with possible impacts on algal blooms; industrial and/or contaminated runoff entering Tom Thumb Lagoon; and impacts on water quality from sewage, industrial and residential sources.

Fisheries

GHD Aquatic Sciences conducted a fish survey on Whartons Creek, Flanagans Creek, Collins Creek and Tom Thumb Lagoon to better understand the fish assemblages and the processes that drive them.

In total, 2738 fish belonging to 14 species were sampled during the study period between 12 March 2007 and 16 March 2007. The most abundant species caught across all sites were Flathead Gudgeon (*Philypnodon grandiceps)*, contributing 40% of the total catch. Commercially significant species such as the Yellowfin Bream (*Acanthopagrus australis)*, the Sand Mullet (*Myxus elongatus)* and the Sea Mullet (*Mugil cephalus)* were locally abundant contributing 8%, 10% and 4% respectively to the overall percentage.

A total of 820 individuals, comprising 7 species, were sampled from Collins Creek during the survey. Native species accounted for 98% of the total number of fish caught. The Mosquito Fish (*Gambusia holbrooki)* was the only introduced species sampled.

316 individuals belonging to 8 families were sampled from Flanagans Creek. The Flathead Gudgeon was the dominant species with 305 individuals accounting for 96% of the total abundance. Samples taken from Whartons Creek returned 263 individuals comprising 5 species. Whartons Creek was the least diverse system with 95% of the total abundance attributed to only two species. These included the Flathead Gudgeon and the Sand Mullet.

Tom Thumb Lagoon was the most diverse estuary sampled as part of this project with 1339 individuals belonging to 9 species. The most abundant species was the Flat-backed Goby *(Mugilogobius platynotus)* accounting for 51% of the total catch. Individuals of all size classes were represented indicating that a viable population exists within this lagoon.

A total of 48 mm of rain fell between the 11 March 2007 and 13 March 2007. The estuaries studied under the scope of this project received stormwater runoff from the urban catchments. Due to this influx of freshwater, all estuaries were open to the sea at the time of the survey. The water quality results and the corresponding fish faunas indicated that these estuaries were freshwater systems.

Bank Erosion

The bank erosion assessment conducted along the estuaries and accessible upstream freshwater reaches identified that:

» The banks of Hargraves Creek are largely stable, although three sites of moderately to highly active bank erosion were identified;

» The right bank of Stanwell Creek Lagoon, and both banks immediately upstream of the causeway are generally stable, although the left bank exhibits active erosion of varying degrees;

» The estuary of Stoney Creek is almost entirely bounded by bedrock and does not exhibit any erosion issues;

» The banks of Flanagans Creek are generally stable or minimally active, with moderately active erosion confined to two short sections along the right bank;

» The lower estuary of Slacky Creek has several sections of moderately to highly active bank erosion;

» The estuarine section of Whartons Creek is relatively stable with only a short section of the left bank (between Bulli Beach Holiday Park and the footbridge downstream) exhibiting moderately active erosion;

- The banks of the Collins Creek estuary are predominantly stable, although there is some minor instability in the vicinity of the footbridge, but the banks in the lower profile at this location consist of bedrock and have limited potential to erode further;
- The banks of Bellambi Lagoon are generally stable with only limited minimally active erosion along the left bank towards the entrance;
- The banks of Bellambi Lagoon are largely stable, although moderately active erosion of the dunes at the entrance was identified. Along the right bank the erosion is associated with the the informal beach access, while the erosion on the left bank is likely to be primarily driven by wave attack during ocean storm events (but exacerbated by catchment flow events and unrestricted access to the dunes). While no moderately to highly active bank erosion was identified within Tom Thumb Lagoon, scour and channelisation is evident across the floor of the saltmarsh flat in the western arm. The banks of the northern arm exhibit minimally active erosion that is generally localised to the lower bank where tidal inundation prevents the growth of vegetation.
- Significant erosion sites were present in the upstream catchment of some estuaries, as identified from either the field investigation or through aerial imagery analysis.

Priority sites/actions for erosion management include:

- Stanwell Creek, as ongoing erosion is threatening road and car parking assets;
- Whartons Creek (as ongoing bed erosion will extend the length of bank instability at the erosion head in the upstream catchment; and
- Undertake additional field investigations to verify the potential upstream catchment erosion sites identified in the Bellambi Gully and Bellambi Lagoon catchments.

Conclusions

Investigations carried out as part of this processes study have identified a number of significant issues and recommended actions that will maintain or improve the value of the Wollongong estuaries that are the subject of this report. This information will be used in the estuary management study and plan to identify and assess management objectives and strategies to address the significant issues.

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Glossary

Alluvial	Referring to landscape features produced by deposits of mud, clay, silt, gravel, or sand; made by a stream
Average Recurrence Interval	The average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that the periods between exceedances are generally random
Barrier system	Typical of beaches subject to high wave energy. Includes the beach face, cusps, channels and dune system
Bay-head beach	Beach where a freshwater source enters an estuarine body
Compound Channel	Naturally occurring stream channel configuration consisting of a distinct main channel for conveying low flows with a wider floodplain channel allowing high flows to spread out and lose energy.
Embayment	A coastal indentation (or bedrock valley) that has been submerged by rising sea level and not significantly infilled by sediment. Also: Drowned River Valley
Flood-ebb delta	Typically found in the entrances of wave-dominated estuaries and deltas (adjacent to the Barrier), and is formed by redistribution of sediment by tidal movement in and out of the entrance.
Fluvial	Pertaining to a river or freshwater source
Geomorphology	The study of the arrangement and form of the Earth's crust and of the relationship between these physical features and the geologic structures beneath
ICOLL	Acronym – Intermittently Closed and Open Lakes and Lagoons, referring to Coastal Lagoons and some Wave-Dominated Estuaries under low runoff conditions
Littoral drift	The process by which sediments move along a beach shore
Microtidal	Coastal ocean or waterway with a low mean tidal range, e.g. less than 2 metres
Orographic	Related to, or caused by, physical geography (such as mountains or sloping terrain)
Riparian	Of, on, or relating to the banks of a natural course of water

List of Abbreviations

ANZECC	Australian and New Zealand Environment and Conservation Council
AR&R-IFD	Australian Rainfall and Runoff – Intensity Frequency Duration Curves
ARI	Average Recurrence Interval
AUSRIVAS	Australian River Assessment System
BG	Bellambi Gully
BL	Bellambi Lagoon
BOD	Biochemical Oxygen Demand
CL	Collins Creek
EEC	Endangered Ecological Community
EC	Electrical Conductivity
EMC	Estuary Management Committee
EMP	Estuary Management Plan
EMSP	Estuary Management Study and Plan
EPS	Estuary Processes Study
EPT	Ephemeroptera Plecoptera Trichoptera Score
COD	Chemical Oxygen Demand
CL	Collins Creek
CVA	Conservation Volunteers Australia
DEC	Department of Environment and Conservation (now DECC)
DECC	Department of Environment and Climate Change (formerly DEC)
DEH	Department of Environment and Heritage
DNR	Department of Natural Resources (now part of DECC and DWE)
DO	Dissolved Oxygen
DPI	Department of Primary Industry
EPA	Environment Protection Authority (now DECC)
FC	Faecal Coliform
FL	Flanagans Creek
GHD	GHD Pty Ltd
GIS	Geographic Information System
GPS	Global Postitioning Satellite location
HG	Hargraves Creek
ICOLL	Intermittently Closed and Open Lake or Lagoon
IDNWA	Illawarra District Noxious Weeds Authority
LEP	Local environmental plan
LGA	Local government area
m^3	Cubic metre
mg/L	Milligrams per litre
NMDS	Non-metric Multi Dimensional Scaling

NPV	Net Present Value
NPWS	NSW National Parks and Wildlife Service
NSW	New South Wales
pH	Measure of acidity or alkalinity
REP	Regional environmental plan
SCA	Sydney Catchment Authority
SEPP	State Environmental Planning Policy
SL	Slacky Creek
SS	Suspended Solids
ST	Stoney Creek
SW	Stanwell Creek
SWC	Sydney Water Corporation
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorus
TS	Total Solids
TSC Act	*Threatened Species Conservation Act 1995*
TTL	Tom Thumb Lagoon
WCC	Wollongong City Council

1. Introduction

1.1 Scope of Study

GHD was commissioned by Wollongong City Council to complete an Estuary Processes Study, Estuary Management Study and Plan for ten creeks and lagoons in the Wollongong local government area (LGA). The study area comprises the tidal waterways, foreshores, surrounding open space and adjacent lands of the following estuaries:

» Tom Thumb Lagoon (including Springhill and J.J. Kelly catchments);
» Bellambi Lagoon;
» Bellambi Gully (including Farrahars Creek catchment);
» Collins Creek;
» Whartons Creek;
» Slacky Creek;
» Flanagans Creek (including Thomas Gibson Creek);
» Stoney Creek;
» Stanwell Creek; and
» Hargraves Creek.

The location of these estuaries is shown in Figure 1.1.

This report documents the findings of the Estuary Processes Study. The Estuary Management Study and Plan is the subject of a separate report.

This processes study incorporated the following activities and tasks:

» Review of existing literature to define existing catchment characteristics and to verify and identify issues potentially relevant to the management of the estuaries;
» Undertake estuary processes investigations comprising:
  – an ecological assessment, including estuarine vegetation mapping, indentification of endangered ecological communities, fauna survey and sampling of macroinvertebrate communities;
  – field sampling and assessment of fish communities;
  – a geomorphological assessment, including bank erosion mapping and prioritisation; and
» A summary of significant issues for estuary management.

The outcomes of the processes study, as documented in this report, will inform the development of the subsequent Estuary Management Study and Plan.

Figure 1.1 Location of the estuaries

1.2 Study Objectives

Wollongong City Council identified two key objectives for the Estuary Processes Study:

» Establish the context for management of the estuaries by:
  - Identifying their significance and any essential features that make them important;
  - Documenting current uses, identify potential future uses and assessing their likely impacts and conflicting uses;
  - Assessing the current condition of the estuaries and the need for environmental protection, conservation and remedial measures;
  - Identifying key stakeholders for management of the estuaries;
  - Documenting current management initiatives and future projects of relevance to the estuaries, to which Council and other agencies have already committed; and

» Developing additional knowledge of estuary processes to inform the management plan.

1.3 Estuary Management Process

This EPS was prepared under the NSW Government's Estuary Management Program and developed in accordance with the requirements of the NSW Estuary Management Policy 1992 and NSW Coastal Policy 1997.

Figure 1.2 summarises the NSW Government's estuary management process. The estuary management program is administered by the Department of Environment and Climate Change (DECC; formerly the Department of Natural Resources), which provides a subsidy to local councils of up to 50% of the cost of completing each stage of the process.

WCC has formed an Estuary Management Committee (EMC) to oversee the process. The committee membership includes Councillors, Council staff, representatives of relevant authorities and agencies, local community groups and users of the estuary.

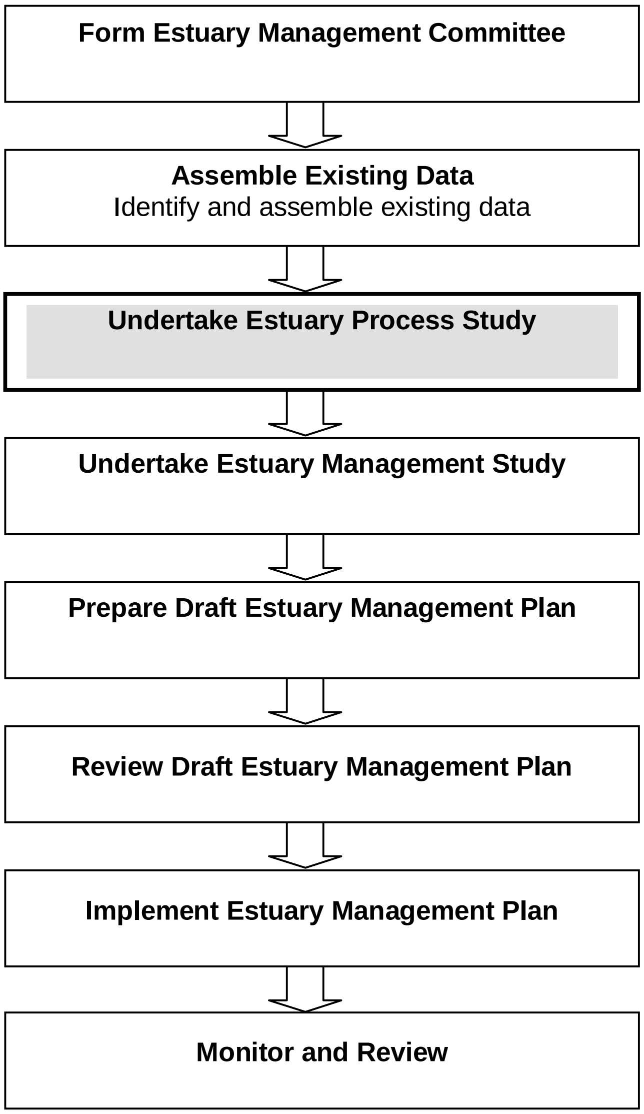
The second step in the estuary management is the identification of existing available information and data for the subject estuaries. This data compilation is most often conducted by specialist consultants, and usually includes assembling the data and then undertaking a review to identify information gaps that may be addressed in the Estuary Processes Study. The data compilation study undertaken for this project was was prepared by WBM (2006) and is discussed in more detail in Section 1.4.

The Estuary Processes Study defines the existing condition of the various estuarine processes and their interactions. The Processes Study documents the physical processes, water quality, ecological and biological parameters and the extent to which human activities have impacted upon estuarine processes.

The information and data obtained during the Estuary Processes Study is subsequently used to develop an Estuary Management Study, which identifies essential features and current uses of the estuaries and develops overall management objectives for the estuaries.

From the findings of the Estuary Management Study, a draft Estuary Management Plan (EMP) is developed. The draft EMP identifies recommended activities to achieve the objectives set out in the Estuary Management Study. The draft EMP may also set out monitoring and review procedures.

Figure 1.2 NSW Government Estuary Management Process



1.4 Study Background and Data Compilation

A Data Compilation and Review Report (WBM, 2006) was prepared for the subject estuaries. The data compiled included:

» Aerial photography of Slacky Creek, Collins Creek, Bellambi Lagoon and Bellambi Gully from as early as 1948 to determine alignment configurations and past impacts on the waterways;

» Ecological processes specifically within the wetland systems present in the study lagoons and waterways;

» Flora within riparian and estuarine areas of the management sites;

» Groundwater modelling by WCC to determine the existence and extent of landfill leachate impacting on saltmarsh;

- Threatened ecological communities survey that defined 57 vegetation communities of which five were defined as proposed Endangered Ecological Communities within the Wollongong LGA;
- Fauna data, specifically fisheries studies in Stanwell Creek, Bellambi Lagoon, Stony Creek, Slacky Creek and Bellambi Creek; bird observations for Hargraves Creek, Stanwell Creek, Stony Creek, Collins Creek, Bellambi Gully, Bellambi Lagoon, and Tom Thumb Lagoon; and Threatened Species present within the process study area;
- Water quality information including comparisons with the ANZECC guidelines, physical and chemical indicators, nutrient levels, metals and biological indicators for each of the sites within the Processes Study area; and
- Nutrient fluxes and erosion and sedimentation data for each of the process study sites.

A summary of the WBM report was supplied to prospective tenders during the proposal stage of the project, and used to guide project development to ensure that key issues were appropriately addressed during preparation of the subsequent Estuary Processes Study and Estuary Management Study and Plan.

1.5 Literature Review

Following award of the project, Council provided copies of relevant report, studies, investigations, policies and procedures to GHD for incorporation into a literature review. The literature review was used to inform and guide the processes studies, and to to provide relevant background information on the estuaries. The review included a consideration of the following publications and reports:

- WBM Oceanics (2006) Wollongong Northern Coastal Creeks and Lagoons: Data Compilation and Review Report;
- Kelly, G. & Doherty, M. (2004) North Wollongong Lagoons: Social Values and Issues in the Fairy, Towradgi and Hewitts/Tramway Estuaries. Urban and Regional Futures Group, CSIRO Sustainable Ecosystems;
- Cardno Lawson Treloar (2005) Fairy, Towradgi and Hewitts/Tramway Creeks Estuary Management Study and Plan. Report prepared for Wollongong City Council;
- NSW Government (1992) NSW State Rivers and Estuaries Policy;
- NSW Government (1992) Estuary Management Manual;
- NSW Government (1992) NSW Wetlands Management Policy;
- NSW Government (1997) NSW Coastal Policy 1997: A Sustainable Future for the New South Wales Coast;
- NSW Fisheries (1999) Policy and Guidelines: Aquatic Habitat Management and Fish Conservation;
- Southern Rivers Catchment Management Authority (2003) Southern Catchment Blueprint: An Integrated Catchment Management Plan for the Southern Catchment. Southern Rivers CMA. Catchment Action Plan;
- City of Wollongong Local Environmental Plan (1990);
- Wollongong City Council Corporate Plan 2005-2009;

- Wollongong City Council (2000-2006) State of the Environment Reports. Six annual SoE reports;
- Wollongong City Council (2002) Generic Plan of Management for Community Land Categorised as Natural Areas;
- Wollongong City Council (2002) Hewitts Creek (Incorporating Slacky, Tramway, Woodlands & Thomas Gibson Creeks) Flood Study;
- Forbes Rigby (2000) Stormwater Management Plan: Wollongong Coastal Catchment;
- DIPNR (2004) Riparian Corridor Management Study Covering All of the Wollongong LGA and Calderwood Valley in the Shellharbour LGA;
- Eco Logical Australia (2006). Wollongong Riparian Corridor Study – Draft;
- Merrin, S.J. and Chafer, C.J. (2000) Illawarra Wetlands Action Plan. Illawarra Catchment Management Committee;
- Anthony (1994) An Environmental Management Plan for Bellambi Creek Catchment;
- AWT (1999a) Priority Sewerage Program Environmental Impact Statement: Appendix E Water Quality Monitoring Study;
- AWT (1999b) Priority Sewerage Program Environmental Impact Statement: Appendix H Water Quality Modeling Study;
- Chafer (1997) Biodiversity of Wetlands in the Illawarra Catchments: An Inventory;
- Department of Infrastructure Planning and Natural Resources (DIPNR) (2004) Riparian Corridor Management Study;
- EcoLogical (2006) Tom Thumb Lagoon Wetland Plan of Management;
- EcoLogical Australia (2006) Draft Wollongong Riparian Corridor Study;
- Neil (2005) Vegetation Management Plan for Hargraves Creek and Stanwell Park;
- NSW National Parks and Wildlife Service (2003) Native Vegetation of the Illawarra Escarpment and Coastal Plain;
- Robinson (1995) Mammals of the Illawarra Escarpment between Stanwell Park and Cambewarra;
- Tuckett Carr (2005) Collins Creek Riparian Vegetation Management Plan;
- Treecreeper Indigenous Land Management (2005) Bellambi Lagoon and Sand Dunes Vegetation Management Plan;
- Centre for Estuarine and Coastal Catchment Studies (1998) Shallow Water Fishes of Illawarra Wetlands;

Database searches were also undertaken to gather information relevant to the study area and locality (10 km radius of the study area). Database searches included:

- Department of Environment and Climate Change (DECC) Atlas of NSW Wildlife records for threatened species, endangered populations and endangered ecological communities listed under the TSC Act which have been recorded within the locality;
- NSW Fisheries records and published information for threatened species, endangered populations and endangered ecological communities listed under the FM Act which have been recorded, or have the potential to occur in the study area;

- Department of Environment and Heritage (DEH) Protected Matters Search Tool for Matters of NES listed under the EPBC Act, which may occur in the study area. Note that Matters of NES are limited to threatened species and migratory species listed under Japan Australia Migratory Bird Agreement (JAMBA), China Australia Migratory Bird Agreement (CAMBA) and the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention) only;
- National Parks and Wildlife Service Threatened Flora database;
- NSW State Forests Threatened Flora and Fauna database; and
- Australian Museum Threatened Fauna database.

The findings of the review were incorporated into the various sections of this processes study.

2. Catchment Characteristics

2.1 Estuary Location and Type

The locations of the estuaries are detailed in Figure 1.1. The majority of the estuaries are characterised as intermittently closed and open lakes or lagoons (ICOLLs) and their entrances only open during periods of high rainfall or during large tidal influenced events. However, Tom Thumb Lagoon is a coastal creek that is permanently open to the ocean and, as a consequence, is subject to daily tidal flushing.

2.2 Climate

The climate experienced in the Wollongong region can be characterised as a mild coastal climate with moderate precipitation and temperature extremes. Meteorological data for the study sites was obtained from the meteorological stations at Wollongong University (for data since 1970) and Wollongong Post Office (for data up until 1953). These stations, which are relatively close to each other, provide similar results for temperature averages but significant variations in monthly rainfall averages, as illustrated in Figure 2.1

Figure 2.1 Rainfall averages at two Wollongong weather stations

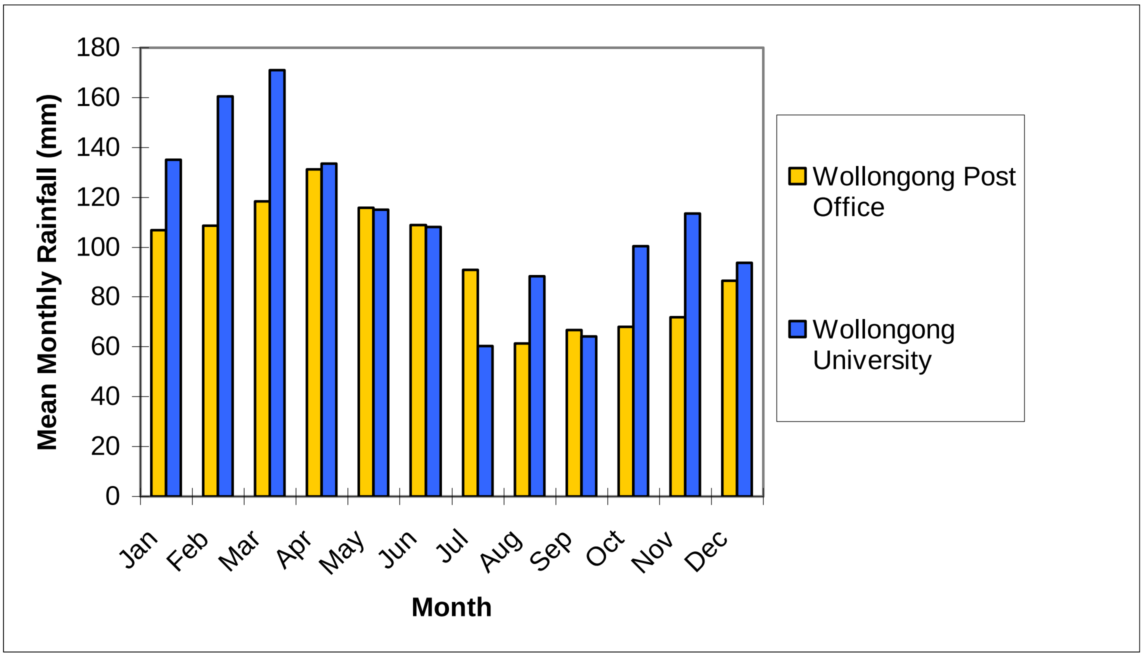


Table 2.1 summarises the climatic averages for Wollongong using data from the University weather station for the period 1970 to 2004.

Table 2.1 Climatic averages - Wollongong University

Weather Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum Temp (deg C)	17.9	18.3	16.8	14.3	11.9	9.5	8.4	8.8	10.6	12.6	14.3	16.6
Maximum Temp (deg C)	25.6	25.6	24.5	22.5	20.0	17.6	17.0	18.2	20.3	22.0	22.8	25.0
Average Humidity (%)	69	71	67.5	63.5	63.5	60.5	57.5	54.5	55	60.5	64	65
Average Wind Speed (km/h)	11.20	10.75	10.20	10.05	10	11.40	11.50	12.80	13.75	13.40	12.70	12.20

As Figure 2.1 and Table 2.1 documents, the highest rainfall occurs in the months of January through to June with 61% of the total annual rainfall falling within this period.

As can be seen in Table 2.1, the average maximum temperature is below 26^{o}C with an average humidity of 60 to 71% for the months with the highest monthly rainfall. A climatic pattern is clearly visible in the averaged data of dry winters and wet summer and autumn.

Monthly evaporation data compiled by WBM (2006), showed that evaporation is highest during the months when moderate to high temperatures are experienced.

2.3 Topography

The original topography of the Wollongong urban area has been modified by development and extractive industries. The Illawarra Escarpment runs parallel to the coast to the west of the city and provides a physical barrier for lateral expansion. The creeks within the study area arise within the Illawarra Escarpment and flow through this generally modified environment towards the coast. The Wollongong Plain lies between the Illawarra Escarpment and the coast and consists of gentle rises of the Illawarra Coal Measures, rolling to steep low hills of volcanic materials and undulating sandstone and alluvium (Hazelton and Tille, 1990).

With the exception of Tom Thumb Lagoon, all creeks rise in, on or adjacent to the escarpment on steep land. They flow in an easterly direction towards the coastal plan, which is characterised by lower gradient slopes and urban and suburban development.

2.4 Geology and soils

The Illawarra region can be broken into three geologic regions of a plateau, range or escarpment and plains. These are further defined as the Woronora Plateau, Illawarra Escarpment and the Wollongong Plain. The four main geological groups found in the Illawarra are Hawkesbury Sandstone, the Narrabeen Group, Illawarra Coal Measures and the Shoalhaven Group.

The Woronora Plateau gradually slopes to the west with Hawkesbury Sandstone, forming the majority of the surface profile, significantly influenced by streams and creeks eroding the sedimentary rock.

The Illawarra Range is orientated northeast to southwest and almost intersects the coast in the vicinity of Stanwell Park. Three primary sandstones, the Hawkesbury, Bulgo and Colo Vale, define the escarpments cliff line profile with two clay benches present below this. The coastline illustrates the influence of the escarpment with a higher occurrence of rocky headlands and protected short beaches compared to the longer beach and sand dune systems of the south.

The occurrence of coastal lagoons can be attributed to the build-up of sand barriers at the outlets of existing creeks and streams feeding into the ocean.

The Wollongong Plain overlies the Illawarra Coal Measures and the alluvial floodplain soils of the Shoalhaven Group. The Wollongong Plain stretches over 30 kilometres along the coast, although it only widens to a maximum of 14 kilometres in the south, bounded by the cliffs of the Illawarra Escarpment.

The specific aspects of the soils likely to be encountered at each of the estuaries is described below:

2.4.1 Tom Thumb Lagoon

The area surrounding Tom Thumb Lagoon and Port Kembla contains soil defined by Hazelton and Tille (1990) as a disturbed landscape. This disturbed profile is defined due to the past removal of the original soil. The subsequent replacement fill has a number of limitations including mass movement hazard, soil impermeability, poor drainage, low fertility and toxic material.

2.4.2 Bellambi Lagoon, Bellambi Gully, Collins, Whartons, Slacky and Flanagans Creeks

These systems generally arise within the Illawarra Escarpment. The upper reaches of the creeks flow through the Gwynneville landscape, through the Fairy Meadow landscape to the Wollongong landscape at its outlet.

The limitations of the Illawarra Escarpment and Gwynneville landscape include steep slopes and extreme erosion hazard, with low to moderate soil fertility. The Fairy Meadow and Wollongong landscapes are prone to flooding from permanently high water tables, contain potential acid sulphate soils and have soils of high permeability with low fertility.

2.4.3 Stoney Creek

The lower reaches of Stoney Creek contain the Watagan landscape, typical of the northern areas of the Illawarra Escarpment. Soils existing within the landscape range from the typical Siliceous Sands of the Wollongong landscape to Yellow, Brown and Red Podzolic Soils. Like the soils of the Illawarra Escarpment, the soils of the Watagan landscape are prone to severe erosion.

2.4.4 Stanwell and Hargraves Creeks

The lower reaches of Stanwell and Hargraves Creeks flow through a basin of the Wollongong landscape. The basin soils are characterised as sands and humus, similar to the beach areas of the Wollongong area. The upper reaches of the creeks flow through the Watagan and Bundeena landscapes. The Bundeena landscape may contain acid peats in poor drainage areas, influencing water quality in the creeks. Both the Bundeena and Watagan landscapes contain soils at risk of erosion, with the soils within the Bundeena group having low fertility and seasonally high water tables.

2.5 Estuary Characteristics

The key estuary characteristics of estuary morphology, catchment ecology, landuse and zoning, catchment runoff and potential pollution sources were assessed from information collated during the literature review and are described below for each estuary. It should be noted that the availability of information for some estuaries was extremely limited, while information on the larger estuaries, such as Tom Thumb Lagoon and Bellambi Lagoon, was extensive. The relative availability of estuary-specific information is reflected in the level of detail provided below for each estuary.

2.5.1 Hargraves Creek

Estuary Morphology

Hargraves Creek is an ICOLL estuarine lagoon at the oceanic outlet of Hargraves Creek. The entrance is often closed by a sand barrier and thus water in the lagoon can be brackish (Chafer 1997). AWT (1999a) noted that wet weather resulted in poor water quality and increased nitrogen, phosphorus and ammonia levels at the downstream site of Hargraves Creek.

Hargraves Creek is bounded by The Park Parade to the north, Hargrave Drive to the west, and Station Street to the South. Hargraves Creek rises at the top of the Illawarra escarpment within a hanging swamp at Stanwell Tops, and flows in an easterly direction through sclerophyll forest that is dominated by eucalypts interspersed with rainforest gullies, through to coastal plain vegetation (Neil 2005).

Hargraves Creek has a catchment area of approximately 210 hectares and a creek length of 3.2 km.

Ecology

The Vegetation Management Plan completed for Hargraves Creek and Stanwell Park (Neil, 2005) identified the following issues of concern: creek bank destabilisation and degradation, weed infestation, lack of appropriate native vegetation, tracks made through bushland causing compaction, soil erosion, and lack of community awareness. Creek bank erosion is also a problem due to urban and road development (Merrin and Chafer 2000).

Neil (2005) recorded Common Reed (*Phragmites australis*) and Sea Rush (*Juncus krausii*) as the dominant riparian species lining Hargraves Creek. The wet sclerophyll forest that occurred outside the estuarine reaches of the creek was confined to the immediate banks of the creek and typified by Grey Myrtle (*Backhousia myrtifolia*), Cheese Tree (*Glochidion ferdinandi*), Lilly Pilly (*Acmena smithii*), Turpentine (*Syncarpia glomulifera*), Bangalay (*Eucalyptus botryoides*) and Prickly-leaved Tea Tree (*Melaleuca styphelioides*), with a relatively dense understorey of shrubs and ferns. This forest has been largely lost to residential development and recreational use. Planted Kikuyu Grass (*Pennisetum clandestinum*) is mown up to the edge of the creek in some areas. The revegetation plan by Neil (2005) recommended the reintroduction of native, indigenous species by using local provenance seed obtained from local sites of similar soils, aspect, and vegetation structure, as the most promising means to reconstructing the former plant community.

Landuse and zoning

The lagoon located at the outlet of the creek is within the zone 6(a) Public Recreation with areas of zone 1 Non Urban, zone 2(a1) Special Low Density Residential, 7(c) Environmental Protection-Residential, 5(b) Roads and 5(c) rail. A tributary flowing into Hargraves Creek has zones of 7(d) Environmental Protection-Hacking River and 7(b) Conservation.

Catchment Runoff and Potential Pollution Sources

Local residents have reported that the lagoon at the mouth of Hargraves Creek becomes odorous at times as a result of sewage pollution from upstream (Merrin and Chafer 2000). Although construction of the Coalcliff, Stanwell Park, Stanwell Tops and Otford Sewerage Scheme was completed in June 2005, and approximately 75% of residences in the catchment have since been connected to the centralised sewerage scheme, 25% of residences are still reliant on on-site sewage treatment systems (Sydney Water, 2006), and consequently the risk of faecal contamination of Hargraves Creek remains.

Hargraves Creek is also heavily utilised for recreational activities, and consequently gross pollutants are a particular concern.

2.5.2 Stanwell Creek

Estuary Morphology

Stanwell Creek is an ICOLL estuarine lagoon at the oceanic outlet of Stanwell Creek. The entrance is often closed by a sand barrier and thus water in the lagoon can be brackish (Chafer 1997).

Stanwell Creek is bounded by Lower Coast Road in the west and south and Beach Road in the north. Stanwell Creek rises on the Illawarra Escarpment and consists of three main tributaries, all of which are impounded. The impoundments provide a wider supply for the Illawarra Coke Company Pty Ltd.

Stanwell Creek has a catchment area of approximately 760 hectares and a creek length of 5.2 km.

Ecology

The literature review did not identify any existing information on the ecological values of the Stanwell Creek catchment.

Landuse and zoning

The lagoon located at the base of the creek system is within the zone 6(a) Public Recreation. The surrounding zones of the creek system are 2(a1) Special Low Density Residential, 7(b) Environmental Protection/Conservation, 5(b) Road and 5(c) Rail.

Catchment Runoff and Potential Pollution Sources

Both Hargraves Creek and Stanwell Creek flow through Stanwell Park, but the water quality of Stanwell Creek is considered to be better than the equivalent site at Hargraves Creek (AWT 1999a).

Although construction of the Coalcliff, Stanwell Park, Stanwell Tops and Otford Sewerage Scheme was completed in June 2005, and approximately 75% of residences in the catchment have since been connected to the centralised sewerage scheme, 25% of residences are still reliant on on-site sewage treatment systems (Sydney Water, 2006), and consequently the risk of faecal contamination of Stanwell Creek remains.

Stanwell Creek is also heavily utilised for recreational activities, and consequently gross pollutants are a particular concern.

2.5.3 Stoney Creek

Estuary Morphology

Stoney Creek is a small ICOLL estuarine lagoon at the oceanic outlet of Stoney Creek. The entrance is often closed by a sand barrier and thus water in the lagoon can be brackish (Chafer 1997). Stoney Creek is bounded by Paterson Road to the south, residential areas to the west, and Coalcliff Surf Club to the north.

Stoney Creek has a catchment area of approximately 425 hectares and a creek length of 3.1 km.

Ecology

The literature review did not identify any existing information on the ecological values of the Stoney Creek catchment.

Landuse and zoning

The density of development in the Stoney Creek catchment is considerably lower than the other systems. The catchment contains areas zoned 5(b) Road and 5(a) Rail, servicing the Low Density Residential areas (zoned 2(a1)). Areas of environmental conservation/protection (zones 7(a) and 7(b)) and non-urban (zone 1) exist throughout the catchment. The Coal Cliff Mine spans the upper reaches of the catchment (zone 4(c) Extractive Industry).

Catchment Runoff and Potential Pollution Sources

The Coalcliff Colliery lies within the Stoney Creek catchment, and impounds all three tributaries to Stoney Creek for supply of water to the plant. The potential hydrological and water quality effects of the impoundment, and of industrial activities undertaken at the site, are unknown. However, AWT (1999a) concluded that Stoney Creek was under threat from releases of coal and coke from the the Coalcliff Colliery coke works, and noted that wet weather resulted in poor water quality and increased nitrogen, phosphorus and ammonia levels at the downstream site.

Although construction of the Coalcliff, Stanwell Park, Stanwell Tops and Otford Sewerage Scheme was completed in June 2005, and approximately 75% of residences in the catchment have since been connected to the centralised sewerage scheme, 25% of residences are still reliant on on-site sewage treatment systems (Sydney Water, 2006), and consequently there remains a risk of faecal contamination of Stoney Creek.

2.5.4 Flanagans Creek

Estuary Morphology

Flanagans Creek is a small ICOLL estuarine lagoon at the oceanic outlet of Flanagans Creek. The entrance is often closed by a sand barrier (Chafer 1997). Flanagans Creek is bounded by Mary Street to the north, The Esplanade to the south and Lawrance Hargrave Drive to the west. Flanagans Creek originally extended south to Harbord Street, Thirroul. However, it was considerably reduced in size in the 1930s to construct the present Thirroul Beach Park and pool complex (Merrin and Chafer 2000).

Flanagans Creek has a catchment area of approximately 266 hectares and a creek length of 2.3 km.

Ecology

The literature review did not identify any existing information on the ecological values of the Flanagans Creek catchment.

Landuse and zoning

The outlet of Flanagans Creek is within zone 6(a) Public Recreation. The upper catchment includes areas of conservation, 7(b) and 7(c), low and medium residential areas zoned 2(a) and 2(b) with road and rail easements zoned 5(b) and 5(c). A disused mine lies within an area of 5(a) Special Uses.

Catchment Runoff and Potential Pollution Sources

Merrin and Chafer (2000) reported that water quality in the lagoon is considered to be of good quality since there has been little urban development along the creek line. However, habitat values are threatened by periodic clearing of vegetation from the lagoon (Merrin and Chafer 2000).

The catchment is highly urbanised and is therefore likely to have a number of diffuse and point sources of pollution. From residential areas the main pollutants of concern are gross pollutants (for example, litter), sediments and nutrients (phosphorus and nitrogen) from general stormwater runoff, plus additional nutrients and pathogens (faecal coliforms) associated with sewage overflow events. Businesses at small-scale industrial estates have the potential to discharge oils, hydrocarbons, chemicals and metals depending on the industry sector.

2.5.5 Slacky Creek

Estuary Morphology

Slacky Creek is a small ICOLL estuarine lagoon at the oceanic outlet of Slacky Creek. The entrance is often closed by a sand barrier (Chafer 1997). Slacky Creek is bounded by Hutton Avenue to the south, the Princes Highway to the west, and Beacon Avenue, Westmascott Parade and Beach Street to the north.

Slacky Creek has a catchment area of approximately 285 hectares and a creek length of 4.6 km.

Ecology

The straightening of Slacky Creek at the beach end is considered to have destroyed the natural hydrology and flora of the wetland (Merrin and Chafer 2000).

Landuse and zoning

The outlet of Slacky Creek is zoned 6(a) Public Recreation. The upper sections of the catchment are designated conservation areas with zonings of 7(a) and 7(b). Just downstream of the conservation area lies Bulli Colliery, zoned 4(c) Extractive Industry. The other land uses and zones within the creek catchment are 9(d) Open Space, 5(a) Road, 5(b) Rail and 2(b) Low Density Residential.

Catchment Runoff and Potential Pollution Sources

The catchment is highly urbanised and is therefore likely to have a number of diffuse and point sources of pollution. From residential areas the main pollutants of concern are gross pollutants (for example, litter), sediments and nutrients (phosphorus and nitrogen) from general stormwater runoff, plus additional nutrients and pathogens (faecal coliforms) associated with sewage overflow events. Businesses at small-scale industrial estates have the potential to discharge oils, hydrocarbons, chemicals and metals depending on the industry sector.

2.5.6 Whartons Creek

Estuary Morphology

Whartons Creek is a small ICOLL estuarine lagoon at the oceanic outlet of Whartons Creek. The entrance is often closed by a sand barrier (Chafer 1997). Whartons Creek is bounded by Bulli Beach Holiday Park to the south, Franklin Avenue to the west and Farrel Road and Bulli High School to the north.

Whartons Creek has a catchment area of approximately 210 hectares and a creek length of 3.4 km.

Ecology

The channelised form of the creek and limited native riparian vegetation are likely to have affected the ecological value of the system.

Landuse and zoning

The upper reaches of Whartons Creek are zoned 4(c) Extractive Industry. The outlet of the creek is zoned 6(a) Public Recreation with areas of low to medium density housing (zones 2(a) and 2(b)) throughout the creek catchment area. Small areas of light industrial (zone 4(a)) and road and rail (zones 9(b) and 5(b)) are also present.

Catchment Runoff and Potential Pollution Sources

The catchment is highly urbanised and is therefore likely to have a number of diffuse and point sources of pollution. From residential areas the main pollutants of concern are gross pollutants (for example, litter), sediments and nutrients (phosphorus and nitrogen) from general stormwater runoff, plus additional nutrients and pathogens (faecal coliforms) associated with sewage overflow events. Businesses at small-scale industrial estates have the potential to discharge oils, hydrocarbons, chemicals and metals depending on the industry sector.

2.5.7 Collins Creek

Estuary Morphology

Collins Creek is a small ICOLL estuarine lagoon at the oceanic outlet of Collins Creek. The entrance is often closed by a sand barrier (Chafer 1997). The oceanic outlet of Collins Creek is located adjacent to Carrington Street, Woonona, and is bounded to the north by Owen and Lawrence Streets, to the west by Thompson Street and to the south by Kareela Road.

Collins Creek has a catchment area of approximately 390 hectares and a creek length of 3.9 km.

Ecology

An inventory of biodiversity at this lagoon recorded 68 plant species, 18 birds, 2 reptiles and 2 fish species (Tuckett Carr 2005). Heavy weed infestation was noted to the west of Carrington Street, together with visual signs of pollution. An area adjacent to the wetland had been rehabilitated with Spiny-headed Mat-rush (*Lomandra longifolia*), Coastal Tea Tree (*Leptospermum laevigatum*), *Isolepis nodosus*, Coastal Wattle (*Acacia longifolia* subsp. *spohorae*) and an occasional Swamp Lily (*Crinum* *pedunculatum*). Tuckett Carr (2005) also noted a suite of weeds within the revegetated area including Bitou Bush (*Chrysanthemoides monilifera* spp. *rotundata*), Beach Pennywort (*Hydrocotyle bonariensis*), Beach Daisy (*Arctotheca populifolia*), Asparagus Fern (*Protoasparagus aethiopicus*) and Kikuyu Grass.

West of Carrington Street, riparian vegetation consisted of mainly introduced species including African Olive (*Olea europaea* ssp. *cuspidata*) and *Senna pendula* with Asparagus Fern prolific in the understorey (Tuckett Carr 2005).

Landuse and zoning

The outlet of Collins Creek is zoned 6(a) Public Recreation. The upstream catchment of the creek system has a range of zones and land uses that potentially influence the creek. Areas of conservation, zoned 7(a) and 7(b) exist in areas at the top of the catchment, small areas of light residential, neighbourhood business, and tourism, zoned 2(b), 3(b) and 6(c) respectively, and general road and rail land uses, zoned 5(b) and 5(c).

Catchment Runoff and Potential Pollution Sources

The catchment is highly urbanised and is therefore likely to have a number of diffuse and point sources of pollution. From residential areas the main pollutants of concern are gross pollutants (for example, litter), sediments and nutrients (phosphorus and nitrogen) from general stormwater runoff, plus additional nutrients and pathogens (faecal coliforms) associated with sewage overflow events. Businesses at small-scale industrial estates have the potential to discharge oils, hydrocarbons, chemicals and metals depending on the industry sector.

2.5.8 Bellambi Gully

Estuary Morphology

Bellambi Gully is an estuarine ICOLL lagoon at the oceanic outlet of Bellambi Gully and Farrahars Creek. An area of freshwater wetlands connects to the northern part of Bellambi Gully, combining to form an extensive area of wetlands known as Bellambi Gully Wetlands (Chafer 1997). Bellambi Gully is bounded by predominantly wetland vegetation and parklands within the estuarine area, which gradually grades into residential areas to the north and Holy Spirit College to the south. A management plan for the Bellambi Creek catchment was prepared in 1994 (Anthony 1994).

Bellambi Gully has a catchment area of approximately 590 hectares and a creek length of 4.1 km.

Ecology

The literature review did not identify any existing information on the ecological values of the Bellambi Gully catchment.

Landuse and zoning

Bellambi Gully, located at Bellambi Beach, is within zone 6(a) Public Recreation. The catchment for the Gully (Farrahars Creek) has land uses of road and rail (zones 5(a) and 9(b)), light to medium density residential areas (zones 2(a) and 2(b)) and light industrial (zone 4(a)).

Catchment Runoff and Potential Pollution Sources

Bellambi Gully catchment has a history of poor water quality. Water quality testing in 1994 indicated that the various tributaries within the catchment were contaminated by pollutants, indicated by high levels of pH, conductivity (possible due to lithology), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and ammonia, in both dry and wet weather (Anthony 1994). In particular, during wet weather periods, high levels of *E. coli* bacteria were detected, whereas sampling in dry weather detected no *E. coli* bacteria. These high levels are possibly caused by sewage effluent contamination (Anthony 1994).

The upper catchment of Bellambi Gully contains the Bellambi Coal Company site; in 1994 the company was discharging treated wastes into Bellambi Creek, under an Environment Protection Licence license issued by the then Environment Protection Authority (EPA), now the Department of Environment and Climate Change (DECC). The results of water quality monitoring data provided by Bellambi Coal Company showed that the company exceeded the discharge quality limits for several parameters, including non filterable residues (NFR; now referred to as total suspended solids or TSS), BOD, COD, Ammonia and *E. coli* (Anthony 1994).

Russell Vale waste disposal area is also located in the upper reaches of the Bellambi Gully catchment on the western side of the Princes Highway. A possible source of pollution is leachate that could escape from the waste disposal site and bypass the collection pond system, resulting in pollution and discolouration of the creek (Anthony 1994).

The middle and lower sections of the Bellambi Gully catchment consist of large areas of urban development including a Pioneer housing estate and recreational facilities such as public parks, reserves and schools. The creek also runs through or near private property including some light industrial units. The main source of pollutants in this section are non-point sources from urban and industrial development, including urban runoff, household rubbish, garden refuse, grazing animals, industrial by-products or wastes, and site contamination (Anthony 1994). Another potential source of contamination throughout the catchment is possible leakage from sewer mains, particularly at over-flow points (Anthony 1994).

2.5.9 Bellambi Lagoon

Estuary Morphology

Bellambi Lagoon is a large estuarine ICOLL located just south of Bellambi Point. The site is bounded by Bott Drive to the north, Birch Crescent to the west and Murray Road to the south. Bellambi Recreation Area is located to the north-east of Bellambi Lagoon. The catchment for the lagoon is a narrow valley three kilometres long with its source in the basal slopes of the Illawarra Escarpment (Chafer 1997). The entrance is often closed by a sand barrier, thus the water quality is often brackish (Chafer 1997).

Bellambi Lagoon has a catchment area of approximately 250 hectares and a creek length of 4.3 km.

Ecology

Bellambi Lagoon is connected to an extensive hind sand dune/wetland/Swamp Oak Forest that includes reed/sedge swamps, saltmarsh and alluvial forest. The Lagoon backs on to a 7 hectare sand dune forest on the lee of 10 metre high sand dunes, making this system one of the few dunal lagoons between Sydney and Jervis Bay that contain a diverse mix of flora and fauna (Chafer 1997). Bellambi Lagoon contains the largest Swamp Oak forest (6.8 hectares) north of Lake Illawarra in Wollongong LGA (Merrin and Chafer 2000).

Bellambi Lagoon Dunecare Group is undertaking continuing work at this site and a vegetation management plan has been prepared for Bellambi Lagoon and associated sand dunes (Treecreeper

Indigenous Land Management (TILM 2005)). The vegetation management plan states that the primary management issues facing the area are weed infestation, vandalism and fires, tracks made through bushland by motor bikes, lack of community knowledge and awareness of the site, lack of interpretative signage and lack of barrier fences and gates (TILM 2005).

Previous flora surveys classified the vegetation at Bellambi Lagoon as made up of local and non-local native species and exotic species. To the north of the lagoon is a large mixed community of reed and sedge swamp and saltmarsh. Species previously recorded here include Sea Rush (*Suaeda australis*), Broad-leaf Cumbungi (*Typha orientalis*), Common Reed and *Baumea juncea.* Adjacent to the lagoon on the eastern side is a Swamp Oak Forest, dominated by *Baumea juncea*, Common Reed, Swamp Oak and Sea Rush. This Swamp Oak forest grades into a forest dominated by Swamp Oak, Swamp Mahogany (*Eucalyptus robusta*), Bangalay, Lilly Pilly, Cheese Tree, Paperbarks (*Melaleuca* spp.) and Red-fruit Saw-sedge (*Gahnia sieberana*). The Swamp Oak Forest along the eastern and north-eastern side of the lagoon is listed as an EEC under the TSC Act and provides potential habitat for the threatened Swift Parrot (*Lathamus discolor*) (TILM 2005).

The indigenous plant community at Bellambi Lagoon has become fragmented and degraded through 170 years of clearing, soil disturbance, lack of natural fire regime, infilling, weed invasion and nutrient influx (TILM 2005). In 2002, fire burnt the Bellambi Lagoon area, affecting dune vegetation and the Swamp Oak Forest. The site has large areas of good native regeneration following the 2002 fire, and the condition of the Swamp Oak Forest is reasonable considering the impacts of fire and weeds.

Chafer (1992) recorded five common reptiles and three common amphibians at the lagoon. The threatened Green and Golden Bell Frog (*Litoria aurea;* GGBF) has been heard previously on the northern side of the lagoon but the sampling time was not conducive to its detection in this study. Green and Golden Bell Frogs appear to utilize the coastal lagoons, wetland remnants and drainage lines as connective corridors to habitat closer to the escarpment (Chafer 1992). Scats from foxes and domestic dogs were also recorded during the survey (Chafer 1992).

Landuse and zoning

The Lagoon and surrounding sporting fields are zoned 6(a) Public Recreation. An adjacent area containing a sewer works is zoned 5(a) Special Uses. Hazelton and Tille (1990) define the secondary use of playing fields as drainage reserves.

Catchment Runoff and Potential Pollution Sources

Bellambi Lagoon is at the end of a heavily urbanised catchment so water quality has suffered. In 1995, Bellambi Lagoon was extensively remodelled to remove and redistribute large quantities of sediment. The lagoon was deepened and two habitat islands created. This improved the wetland environment for birds and fish that breed in the lagoon. However, the problem of sediment and high nutrients in stormwater run-off has not been solved (Chafer 1997).

The catchment is highly urbanised and is therefore likely to have a number of diffuse and point sources of pollution. From residential areas the main pollutants of concern are gross pollutants (for example, litter), sediments and nutrients (phosphorus and nitrogen) from general stormwater runoff, plus additional nutrients and pathogens (faecal coliforms) associated with sewage overflow events. Businesses at small-scale industrial estates have the potential to discharge oils, hydrocarbons, chemicals and metals depending on the industry sector.

2.5.10 Tom Thumb Lagoon

Estuary Morphology

Tom Thumb Lagoon has a catchment area of approximately 350 hectares.

The current Tom Thumb Lagoon (TTL) is a 7.7 hectare remnant of a formerly extensive shallow coastal lagoon, located approximately 2 kilometres south of Wollongong, and bounded by Springhill Road, Port Kembla Road, Tom Thumb Road and the freight railway line into Port Kembla. Port Kembla lies to the south of the site and includes a large coal terminal and steelworks. A sewage treatment plant, golf course and Coniston Beach are located to the east of the site. A capped and partly revegetated landfill facility is located to the immediate north of the lagoon, and has recently been renamed as Wollongong Greenhouse Park. In 1993, landfill materials including slag (a by-product of the steelworks) and rock were removed from sections of the wetlands to form depressions, ponds and permanent standing water bodies, which remain permanently brackish and are flushed during large tides (Gill 2005). The site is connected to J.J. Kelly Park to the north via a culvert underneath Springhill Road.

The site has a complex history of disturbance from development of the Port Kembla industrial site and inner harbour. Development of the inner Port Kembla harbour during the 1950s and 1960s, and reclamation for industrial development up to the 1980s, reduced the extent of the wetlands to less than 1 percent of the original area (Gill 2005). Extensive restoration works in and around the wetland began in 1991 with involvement from WCC, industry and community groups. The majority of the restoration works have been undertaken by the Friends of Tom Thumb Lagoon Wetland and have included earthworks, weed removal and revegetation by Conservation Volunteers Australia (CVA).

Ecology

The remnant TTL is an estuarine wetland consisting of saltmarsh, mudflats, mangroves, freshwater and brackish lagoons and revegetated riparian areas. Chafer (1997) recorded 24 native flora species and 31 weed species within the wetland. Vegetation on the slopes of the landfill site has undergone substantial growth since planting in the early 1990s, and now consists of tall stands of Swamp Oak (*Casuarina glauca*), River Sheoak (*Casuarina cunninghamiana*), Swamp Mahogany (*Eucalyptus robusta*) , Prickly-leaved Paperbark (*Melaleuca styphelioides*) and Swamp Paperbark (*M. ericifolia*). Many weed species are present at TTL, including Bitou Bush (*Chrysanthemoides monilifera* spp. *rotundata*), Kikuyu Grass (*Pennisetum clandestinum*) and Spanish Reed (*Arundo donax*), and these are being managed in accordance with bush regeneration practices (EcoLogical 2006). The introduced Fox (*Vulpes vulpes*) and European Rabbit (*Oryctolagus cuniculus*) have also been previously recorded at the lagoon (EcoLogical 2006). Previous surveys have recorded 55 native bird species and seven introduced birds (Chafer 1997, Sydney Water Corporation (SWC) & WCC 1993). Until the 1960's, TTL contained one of the largest Little Tern (*Sterna albifrons*) breeding colonies in NSW; this colony survived in dwindling numbers until the last pair bred there in 1991 (Chafer 1997). Prior to reclamation, TTL was periodically closed to the ocean and became hypersaline, allowing extensive macroalgae beds to flourish (Chafer 1997). This attracted large numbers of waterbirds and there are several records of over 1000 Black Swans (*Cygnus atratus*) through the 1950s and 60s. This species no longer occurs in the remnant lagoon (Chafer 1997). Prior to reclamation, TTL was one of only two sites in the Illawarra to have been used by Banded Stilt (*Cladorhynchus leucocephalus*) and Red-necked Avocet (*Recurvirostra novaehollandiae*) for nesting, however the habitat used by these species has also now been reclaimed (Chafer 1997). The lagoon is also noted to be one of the few habitats between Lake Illawarra and Sydney where the cryptic striated heron (*Ardeola striatus*) can be regularly seen (Chafer 1997).

The most recent management plan for the wetland did not record any threatened flora or fauna at the site (EcoLogical 2006). There is a historical record of Green and Golden Bell Frog (*Litoria aurea*) at the lagoon, however, after extensive searching and call playback, no Green and Golden Bell Frogs have been recorded at this site in previous studies. An honours thesis by Threlfall (2006) involved undertaking surveys for GGBF once a month during the daytime from September 2005 to February 2006, and on three occasions at night. No GGBF were found despite using call playback techniques (Threlfall 2006).

The 1993 management plan by SWC and WCC stated that mangroves were not present at the site and recommended planting mangroves at the lower south-east corner of the lagoon. A dense stand of Grey Mangroves (*Avicennia marina*) has developed at the lower end of the lagoon following planting approximately ten years ago, and further mangrove recruitment is evident along other mud-lined channels adjacent to the saltmarsh flats, The mangrove habitat would provide refuges for crabs and estuarine fish, including mullet (*Mugil cephalus*), which have been observed in the channels (SWC and WCC 1993).

Coastal Saltmarsh, listed as an EEC under the TSC Act, and mangroves (which are protected marine vegetation under the Fisheries Management Act), have been recorded at the site (EcoLogical 2006). However, the presence of the culverts connecting the deeper waters of Port Kembla, the absence of nearby shallow water estuarine habitats including seagrass beds, and the highly fragmented and disturbed nature of TTL were considered by EcoLogical (2006) to substantially reduce the lagoon's value as a fish habitat and nursery ground.

A long-term monitoring study is recording the extent and health of saltmarsh at TTL (WCC unpublished data). The health of the saltmarsh is affected by pollutants and mangrove invasion, and has suffered dieback in recent years, possibly due to high rainfall events or leachate of pollutants from the adjacent decommissioned landfill site (WCC pers. comm.).

Landuse and zoning

The Lagoon is located within the industrial area of Port Kembla and is zoned 5(a) Special Uses. The main industries include port related facilities, a municipal sewage treatment plant and road and rail facilities.

Catchment Runoff and Potential Pollution Sources

The location of Tom Thumb Lagoon immediately downstream of Wollongong CBD, and surrounded by industrial landuses, increases the potential risk to the estuary in relation to water quality issues. The Garangaty waterway is essentially a stormwater drain for the entire CBD of Wollongong, and responds rapidly to rainfall in the catchment. The stormwater has a heavy load of gross pollutants (litter) from the city streets even though it passes through a gross pollutant trap in J J Kelly Park. The stormwater would also be likely to contain relatively high levels of suspended sediment, nutrients and oil and grease.

Wollongong sewage treatment plant is located immediately to the east of the Garangaty waterway and may discharge to the catchment during storm events when high flow-bypass is required. In addition, a sewage overflow point is located immediately upstream of Tom Thumb Lagoon and is known to discharge untreated sewage into the lagoon during periods of wet weather.

The water quality in the estuary is also likely to be adversely affected by leachate seeping from the old landfill facility located immediately to the north, from industrial waste materials (slag, coal wash, etc) dumped in the estuary in previous decades, and from current discharges to Port Kembla that might be conveyed into the estuary on incoming tides

3. Water Quality

Wollongong City Council (WCC) monitored water quality at 36 sites in 23 creeks and lagoons in 17 catchments on an approximately monthly basis between August 2002 and March 2006 (WCC 200b7). The study investigated water quality at Flanagan's Creek (2 sites), Slacky Creek (1 site), Whartons Creek (1 site), Collins Creek (2 sites), Bellambi Gully (2 sites), Bellambi Lagoon (2 sites) and Tom Thumb Lagoon (1 site), plus other creeks outside the scope of this estuary processes study. Although the lower sites on Flanagans Creek, Bellambi Lagoon and Tom Thumb Lagoon were located within the estuarine reaches, all the other sites were located in the freshwater reaches. Consequently, the water quality data should be considered to be only indicative of the potential water quality in the estuarine reaches of the other catchments.

The monitoring program assessed a range of physical, chemical and microbiological water quality indicators, including metals, nutrients and faecal coliforms. The monitoring results were assessed against the commonly used ANZECC (2000) guidelines for fresh and marine water quality, using the trigger values for the protection of aquatic ecosystems in slightly to moderately disturbed ecosystems. Faecal coliform results were assessed against trigger values for recreational activities.

Table 2.2 outlines the colour-coded system used in Table 2.3 to indicate the level of compliance with ANZECC and other guidelines. The appearance of the last three colours for any parameter indicates a water quality issue with regard to that parameter. For metals, however, caution is necessary in interpreting the results since the results could include metals that are in a form that is not of great concern from a contamination perspective (WCC 2007b).

Table 3.1 ANZECC compliance criteria

Colour	Compliance
	At least 75% of occasions
	Between 50 and 75% of occasions
	Between 25 and 50% of occasions
	Between 10 and 25% of occasions
	Less than 10% of occasions

Table 3.2 Summary of water quality characteristics

Parameter	Flanagans Creek		Slacky Creek	Whartons Creek	Collins Creek		Bellambi Gully		Bellambi Lagoon		Tom Thumb Lagoon
	Site Number										
	1	2	7	8	9	10	11	12	13	14	26
pH											
Dissolved Oxygen (DO) saturation											
Suspended Solids											
Total Nitrogen (TN)											
Total Kjeldahl Nitrogen (TKN)											
Ammonia											
Nitrate											
Phosphorus											
Arsenic											
Copper											
Lead											
Manganese											
Zinc											
Faecal Coliforms – primary rec.											
Faecal Coliforms – secondary											

The WCC study found that the majority of creeks and lagoons had low dissolved oxygen saturation values, high nutrient concentrations and high faecal coliform counts, making the waters unsuitable for primary recreational activities. There were also clearly evident spatial differences between sites, with some waterways not meeting the guideline values on much more than 50% of the occasions. For example, nutrient concentrations at Bellambi Gully exceeded the guidelines almost 100% of the time. Copper and zinc concentrations were also higher than guideline values at many of the sites. However, the report indicates that caution may be necessary in interpreting these results since the results refer to total metal concentrations while the ANZECC guideline trigger values might refer to the dissolved metal concentration.

In addition to the common water quality problems of low dissolved oxygen, and high nutrients and faecal coliforms, other, site-specific, issues were also identified: sites along Bellambi Gully had high pH values; Slacky Creek, Bellambi Gully and Tom Thumb Lagoon had elevated levels of suspended solids; arsenic was detected in reasonably high concentrations (but not over the guideline value) in Bellambi Gully and

Tom Thumb Lagoon; and elevated levels of manganese were detected in Flanagans and Slacky Creeks and Tom Thumb Lagoon.

The study interpreted the spatial differences in water quality based on the catchment characteristics and land use patterns extracted from the Wollongong LEP 1990. As expected, the less urbanised catchments in the north appeared to have better water quality than more urbanised catchments in the central areas of Wollongong.

Differences in water quality over time were harder to assess as there was insufficient data for an assessment of the potential impacts of seasonality and rainfall patterns. However, there was conclusive evidence that conductivity (at freshwater sites) and dissolved oxygen were affected by seasonal differences. Nitrate and faecal coliform results also exhibited a reasonable suggestion of a correlation with rainfall. These correlations need to be further investigated, with further monitoring targeted to identify the effects of season and rainfall.

The results of the monitoring program identified key water quality issues for each estuary, as summarised in Table 2.4.

Table 3.3 Summary of Key Water Quality Issues

Site	Water Quality Issues
Flanagans Creek	In the upper reach, only dissolved oxygen and nitrate appeared to be an issue whilst in the lower reaches, a number of other issues were also of concern. Amongst the nutrients, total nitrogen (TN), ammonia and nitrate were high. Copper and manganese were of concern but the effect of sample acidification on metal concentrations would have to be verified before this matter is further considered. The water was not suitable for primary contact recreational activities in the lower reaches of the creek.
Slacky Creek	Dissolved oxygen was an issue, as were a number of nutrients including TN, ammonia and nitrate, with nitrate being the form of most concern. It is likely that TN was an issue because of the high nitrate concentrations. Manganese was also of concern for recreational purposes. Faecal coliforms did not appear to be of major concern. However, the site monitored was in the middle reaches of the creek and should not be taken as an indication of the condition in the lower reaches. Suspended solids were higher than at other sites.
Whartons Creek	As at other sites, dissolved oxygen was an issue. Nutrients that were of concern include TN, nitrate and phosphorus, with nitrate showing a greater degree of non-compliance than other nutrient forms. Copper and zinc were the metals of most concern with copper showing a greater degree of non-compliance. Water at this site was not suitable for primary contact recreational activities.
Collins Creek	Dissolved oxygen did not appear to be an issue for the sites monitored along Collins Creek. However, this should not be taken to be an indication of the lower reaches of the creek. At the upstream site, the only nutrient form that was of concern is TN whilst in the middle reaches, TN as well as nitrate and phosphorus were also of concern. Copper was an issue at both sites, with the middle reach showing a greater degree of non-compliance than the upper site. Zinc was the other metal that appeared to be of concern in the middle reaches. In addition, neither of the locations were suitable for primary contact

Site	Water Quality Issues
	recreational activities.
Bellambi Gully	This was the only catchment in which pH values were an issue. pH values higher than the ANZECC upper trigger of 8.0 were recorded at both sites. Suspended solids also appeared to be an issue at the upstream site as the second highest concentration was recorded at this site. All nutrient forms were an issue at both sites with the upstream site showing a greater degree of non-compliance than the downstream site. Copper and zinc were of concern with both sites showing the same degree of non-compliance. Water at the downstream site was not suitable for primary contact recreational activities.
Bellambi Lagoon	Water quality appeared to be generally worse at the northern end of the lagoon than at its mouth. Dissolved oxygen was low at the northern site, presumably due to the stormwater discharges at this site, and high near the mouth possibly because of algal blooms within the lagoon. Nutrients including TN, ammonia, phosphorus were an issue at both sites but nitrates were an issue at only the northern site. Copper and zinc were both an issue at the northern site but only copper was an issue at the mouth. Water at the northern site was not suitable for primary contact recreational activities.
Tom Thumb Lagoon	Amongst the physical parameters, only suspended solids showed a high degree of non-compliance and this would most likely be related to tidal movements stirring up sediment. The highest concentrations for suspended solids were recorded at this site. For nutrients, the only species that was not of concern was nitrate. The source of the nutrients is likely to be leachates from the decommissioned landfill site at Greenhouse Park. The highest metal concentrations were present at this site with all metals except arsenic exceeding the guideline on a significant number of occasions. Faecal coliforms appeared not to be an issue for Tom Thumb lagoon, although primary and secondary recreational activities would not usually be undertaken in this system in any case.

In addition to the data generated by the Wollongong City Council study, limited water quality data for the northern catchments (Hargraves, Stanwell and Stoney Creeks) was collected as part of the Northern Illawarra Towns Water Quality Study (AWT 1999). The study found that:

» Faecal coliform levels in the three creeks were elevated and exceeded the secondary recreational contact guideline then in force;

» Faecal sterol biomarkers measured upstream of Hargraves Creek were predominantly from non-human and non-herbivorous sources. Downstream sites had human and herbivore contributions at 65% and 32%, respectively, but both the bacterial indicator and faecal sterol concentrations were very low;

» Conductivity, mean pH, and dissolved oxygen generally complied with the ANZECC 1992 guidelines limits for the protection of aquatic ecosystems;

» Mean turbidity levels increase at all sampling locations in wet weather;

» Dry weather mean oxidised nitrogen concentrations were significantly higher at downstream sites, compared to upstream at Hargraves and Stanwell Creek;

- Dry and wet weather total nitrogen concentrations were significantly higher at downstream sites, compared to upstream at Hargraves Creek. However there was no significant difference between sampling locations in Stanwell and Stoney Creeks;
- Mean concentrations of total phosphorus were significantly higher downstream in Hargraves Creek, compared to upstream, in both wet and dry weather conditions;
- Mean soluble reactive phosphorus concentrations were significantly higher downstream in Hargraves Creek during wet weather; and
- None of the upstream sites of Stoney Creek had human or herbivore faecal contamination based on faecal biomarkers.

Since the AWT water quality assessment was undertaken in 1999, Sydney Water has constructed the Stanwell Tops Sewerage Scheme, and approximately 75% of residences in the catchments of Hargraves, Stanwell and Stoney Creeks have been connected to the system. It is likely that water quality in these creeks has improved in comparison to the date presented above.

3.1 Estuary Usage

With the exception of Tom Thumb Lagoon, which is located in a heavily industrialised area not conducive to recreation, all the estuaries are used for primary and secondary recreational activities, including paddling and swimming. The use of the estuaries for these activities is particularly associated with young children, for whom bathing in the adjacent surf zone is considered to be unsafe.

Other recreational activities undertaken at some of the estuaries include fishing, bird watching, nature observation, walking, jogging, cycling. Many of the estuaries are linked by a coastal shared foot and bike path providing easy access between creek systems.

Non-recreational activities observed at Tom Thumb Lagoon include commuting by foot or bicycle.

Stanwell and Hargraves Creeks and their associated park and foreshore areas are popular recreational areas with cafes, picnic and BBQ facilities and shade shelters. These estuaries are used for primary and secondary recreational activities and the foreshore reserves are also used for informal group social and sporting activities such as football and family gatherings.

4. Processes Studies – Ecological Assessment

4.1 Methods

4.1.1 Definitions

Ecological issues considered in this report are limited to the estuarine reaches of the specified lagoons. Estuarine vegetation within a 50 metre wide buffer from the high water mark of each lagoon was mapped. Fauna habitat surveys, stag watching, spotlighting and call playback were also undertaken within this estuarine area, unless fauna habitat values were low within these areas (for example if the estuary was located within a mown park area with no hollow-bearing trees or riparian vegetation). In this case, fauna habitat surveys, spotlighting and call playback were undertaken within the freshwater reaches of the estuary in an effort to gain insight into the fauna habitat values of the catchment.

At the request of WCC, macroinvertebrate surveys were undertaken within the freshwater reaches of the estuaries using the AUSRIVAS methods.

4.1.2 Literature Review and Database Searches

The study area has been the subject of a number of investigations. Information on the environmental features of both the study area and the local area, including vegetation communities, ecology and threatened species, was gathered through a review of the available relevant literature, and database searches, as detailed in Section 1.5 of this report. The relevant information has been incorporated into this report where appropriate.

4.1.3 Field Surveys

The Data Compilation Study by WBM Oceanics (2006) identified the need for several technical studies to be completed as a high priority prior to the development of an estuary management plan for the ten estuaries specified in Section 1 of this report. GHD undertook the following high and medium priority ecological surveys as part of the Estuary Processes Study:

- Mapping of the distribution of estuarine flora and endangered ecological communites within 50 metres of the tidal limit to determine the potential threats to estuarine vegetation, including coastal saltmarsh in the estuaries;
- Fauna habitat assessment within the estuarine study areas to determine the potential for birds, mammals, frogs and reptiles to utilise the estuarine creeks and lagoons, with particular attention paid to threatened species; and
- Aquatic macroinvertebrate surveys within the freshwater reaches immediately upstream of the estuaries (apart from Hargraves, Stanwell and Stony Creeks, which have been previously been sampled by AWT [1999a]).

4.1.4 Estuarine Vegetation Mapping and Endangered Ecological Communities

Vegetation mapping and descriptions of the Illawarra Escarpment and Coastal Plain across the Wollongong LGA has been previously undertaken (NPWS 2003). This was used as a guide to conduct mapping of the study sites within 50 metres of the tidal zone. Vegetation communities previously mapped by NPWS (2003) east of the Illawarra escarpment included Escarpment Blackbutt Forest, Escarpment Moist Blue Gum Forest and Moist Blue Gum/ Blackbutt Forest. Vegetation communities associated with the estuaries included Coastal Sand Scrub, Coastal Heathland, Beach Sand Spinifex, Saltmarsh, Coastal Swamp Oak Forest and Coastal Bangalay/ Blackbutt Forest.

Coastal Saltmarsh and Mangroves

Saltmarsh is an area of land bordering the sea that is mostly covered in vegetation and subject to periodic inundation by the tide, and is composed of halophytic plants. Aerial photographs were interpreted using GIS to extrapolate areas of saltmarsh. All sites were ground-truthed to determine boundaries and species present. Additionally, mangroves were surveyed to determine extent and species present.

GHD undertook vegetation mapping of vegetation communities at each of the estuaries (within 50 metres of the tidal zone). Vegetation communities were verified through characterisation of estuarine vegetation within sampling quadrats (20 metres x 20 metres) placed randomly within each vegetation community. All species present within each quadrat were recorded and notes were taken on the dominant species, sediment type and condition, the level of weed invasion and any other signs of disturbance.

GIS was used to create maps showing extent and type of vegetation communities, including Coastal Saltmarsh EEC at the sites.

Seagrass Beds

Seagrasses usually grow on sandy or muddy substrates, and their extensive rhizome systems help stabilise underlying sediment. There have been significant losses of seagrass communities through both natural (cyclones, floods) and anthropogenic events (nutrient enrichment, coastal development) (DPI 2005). Most losses from these influences can be attributed to reduced light intensity. Once destroyed, seagrass systems do not readily recover. If an area does recover, the timeframes are long (years or decades), increasing the importance of seagrass bed conservation and preservation (DPI 2005).

Aerial photographs of the creeks and lagoons were interpreted to extrapolate areas of seagrass, and determine particular areas of interest. Following the methods from Braun-Blanquet (1993), two ecologists ground-truthed the seagrass areas to determine boundaries and species present.

A spatial dataset was created through a combination of the captured information from the GPS, field investigation, and interpretation of aerial imagery. Each mapping unit of seagrass was attributed with the following metadata: species, density and cover.

4.1.5 Fauna Surveys

The fauna assessment aimed to ascertain the importance of the estuarine areas for native fauna, and particularly threatened species. A number of fauna survey methods were used as outlined below.

Fauna Habitat Assessment

The fauna habitat assessment examined the nature and condition of habitats, detailing specific resources and features of relevance for native fauna, such as tree hollows, logs, fallen timber, leaf litter, grassy groundcover, shrub strata, foraging substrates, winter-flowering eucalypts, casuarinas, mistletoe, etc. In addition, indirect evidence of fauna (i.e. scats, feathers, fur, tracks, dens, nests, scratches, chew marks and owl wash) were recorded.

Hollow-bearing Tree Counts

Hollow-bearing trees are essential habitat for numerous fauna species including arboreal mammals, bats, owls and other hollow-dependent bird species. The estuarine study areas were traversed using the random meander technique and all hollow-bearing trees recorded using a GPS. The following features were recorded:

» Tree height;

» Number of hollows;

» Average diameter of hollows; and

» Presence of scratch marks and other signs of faunal activity.

Spotlighting and Stagwatching

Spotlighting was undertaken using hand-held 55W spotlights to ascertain the presence of arboreal fauna, including gliders and owls, within the estuarine study areas. In estuaries where fauna habitat potential was low (for example with no hollow-bearing trees and no dense riparian vegetation), spotlighting was undertaken within the freshwater reaches of the estuaries to gain insight into the value of the catchment for fauna habitat. Each spotlighting session was 1½ to 2 hours in duration in a variety of habitats. Spotlighting was preceded by a period of stag watching for approximately 40 minutes following sunset. Stag watching involves an observer being positioned so as to observe animals emerging from hollows.

Call Playback

In order to elicit call responses, pre-recorded calls of frogs and owls were played through an amplifier before and/or after the spotlighting sessions, within the estuarine study areas. The pre-recorded calls of two threatened frog species, the Green and Golden Bell Frog (*Litoria aurea*) and Red-crowned Toadlet (*Pseudophryne australis*), and one threatened owl, the Sooty Owl (*Tyto tenebricosa*) were broadcast within potential habitat. Calls were broadcast for approximately 5 minutes and followed by a 10 minute listening and intermittent spotlighting period. Calls were then played again and another 10 minute listening period undertaken. Each species was targeted separately with only one species broadcast during each period.

Due to the lack of potential nesting habitat within the estuarine reaches of the study area, call playback was not undertaken for the owl species within these areas, but rather in the freshwater reaches immediately upstream of the estuaries to gain insight into the value of the catchment for fauna habitat.

Opportunistic Records

Incidental records of bird, amphibian, reptile and mammal species were collected during the entire survey period for each estuary.

4.1.6 Macroinvertebrate Sampling

Aquatic macroinvertebrates are commonly used biological indicators for water quality and freshwater health. GHD sampled macroinvertebrates at all creeks excluding Hargraves, Stanwell and Stony Creeks, since these creeks were previously sampled by AWT (1999a). GHD replicated the sampling design and methods used by AWT (1999a), and undertook sampling in accordance with the NSW AUSRIVAS Sampling and Processing Manual for the collection and processing (live-picking) of macroinvertebrate samples. These methods involved taking standardized samples from two distinct habitats; pool edges and pool rocks.

Two sites were sampled at each estuary. GPS locations for each site are provided in Table 4.1. The operation of the GPS used to record the site locations is likely to have been affected by cloud cover and consequently the coordinates are likely to be accurate to 5 – 30 m.

Table 4.1 Macroinvertebrate Site Location Coordinates

Estuary	Site No	Easting	Northing
Flanagans Creek	1	309085	6201150
	2	309047	6201245
Slacky Creek	1	308420	6199047
	2	308398	6199062
Whartons Creek	1	308409	6198436
	2	307898	6198696
Collins Creek	1	307000	6197685
	2	306941	6197759
Bellambi Gully	1	307423	6195563
	2	307561	6195471
Bellambi Lagoon	1	308701	6194641
	2	308722	6194566
Tom Thumb Lagoon	1	305697	6156714
	2	306679	6187553

Each sampling site was defined as a 100 metre reach. Within each reach, a distance of 10 metres of each habitat type was sampled using a 250-micrometre sweep/dip net with an opening of 250 mm x 250 mm x 250 mm. The contents of the net for each habitat was emptied into separate sorting trays and individuals were live-picked using forceps over a minimum 60-minute period. The resulting specimens were placed into labeled sample jars containing 70% ethanol and transported to the laboratory for identification (to Family level) and counting.

Data Analysis

Based on the data collected, species lists, basic descriptive statistics, and multivariate statistics using Primer V6 were undertaken to examine macroinvertebrate assemblages. The outcomes of this analysis examined not only community assemblages, presence and absence between sites and density of populations but also attempted to determine the reasons for these patterns in relation to the water quality parameters recorded. This provided a statistically robust review of the baseline data and was linked to habitat data. A review of the results in comparison to previous surveys was also undertaken.

4.1.7 Limitations

This survey was not designed to enable all species, either resident or transitory to the study area, to be detected. Instead it was aimed at providing an overall assessment of the ecological values of the site, together with the overall study area, with particular emphasis on endangered ecological communities and threatened species. For those species of conservation significance that were not detected but with the potential to occur within the subject site, an assessment of the likelihood of their occurrence was made based on known habitat requirements.

Surveys were undertaken outside the optimal survey period for some species, particularly amphibians and migratory avifauna, and therefore it is possible that some species that use the study area seasonally were not detected during the survey period. Additionally, no temporal replication of surveys was undertaken, and the highly dynamic nature of the ICOLLs was unable to be examined within the current scope of works. Despite these constraints, it is considered that the survey effort employed during this assessment was satisfactory when used in combination with the literature review and mapping of potential habitat.

AUSRIVAS is a sampling and prediction system used to assess the health of freshwater systems. These methods were applicable to the majority of creek sites in the upper catchment within the locality. However, as freshwater habitats upstream of Bellambi Lagoon and Tom Thumb Lagoon were limited to channelised stormwater drains, the macroinvertebrate samples were obtained from these brackish reaches of the estuaries. Consequently, the results of these samples should be treated with caution, and comparisons are not able to be made between all lagoons sampled as sampling habitats were not the same at all estuaries. As discussed with WCC prior to sampling proceeding, benthic macroinvertebrate cores would be a more effective way to examine macroinvertebrates within the estuarine systems.

4.1.8 Survey Effort

The ecological surveys were undertaken by three ecologists over five days between 26 and 30 of March 2007. The weather during the survey was mild, with a maximum rainfall on Monday of 8.8 mm. The minimum temperature was 14.7 ºC and maximum 24.5 ºC, as detailed in Table 4.2.

Table 4.2 BOM Weather Records for Bellambi AWS

Date	Day	Temperature (^oC)		Rain (mm)
		Maximum	Minimum	
26-3-2007	Monday	15.8	20.9	8.8
27-3-2007	Tuesday	14.7	21.6	3.0
28-3-2007	Wednesday	15.6	24.5	0
29-3-2007	Thursday	18.5	22.6	0
30-3-2007	Friday	14.7	22.8	0.4

Table 4.3 details the survey effort implemented during the surveys.

Table 4.3 Survey Effort

Survey	Technique	Approximate Number of Person Hours
Vegetation Survey	-	80
Fauna Habitat Assessments, including SEPP 44 Assessment and Hollow-bearing Tree Transects	-	25
Macroinvertebrate Survey	AUSRIVAS	42
Owl and Frog Survey	Call Playback / Spotlighting	12.5
Nocturnal Fauna Survey	Spotlighting/ Stagwatching	6

4.2 Results: Estuarine Vegetation and EECs

The following is a description of the vegetation communities including endangered ecological communities (EECs), occurring within 50 metres of the estuarine influence of the lagoons surveyed. A full list of flora species recorded in each lagoon is located in Appendix A, while fauna species are presented in Appendix B. Figures detailing the location of threatened flora species recorded on DECC's threatened flora database are presented in Appendix C as Figures C1-C10.

Table 4.4 summarises the estuarine vegetation communities and EECs identified at each site.

Table 4.4 Estuarine Vegetation Communities and EECs

Vegetation Community	Hargraves Creek	Stanwell Creek	Stoney Creek	Flanagans Creek	Slacky Creek	Whartons Creek	Collins Creek	Bellambi Gully	Bellambi Lagoon	Tom Thumb Lagoon
Saltmarsh (EEC)	X	X	X				X	X	X	X
Beach Grasses	X	X	X	X	X	X	X	X	X	
Coastal Dune Vegetation	X	X	X	X		X	X	X	X	
Freshwater/Brackish Reeds	X	X	X	X	X	X	X	X	X	X
Swamp Oak Forest (EEC)		X							X	X
Mangroves								X	X	X
Bangalay Sand Forest (EEC)									X	
Seagrasses									X	

4.2.1 Hargraves Creek

Vegetation within 50 metres of the estuarine reach of Hargraves Creek falls broadly into four categories as described below and shown on Figure C1 (Appendix C). Riparian vegetation west of the beach dunes is severely limited and consists of mown Kikuyu Grass (*Pennisetum clandestinum*) to within approximately two to five metres of the creek. On the southern side of the creek some revegetation work has been undertaken, including planting of Spiny-headed Mat-rush (*Lomandra longifolia*) in an effort to widen the riparian vegetation corridor. The creek grades into terrestrial vegetation west of the footbridge located approximately 200 metres west of the entrance bar. No seagrasses or mangroves occur at this site. The estuarine vegetation links to terrestrial and coastal vegetation to the north, south and west of the site.

Saltmarsh

Three areas of saltmarsh occur at this site. Two areas fringe the northern side of the creek in an approximate area of 50 metres by 10 metres. This area is dominated by *Isolepis nodosa*, Sea Rush (*Juncus kraussii*), Sand Couch (*Sporobolus virginicus)*, Coast Couch (*Zoysia macrantha*), the introduced Buffalo Grass (*Stenotaphrum secundatum*), and grades into coastal dune vegetation. The second area of saltmarsh is dominated by Sea Rush and is located on spit within the lagoon. These areas of saltmarsh, although small, are characteristic of Coastal Saltmarsh EEC as described by the NSW Scientific Committee (2004a).

Beach Grasses

Beach grasses including Hairy Spinifex (*Spinifex sericeus*), Beach Daisy (*Arctotheca populifolia*) and Coast Couch fringe the entrance bar, grading into coastal dune vegetation on the southern side of the lagoon and coastal saltmarsh on the northern side of the lagoon.

Coastal Dune Vegetation

Coastal dune vegetation occurs on the northern edge of the lagoon and is dominated by Coastal Banksia (*Banksia integrifolia*), Sea Rocket (*Cakile maritime*), Coastal Wattle (*Acacia longifolia* ssp. *sophorae*), Coastal Tea Tree (*Leptospermum laevigatum*) and Coastal Rosemary (*Westringia fruticosa*). The introduced Lantana (*Lantana camara*) and Asparagus Fern (*Asparagus aethiopicus*) are also present.

Freshwater/Brackish Reeds

West of the saltmarsh, dense Common Reed (*Phragmites australis*) lines the creek, creating a reed area approximately two to five metres wide. Broad-leaf Cumbungi (*Typha orientalis*) is also present and is locally dense.

4.2.2 Stanwell Creek

Vegetation within 50 metres of the estuarine reach of Stanwell Creek falls broadly into five categories as described below and shown in Figure C2 (Appendix C). Riparian vegetation west of the beach dunes is severely limited and consists of mown Kikuyu Grass to within approximately five to ten metres of the creek. The creek grades into terrestrial vegetation at the causeway, which is, located approximately 300 metres west of the entrance bar. No seagrasses or mangroves occur at this site. The estuarine vegetation links to terrestrial and coastal vegetation to the north and west of the site.

Saltmarsh

One area of saltmarsh occurs on the southern side of the entrance bar. The saltmarsh is located within a small area approximately 20 metres long and 5 metres wide. This area is dominated by *Isolepis nodosa*, Sand Couch, Sea Rush, Coast Couch, Common Couch (*Cynodon dactylon*), and the introduced Buffalo Grass, Asparagus Weed and Beach Pennywort (*Hydrocotyle bonariensis*). This area of saltmarsh, although small and modified by introduced species, is characteristic of Coastal Saltmarsh EEC as described by the NSW Scientific Committee (2004a).

Beach Grasses

Beach grasses including Hairy Spinifex, Beach Daisy and Coast Couch fringe the northern entrance bar, grading into mown Kikuyu Grass.

Coastal Dune Vegetation

Coastal dune vegetation occurs on the southern edge of the lagoon and is dominated by Coastal Banksia and Coastal Wattle. The introduced Lantana, Asparagus Fern, Mirror Bush (*Coprosma repens*), *Senna pendula* and Beach Pennywort are also present.

Freshwater/Brackish Reeds

West of the saltmarsh, dense Common Reed lines the creek, creating a reed bed approximately five to ten metres wide, and grading into Swamp Oak Forest.

Swamp Oak Forest

Swamp Oak (*Casuarina glauca*) dominates as the creek grades into terrestrial vegetation, with Lilly Pilly (*Acmena smithii*) and the introduced Lantana also occurring. Common Reed and Spiny-headed Mat-rush are the dominant groundcover. This area of Swamp Oak Forest, although only a small corridor (which may extend further upstream), is characteristic of Swamp Oak Floodplain Forest EEC as described by the NSW Scientific Committee (2004b).

4.2.3 Stoney Creek

Vegetation within 50 metres of the estuarine reach of Stanwell Creek falls broadly into four categories as described below and shown on Figure C3 (Appendix C). Due to the steep rise in Stoney Creek, riparian vegetation west of the beach dunes grades rapidly into terrestrial vegetation consisting of Lilly Pilly and *Elaeodendron australe*. Estuarine vegetation in Stoney Creek is confined to an area approximately 100 metres long and 10 metres wide at the entrance barrier. No mangroves or seagrasses are present at this site. The estuarine vegetation links to terrestrial and coastal vegetation to the north, south and west of the site.

Saltmarsh

One area of saltmarsh occurs on the southern side of the entrance bar. The saltmarsh is located within a small area approximately five metres long and one metre wide. This area is dominated by Sand Couch, Coast Couch and Common Couch. The introduced Buffalo Grass, Asparagus Weed and Beach Pennywort fringe this vegetation community. This area of saltmarsh, although small and highly modified by introduced species, is characteristic of Coastal Saltmarsh EEC as described by the NSW Scientific Committee (2004a).

Beach Grasses

Beach grasses including Hairy Spinifex, Beach Daisy and Coast Couch fringe the northern entrance bar, grading into coastal dune vegetation.

Coastal Dune Vegetation

Coastal dune vegetation is limited at this site and grades quickly into exotic garden escapee species. Coastal dune vegetation includes Coastal Banksia, Swamp Oak, Coastal Rosemary and Spiny-headed Mat-rush. The introduced Lantana, Asparagus Fern, Oleander (*Nerium oleander*), *Senna pendula* and Beach Pennywort are also present.

Freshwater/Brackish Reeds

On the southern side of the lagoon dense Common Reed, Sea Rush and Knobby Club-rush line the creek, creating a reed area approximately ten metres long by two metres wide.

4.2.4 Flanagans Creek

Vegetation within 50 metres of the estuarine reach of Flanagans Creek falls broadly into three categories as described below and shown in Figure C4 (Appendix C). Estuarine vegetation in Flanagans Creek is confined to an area approximately 500 metres long and 10 metres wide. West of the entrance bar, estuarine vegetation is extremely limited, basically consisting of Common Reed lining the creek as described below, and mown grasses. No mangroves, saltmarsh or seagrasses are present at this site. The estuarine vegetation links to coastal vegetation to the south, beach grasses to the north, and terrestrial vegetation to the west of the site.

Beach Grasses

Beach grasses including Hairy Spinifex, Sea Rocket and Beach Pennywort, fringe the entrance bar grading into mown Kikuyu Grass on the northern side, and coastal dune vegetation on the southern side of the lagoon.

Coastal Dune Vegetation

Coastal dune vegetation is limited at this site to a small (approximately 40 m x 10 m) area on the southern side of the creek. Coastal dune vegetation includes Coastal Tea Tree, *Elaeodendron australe* and Coastal Wattle. The introduced Lantana, *Ipomoea cairica* and Beach Pennywort are also present.

Freshwater/Brackish Reeds

Dense Common Reed (approximately 2 to 5 metres wide) lines both sides of the creek up to the intersection with Lawrence Hargraves Drive.

4.2.5 Slacky Creek

Vegetation within 50 metres of the estuarine reach of Slacky Creek falls broadly into two categories as described below and shown on Figure C5 (Appendix C). Estuarine vegetation in Stoney Creek is confined to an area approximately 200 metres long and 5 metres wide. West of the entrance bar, riparian vegetation is extremely limited, consisting of mown exotic grasses lining the creek. No mangroves, saltmarsh or seagrasses are present at this site. The estuarine vegetation links to beach grass vegetation to the north and south of the site and terrestrial vegetation to the west of the site.

Beach Grasses

Beach grasses including Hairy Spinifex, Beach Daisy, Common Couch, Sea Celery, Sea Rocket and Beach Pennywort fringe the entrance bar, grading into mown Kikuyu Grass on both sides of the lagoon. Several Sea Rush plants are scattered on the northern side of the lagoon.

Freshwater/Brackish Reeds

The creek is lined on both sides by native Blady Grass (*Imperata cylindrica*), *Schoenoplectus mucronatus* and the introduced Kikuyu Grass and Beach Pennywort. Scattered Coastal Wattles and Coastal Banksia occur on both sides of the creek. As the creek grades into terrestrial vegetation, Coastal Wattle, Swamp Oak, eucalypts and Coastal Banksia become dominant and appear to have been planted. Lantana occurs at a high density in this area.

4.2.6 Whartons Creek

Vegetation within 50 metres of the estuarine reach of Whartons Creek falls broadly into three categories as described below and shown on Figure C6 (Appendix C). Estuarine vegetation in Whartons Creek is confined to an area approximately 200 metres long and 10 metres wide. West of the entrance bar, estuarine vegetation is limited, comprising Common Reed and Sea Rush lining the creek as described below, and mown grasses. No mangroves, saltmarsh or seagrasses are present at this site. The estuarine vegetation links to coastal vegetation to the north and south of the site and terrestrial vegetation to the west of the site.

Beach Grasses

Beach grasses including Hairy Spinifex, Sea Rocket, Beach Daisy and Beach Pennywort, fringe the entrance bar. Beach grasses grade into coastal dune vegetation on both the northern and southern sides of the lagoon.

Coastal Dune Vegetation

Coastal dune vegetation is present on both the northern and southern sides of the creek. The vegetation on the northern side is approximately 40 m x 20 m in extent, while the southern area is approximately 20 m by 20 m in extent. The coastal dune vegetation includes Coastal Tea Tree, Coastal Wattle, Coastal Rosemary and the introduced Lantana and *Senna pendula*.

Freshwater/Brackish Reeds

Dense Common Reed and Sea Rush (approximately 2 to 5 metres width) line both sides of the creek, which grades into terrestrial vegetation west of the entrance to the caravan park. Blady Grass, Lantana and Swamp Oak are also scattered along the creekline.

4.2.7 Collins Creek

Vegetation within 50 metres of the estuarine reach of Collins Creek falls broadly into four categories as described below and shown on Figure C7 (Appendix C). Riparian vegetation west of the beach dunes has been replanted, creating a corridor approximately 10 metres wide on both sides of the creek. The creek grades into terrestrial vegetation at Carrington Street, located approximately 300 metres west of the entrance bar. A small area of saltmarsh is present at this site, however there are no seagrasses or mangroves. The estuarine vegetation links to coastal dune vegetation to the north of the site and terrestrial vegetation to the west of the site.

Saltmarsh

One area of saltmarsh occurs, fringing the southern side of the lagoon in an area of approximately 50 metres by 10 metres. This area is dominated by Sea Rush, Sand Couch, Coast Couch, Common Couch, Sea Rocket, and the introduced Beach Pennywort. The saltmarsh grades into coastal dune vegetation to the south and west. This area of saltmarsh, although small, is characteristic of Coastal Saltmarsh EEC as described by the NSW Scientific Committee (2004a).

Beach Grasses

Beach grasses including Hairy Spinifex, Beach Daisy, Sea Rocket and Coast Couch fringe the entrance bar, grading into coastal dune vegetation on both sides of the lagoon. The area of beach grasses is larger on the northern side than the southern side of the lagoon.

Coastal Dune Vegetation/ Revegetated

The coastal dune vegetation has been rehabilitated through revegetation work on both sides of the creek west of the footbridge, and east of the footbridge on the southern side of the lagoon. The vegetation is dominated by Coastal Banksia, Coastal Wattle, Coastal Tea Tree and Spiny-headed Mat-rush. Although the introduced Lantana and Beach Pennywort are common in some areas, this site receives regular weed control activities, as witnessed during this survey.

Freshwater/Brackish Reeds

Dense Common Reed lines both sides of the creek, creating a 1 to 2 metre wide reed area that grades into coastal dune vegetation on both sides of the creek. Dense Common Reed lines both sides of the creek throughout the park and adjacent to Carrington Street. Broad-leaf Cumbungi is also present and is dense in parts.

4.2.8 Bellambi Gully

Vegetation within 50 metres of the estuarine reach of Bellambi Gully falls broadly into five categories as described below and shown in Figure C8 (Appendix C). Bellambi Gully connects to an area of freshwater/brackish wetlands to the north, which together with the estuarine vegetation provides a large habitat area of approximately 200 metres by 600 metres. Estuarine riparian vegetation at Bellambi Gully extends upstream to the intersection of Pioneer Drive, located approximately 800 metres west of the entrance bar. No seagrasses occur at this site. The estuarine vegetation links to coastal dune vegetation to the north and terrestrial vegetation to the west of the site.

Saltmarsh

Two areas of saltmarsh occur. The larger area (approximately 200 x 10 metres) fringes the southern side of the gully and is dominated by Sea Rush, Sand Couch, Common Reed, Coast Couch, Hairy Spinifex, Sea Rocket, Water Couch (*Paspalum distichum*) and the introduced Beach Pennywort. This area of saltmarsh grades into coastal dune vegetation to the south and west. On the northern side of the gully one small (approximately 40 by 5 metres) area of saltmarsh occurs, consisting of Sand Couch only. The areas of saltmarsh are characteristic of Coastal Saltmarsh EEC as described by the NSW Scientific Committee (2004a).

Mangroves

Four young Grey Mangroves (*Avicennia marina*) are scattered within the saltmarsh area on the southern side of the gully, although their density was too low to map.

Beach Grasses

Beach grasses including Hairy Spinifex, Beach Daisy and Sea Rocket fringe the entrance bar, grading into saltmarsh on the southern side of the gully and coastal dune vegetation on the northern side of the gully. The area of beach grasses is larger on the southern side than the northern side of the gully, where the vegetation is fragmented.

Coastal Dune Vegetation

Coastal dune vegetation occurs on both sides of the gully. On the southern side of the gully it occurs south and west of the saltmarsh area and is dominated by Coastal Wattle, Swamp Paperbark (*Melaleuca ericifolia*) and Water Couch. On the northern side of the gully, coastal dune vegetation is dominated by Coastal Wattle and the introduced Bitou Bush. Coastal dune vegetation grades into freshwater/brackish reeds on both sides of the gully.

Freshwater/Brackish Reeds

Dense Common Reed (approximately 2 to 5 metres wide) lines both sides of the gully west of the footbridge, extending to Pioneer Drive, with a large area (approximately 200 metres by 50 metres) of dense Common Reed and Broad-leaf Cumbungi that fringe a freshwater/brackish pond.

4.2.9 Bellambi Lagoon

Vegetation within 50 metres of the estuarine reach of Bellambi Lagoon falls broadly into eight categories as described below and shown in Figure C9 (Appendix C). Bellambi Lagoon connects to an area of freshwater wetlands to the northwest of the lagoon; Swamp Oak Forest, Bangalay Sand Forest and coastal dune vegetation to the east of the lagoon. Together with the estuarine vegetation, these communities provide a large riparian area of approximately 800 metres by 300 metres. The freshwater reaches of the lagoon are contained in stormwater channels.

Saltmarsh

Several areas of saltmarsh occur. A corridor approximately two to five metres wide fringes the western edge of the lagoon, dominated by Sea Rush, Sand Couch, *Isolepis nodosa* and *Sarcocornia quinqueflora*. Several smaller patches also occur on the islands within the lagoon. The saltmarsh areas are characteristic of Coastal Saltmarsh EEC as described by the NSW Scientific Committee (2004a).

Mangroves

Several Grey Mangroves are scattered along the western edge of the lagoon and on the islands within the lagoon, although their density was too low to map.

Seagrass

Two species of seagrass are present in the lagoon, *Ruppia megacarpa* and *Zostera capricorni*. One small area (approximately 10 metres by 2 metres) of *Z. capricorni* is located on the western bank of the lagoon, in low, patchy density. *R. megacarpa* occurs along the western and northern banks within the lagoon also with a low, patchy density and during the survey this species was smothered to a depth of approximately 5 centimeters by prolific green macroalgae. Chafer (1997) has previously recorded *R. megacarpa* as smothered by the green algae *Lamprithamnion populosum* in Lake Illawarra.

Beach Grasses

Beach grasses including Hairy Spinifex, Beach Daisy and Sea Rocket fringe the entrance bar, grading into saltmarsh on the southern side of the gully and coastal dune vegetation on the northern side of the gully. The beach grass area is slightly more extensive on the northern than the southern side of the lagoon.

Coastal Dune Vegetation

Coastal dune vegetation occurs on the northern side of the gully and is dominated by Coastal Wattle, Coastal Banksia and Bitou Bush. The coastal dune vegetation grades into Bangalay Sand Forest and Swamp Oak Forest.

Freshwater/Brackish Reeds

Dense areas of Common Reed line the northwest and north of the lagoon. On the northwest edge of the lagoon, Common Reed is generally restricted to a corridor approximately five metres wide fringing the edge of the lagoon. The northern area of the lagoon is characterised by a large area of Common Reed (approximately 50 metres by 200 metres). Broad-leaf Cumbungi is also present and is dense in parts.

Swamp Oak Forest

Several areas of Swamp Oak Forest are present, the largest areas line the eastern and northeastern edge of the lagoon. The canopy is dominated by Swamp Oak, with some young Prickly-leaved Tea Tree (*Melaleuca styphelioides)* occurring in the shrub layer. There is a dense groundcover of *Baumea juncea,* Sea Rush, *Isolepis inundata,* Tall Saw-sedge (*Gahnia clarkei)* and the introduced Buffalo Grass, Bitou Bush and Beach Pennywort. This area of Swamp Oak Forest is characteristic of Swamp Oak Floodplain Forest EEC as described by the NSW Scientific Committee (2004b).

Several large stands of planted Swamp Oaks occur within the northern and northwestern freshwater/brackish reed areas. Swamp Oaks also occur on the islands within the lagoon. These areas of Swamp Oak Forest, although planted, contain characteristic species of Swamp Oak Floodplain Forest EEC as described by the NSW Scientific Committee (2004b).

Bangalay Sand Forest

On the eastern boundary of the Swamp Oak Forest fringing the eastern edge of the lagoon, the vegetation grades into Bangalay Sand Forest. The canopy is dominated by Bangalay (*Eucalyptus botryoides*), with occasional Swamp Mahogany *(Eucalyptus robusta*) and Woollybutt *(Eucalyptus longifolia*). The dense shrub layer includes Lilly Pilly, Swamp Oak, Coastal Tea Tree and Tall Saw-sedge. The sparse groundcover includes Blady Grass, Bracken (*Pteridium esculentum*), Spiny-headed Mat Rush and the introduced Bitou Bush. This area of Bangalay Sand Forest is characteristic of Bangalay Sand Forest EEC as described by the NSW Scientific Committee (2005).

4.2.10 Tom Thumb Lagoon

Vegetation within 50 metres of the estuarine reach of Tom Thumb Lagoon (TTL) falls broadly into four categories as described below and shown in Figure C10 (Appendix C). TTL connects to J.J. Kelly Park to the north, which is a grassed park with riparian vegetation limited to reeds lining the creek and revegetated areas. The freshwater reaches of this lagoon are contained in stormwater channels. No seagrass occurs at this site. The estuarine vegetation connects with terrestrial vegetation to the northwest, which was replanted on the former landfill site.

Saltmarsh

One large area of saltmarsh occurs, bounded by the rail corridor to the south, Springhill Road to the west, the cycleway to the north and the creekline to the east. The saltmarsh is dominated by Sea Rush, Sand Couch, Coast Couch, *Sarcocornia quinqueflora* and *Suaeda australis*. Some grasses occur in the western areas of the saltmarsh including the introduced Kikuyu Grass and the native *Schoenoplectus mucronatus*. Grey Mangroves occur at a low density within the saltmarsh area. This area of saltmarsh is characteristic of Coastal Saltmarsh EEC as described by the NSW Scientific Committee (2004a).

Mangroves

Grey Mangroves occur in the large saltmarsh area at a low density. A very dense stand of Grey Mangroves occurs at the southeast arm of the lagoon. Scattered Grey Mangroves occur at a low density in both arms of the creekline as it extends northwest through J.J. Kelly Park until the intersection with Swan Street.

Freshwater/Brackish Reeds and Revegetated

A small area (approximately 20 metres by 5 metres) of Common Reed is located on the southern edge of the large saltmarsh area.

Dense areas of *Schoenoplectus mucronatus*, Broad-leaf Cumbungi and Common Reed line the three upper arms of the creek as it extends northwest through J.J. Kelly Park. The reeds occur on both sides of the creek, creating a reed area approximately two to five metres wide. Riparian vegetation within J.J. Kelly Park is otherwise limited to several revegetated areas that include River Sheoak (*Casuarina cunninghamiana*), Swamp Oak, eucalypts and *Melaleuca* spp. Weeds are prolific within the riparian corridor of J.J. Kelly Park and include dense areas of Bitou Bush and Lantana.

Riparian vegetation lining TTL as it extends north past the Wollongong Greenhouse Park is dominated by weeds, predominantly Lantana, Bitou Bush, Castor Oil Plant (*Ricinus communis*), Madeira Vine (*Anredera cordifolia*) and Giant Reed (*Arundo donax*).

Swamp Oak Forest

Swamp Oak Forest lines the southern and northern side of the western arm of TTL . The canopy is dominated by Swamp Oak and River Sheoak, with Prickly-leaved Tea Tree and Broad-leaved Tea Tree (*Melaleuca quinquenervia*) also occurring in the shrub and canopy layer. There is a sparse groundcover of introduced grasses including Kikuyu Grass. This area of Swamp Oak Forest, although planted, contains characteristic species of Swamp Oak Floodplain Forest EEC as described by the NSW Scientific Committee (2004b).

4.3 Results: Fauna Surveys

The following provides a description of the fauna assemblages recorded during the surveys, and fauna habitat values associated with the estuarine reaches of the lagoons. A full list of fauna species recorded in each lagoon is located in Appendix B. Figures detailing the location of threatened fauna species recorded on DECC's threatened flora database are presented in Appendix C as Figures C11-C12.

4.3.1 Hargraves Creek

The estuarine reaches of Hargraves Creek provide good potential foraging habitat for amphibians, microchiropteran bats, terrestrial and coastal birds, and birds of prey. Structural complexity is quite high at the entrance bar, with a mixed assemblage of saltmarsh species, beach grasses and coastal dune vegetation. The coastal dune vegetation includes an intact understorey of Coastal Banksia and Coastal Tea Tree. However, there are no hollow-bearing trees or stags to provide potential roosting and/or nesting habitat for birds, mammals and bats. There is dense riparian vegetation, predominantly Common Reed and Broad-leaf Cumbungi, lining the two arms of Hargraves Creek that gives a good leaf litter cover and provides potential foraging habitat for reptiles. However the mown grass areas (to within two metres of the creek) severely limit fauna habitat outside the immediate vicinity of the creek. There are no fallen logs to provide potential refuge habitat for amphibians and reptiles. There are no SEPP 44 listed koala feed tree species within the estuarine reaches. There is a small area of saltmarsh on the northern side of the entrance bar that provides an area of potential habitat for estuarine waders and invertebrates.

The Common Reed and Broad-leaf Cumbungi that fringe both arms of Hargraves Creek provide potential habitat for common amphibians such as Eastern Common Froglet (*Crinia signifera*) and Striped Marsh Frog (*Limnodynastes peroni*). Striped Marsh Frog was recorded calling at multiple locations at Hargraves Creek during the survey. The creekline provides potential foraging habitat for common insectivorous species such as microchiropteran bats, birds and reptiles. Several microbats were observed at dusk. The entrance bar and shallow areas of the creek provides potential foraging habitat for a range of common coastal species such as Crested Tern (*Sterna bergii*). A number of common bird species were recorded within the estuarine reaches including Black-shouldered Kite (*Elanus axillaris*), Silver Gull (*Larus novaehollandiae*), White faced Heron (*Egretta novaehollandiae*), Spur-winged Plover (*Vanellus miles*), and Dusky Moorhen (*Gallinula tenebrosa*). A pair of Dusky Moorhen were sighted in a nest within the dense Sea Rush bed at the entrance bar of Hargraves Creek.

Hargraves Creek grades into terrestrial habitat within approximately 200 metres of the entrance bar. Fauna habitat values here are greater, with increased riparian vegetation surrounding both sides of the creek. The depth of leaf litter also increases within the upper terrestrial and freshwater reaches of Hargraves Creek, providing potential habitat for amphibians including the threatened Red-crowned Toadlet (*Pseudophryne australis*) and Littlejohn's Tree Frog (*Litoria littlejohni)*. The terrestrial reaches of Hargraves Creek also contains abundant berry-producing vegetation, suitable foraging habitat for fruit eating species, including the threatened Rose-crowned Fruit Dove (*Ptilinopus regina*) and Grey-headed Flying-fox (*Pteropus poliocepalus*).

Call playback for Green and Golden Bell Frog and Red-Crowned Toadlet was undertaken within the estuarine reaches of Hargraves Creek. Diurnal searches for the species were also undertaken. Whilst no threatened amphibians were recorded at this creek, potential habitat for Green and Golden Bell Frog is present at this site within the dense Broad-leaf Cumbungi stands.

Due to the close proximity of residences within the estuarine reaches of Hargraves Creek, no owl call playback was undertaken at this site as the sound of owl call playback can be distressing if people are not aware that the sound is not human. However, a limited area of potential foraging habitat for Sooty Owl (*Tyto tenebricosa*), Powerful Owl (*Ninox strenua*) and Barking Owl (*N. connivens*) is present in the estuarine reaches of this site. Extensive foraging and nesting habitat for owls is present in the freshwater and terrestrial reaches of Hargraves Creek catchment. Owl call playback was undertaken in the freshwater reaches of the catchment away from residences, however no threatened species were recorded.

4.3.2 Stanwell Creek

The estuarine reaches of Stanwell Creek provide good potential habitat for amphibians, microchiropteran bats, and birds. Structural complexity is moderate at the entrance bar, with bare sand and beach plants on the northern side and dense Common Reed, and scattered saltmarsh and beach plants on the southern side of the entrance bar. There are no trees or intact understorey within the estuarine reaches and no hollow-bearing trees or stags to provide potential roosting and/or nesting habitat for birds, mammals and bats. Leaf litter is generally low in depth and cover on the northern side of the creek but high within the dense Common Reed on the southern side of the creek, which would provide foraging habitat for reptiles. A juvenile Eastern Water Dragon (*Physignathus lesueurii lesueurii*) was recorded at this site. There are no fallen logs to provide potential refuge habitat for amphibians and reptiles. There are no SEPP 44 listed koala feed tree species within the estuarine reaches. The occurrence of saltmarsh species is limited to a small area on the southern side of the creek consisting of Sea Rush and Sand Couch that would provide limited potential habitat for estuarine waders and invertebrates.

Common Reed fringes the southern side of Stanwell Creek, providing potential habitat for common amphibians such as Eastern Common Froglet, however no amphibians were recorded calling at Stanwell Creek during the survey. The creekline provides potential foraging habitat for common insectivorous species such as microchiropteran bats, birds and reptiles. Several microbats were recorded at this site at dusk. The entrance bar and shallow areas of the creek provides potential foraging habitat for a range of common coastal species. The open, rocky area at the entrace bar provides potential foraging habtiat for the threatened Sooty Oystercatcher (*Haematopus fuliginosus*). A range of common bird species were recorded within the estuarine reaches including Silver Gull, Dusky Moorhen, White-faced Heron and Magpie-lark (*Grallina cyanoleuca*).

Stanwell Creek grades into terrestrial habitat within approximately 300 m of the entrance bar. Riparian vegetation gradually increases upstream with Swamp Oak (*Casuarina glauca*) and Lilly Pilly fringing both sides of the creek. The terrestrial and freshwater upper reaches of Stanwell Creek provide potential habitat for the threatened Red-crowned Toadlet, Littlejohn’s Tree Frog, Grey-headed Flying-fox, fruit doves including the Rose-crowned Fruit Dove and the threatened Rosenberg’s Goanna (*Varanus rosenbergi*).

Call playback for Green and Golden Bell Frog and Red-Crowned Toadlet was undertaken within the estuarine reaches of Stanwell Creek. Diurnal searches for these species were also undertaken. Whilst no threatened amphibians were recorded at this creek, potential habitat for Green and Golden Bell Frog is present at this site within the dense Broad-leaf Cumbungi stands.

Due to the close proximity of residences within the estuarine reaches of Stanwell Creek, no owl call playback was undertaken at this site. However, a limited area of potential foraging habitat for Sooty Owl, Powerful Owl and Barking Owl is present in the estuarine reaches of this site. Extensive foraging and nesting habitat for owls is present in the freshwater and terrestrial reaches of Stanwell Creek catchment. Owl call playback was undertaken in the freshwater reaches of the catchment away from residences, however no threatened species were recorded.

4.3.3 Stoney Creek

The estuarine reaches of Stoney Creek provide limited habitat for fauna. Structural complexity is generally low at the entrance bar where bare sand and beach plants dominate the groundcover. There are no trees or intact understorey, and no hollow-bearing trees or stags to provide potential roosting and/or nesting habitat for birds, mammals and bats. Leaf litter is generally low in depth and cover, however the abundant rocky areas surrounding the creek would provide foraging habitat for reptiles. There are no fallen logs to provide potential refuge habitat for amphibians and reptiles. There are no SEPP 44 listed koala feed tree species within the estuarine reaches. The occurrence of saltmarsh species is limited to scattered areas of Sea Rush and Sand Couch on the southern side of the creek, providing limited potential habitat for estuarine waders and invertebrates.

Common Reed fringes the southern side of Stoney Creek, providing potential habitat for common amphibians such as Eastern Common Froglet, however no amphibians were recorded calling at Stoney Creek during the survey. The creekline provides potential foraging habitat for common insectivorous species such as microchiropteran bats, birds and reptiles. The entrance bar and shallow areas of the creek provide potential foraging habitat for a range of common coastal species. A range of common bird species were recorded within the estuarine reaches including Welcome Swallow (*Hirundo neoxena*), Pied Cormorant (*Phalacrocorax varius*) and Rainbow Lorikeet (*Trichoglossus haematodus*).

Stoney Creek rises steeply within 100 m of the entrance bar, grading rapidly into dense terrestrial habitat, and fauna habitat values increase with dense riparian vegetation surrounding both sides of the creek, high levels of leaf litter and abundant fruit-bearing figs. The upper freshwatrer and terrestrial reaches of Stoney Creek provide potential habitat for the threatened Red-crowned Toadlet, Littlejohn's Tree Frog, Grey-headed Flying-fox, fruit doves including the Rose-crowned Fruit Dove and a number of owl species including Sooty Owl, Powerful Owl and Barking Owl.

Due to the generally low fauna habitat values within the estuarine areas of Stoney Creek, no amphibian and owl call playback was undertaken at this site. Extensive foraging and nesting habitat for owls is present in the freshwater and terrestrial reaches of Stoney Creek catchment. Owl call playback was undertaken in the freshwater reaches of the catchment away from residences, however no threatened species were recorded.

4.3.4 Flanagans Creek

The estuarine reaches of Flanagans Creek provide limited habitat for fauna. Structural complexity is low at the entrance bar. Bare sand and beach plants dominate the groundcover north and south of the lagoon. The area south of the entrance bar connects with dune vegetation with an intact understorey including Coastal Banksia and Coastal Tree in a width of approximately 10 metres.

Riparian vegetation within the estuarine reaches of this creek is characterised by dense Common Reed lining both sides of the creek grading into mown Kikuyu Grass towards the surrounding residential areas. This area of dense Common Reed would provide potential habitat for common amphibians such as the Striped Marsh Frog, which was recorded during the survey. Call playback for Green and Golden Bell Frog was undertaken at this site, however no individuals were recorded. Given the limited riparian vegetation at the site and the absence of preferred habitat, it is considered that Flanagans Creek is unlikely to provide potential habitat for threatened amphibians, including the Green and Golden Bell Frog.

There are no hollow-bearing trees or stags to provide potential roosting and/or nesting habitat for birds, mammals and bats within the estuarine reaches of Flanagans Creek. Levels of leaf litter are generally low in cover and depth, apart from within the Common Reed areas, which would provide foraging habitat for common reptiles. There are no fallen logs to provide potential refuge habitat for amphibians and reptiles. There are no SEPP 44 listed koala feed tree species within the estuarine reaches and no saltmarsh species.

The creekline provides potential foraging habitat for insectivorous species such as common microchiropteran bats, birds and reptiles. The entrance bar and shallow areas of the creek provides potential foraging habitat for a range of common coastal species. A range of common bird species were recorded within the estuarine reaches including Dusky Moorhen, Purple Swamphen (*Porphyrio porphyrio*) and Domestic Duck (*Anas platyrhynchos*). There are several historical records of the threatened Sooty Oystercatcher (*Haematopus fuliginosus*) along the coast near Flanagans Creek. Potential foraging habtiat for Sooty Oystercatcher is available along the coastline, including at Flanagans Creek.

Flanagans Creek gradually grades into terrestrial riparian vegetation within residential areas west of Lawrence Hargraves Drive. Fauna habitat values remain relatively low despite higher levels of riparian vegetation, as weed species dominate. The upper reaches of Flanagans Creek provide potential foraging habitat for a range of owl species. There is a historical record for the threatened Pink Robin (*Petroica rodinogaster*) in Flanagans Creek catchment, however there is considered that there is limited potential habitat for this species in Flanagans Creek.

4.3.5 Slacky Creek

The estuarine reaches of Slacky Creek provide limited habitat for fauna. Structural complexity is low at the entrance bar. Bare sand and beach plants dominate the groundcover north and south of the lagoon. There are no trees or intact understorey, and no hollow-bearing trees or stags to provide potential roosting and/or nesting habitat for birds, mammals and bats. Leaf litter is generally low in cover apart from the grassed areas lining the creek, which would provide limited foraging habitat for reptiles. There are no fallen logs to provide potential refuge habitat for amphibians and reptiles. There are no SEPP 44 listed koala feed tree species within the estuarine reaches.

Riparian vegetation within the estuarine reaches of this creek is very limited and consists of mown Kikuyu Grass with some scattered shrubs on both sides of the creek. No amphibian species were recorded calling and, given the limited riparian vegetation at the site and the absence of preferred habitat, it is considered that Slacky Creek does not provide potential habitat for threatened amphibians, including Green and Golden Bell Frog.

Further upstream, riparian vegetation increases on both sides of the creek and includes eucalypts, Swamp Oaks and fruit-bearing subtropical rainforest species including figs. The upper reaches provide potential foraging habitat for a range of owl species. Fauna habitat values increase within the freshwater reaches of Slacky Creek, with one hollow-bearing tree and several fallen logs recorded within the riparian vegetation. Spotlighting and stagwatching for mammals and birds was undertaken within the freshwater reaches but no nocturnal fauna were recorded.

The creekline provides potential foraging habitat for insectivorous species such as common microchiropteran bats, birds and reptiles. The entrance bar and shallow areas of the creek provide potential foraging habitat for a range of common coastal species. There are several historical records of the threatened Sooty Oystercatcher along the coast near Slacky Creek. Potential foraging habtiat for Sooty Oystercatcher is available along the coastline, including at Slacky Creek. A range of common bird species were recorded within the estuarine reaches including Rainbow Lorikeet, Australian Raven (*Corvus coronoides*) and Crested Pigeon (*Ocyphaps lophotes*).

4.3.6 Whartons Creek

The estuarine reaches of Whartons Creek provide limited habitat for fauna. Structural complexity is low at the entrance bar. Bare sand and beach plants dominate the groundcover north and south of the lagoon. There are no hollow-bearing trees or stags to provide potential roosting and/or nesting habitat for birds, mammals and bats. An area of coastal dune vegetation lines both the northern and southern sides of the creek and includes an intact understorey of Coastal Banksia and Coastal Tea Tree. Leaf litter is generally low in cover and depth apart from within the coastal vegetation, which would provide foraging habitat for reptiles. There are no fallen logs to provide potential refuge habitat for amphibians and reptiles. There are no SEPP 44 listed koala feed tree species within the estuarine reaches. The occurrence of saltmarsh species is limited to scattered areas of Sea Rush on the southern side of the creek, providing limited potential habitat for estuarine waders and invertebrates.

Riparian vegetation within the estuarine reaches of this creek is very limited and consists of mown Kikuyu Grass to the north and south of the creek, and dense Common Reed fringing both banks. No amphibian species were recorded calling, and, given the limited riparian vegetation at the site and the absence of preferred habitat, it is considered that Whartons Creek is unlikely to provide potential habitat for threatened amphibians including Green and Golden Bell Frog.

Further upstream, riparian vegetation increases but is still generally low on both sides of the creek, and includes eucalypts, Swamp Oak and exotic species. Fauna habitat values are generally low within the freshwater reaches of the creek with limited riparian vegetation and a high occurrence of weeds. However, the upper reaches provide potential habitat for a range of owl species.

The creekline provides potential foraging habitat for insectivorous species such as common microchiropteran bats, birds and reptiles. The entrance bar and shallow areas of the creek provide potential foraging habitat for a range of common coastal species. A number of common bird species were recorded within the estuarine reaches including Welcome Swallow, Australian Raven and Silver Gull. The threatened Sooty Oystercatcher was recorded near the entrance bar of Whartons Creek during this survey. The species is known from a range of habitats including rocky headlands, beaches and estuaries, and forages on exposed rock or coral at low tide for foods such as limpets and mussels (Pizzey and Knight 2003). Whilst there is limited foraging habitat available for this species within Whartons Creek, there is considerable foraging habitat available for this species along the coastline between Hargraves Creek and Bellambi Lagoon.

4.3.7 Collins Creek

The estuarine reaches of Collins Creek provide good potential foraging habitat for amphibians, microchiropteran bats, terrestrial and coastal birds, and birds of prey. Structural complexity is quite high at the entrance bar, with a mixed assemblage of saltmarsh species, beach grasses and coastal dune vegetation. The coastal dune vegetation has been recently planted and includes an intact understorey of Coastal Banksia, Coastal Tea Tree and Spiny Mat-rush. However, there are no hollow-bearing trees or stags to provide potential roosting and/or nesting habitat for birds, mammals and bats. Dense riparian vegetation, predominantly Common Reed and Broad-leaf Cumbungi, lines Collins Creek and gives a high leaf litter cover, providing potential foraging habitat for reptiles. However the mown areas of grass (to within five metres of the creek) severely limit fauna habitat outside the immediate vicinity of the creek. There are no fallen logs to provide potential refuge habitat for amphibians and reptiles. There are no SEPP 44-listed koala feed tree species within the estuarine reaches. There is a small area of saltmarsh on the southern side of the entrance bar that provides an area of potential habitat for estuarine waders and invertebrates.

The Common Reed and Broad-leaf Cumbungi reeds that fringe Collins Creek provides potential habitat for common amphibians such as Eastern Common Froglet and Striped Marsh Frog. However, no amphibians were recorded during the survey. No call playback for amphibians was conducted at this site, however it is considered that there is limited potential foraging habitat available for the threatened Green and Golden Bell Frog.

There are historical records for the threatened Black Bittern (*Ixobrychus flavicollis*) in Collins Creek catchment, however it is considered that there is limited potential habitat for this species at this site.

The creekline provides potential foraging habitat for common insectivorous species such as microchiropteran bats, birds and reptiles. The entrance bar and shallow areas of the creek provides potential foraging habitat a range of common coastal species. A number of common bird species were recorded within the estuarine reaches including Black-shouldered Kite, Silver Gull and Pacific Black Duck (*Anas superciliosa*).

Collins Creek grades into terrestrial riparian vegetation within approximately 400 m of the entrance bar. Riparian vegetation is limited to approximately five metres on both sides of the creek and dominated by Lantana, *Elaeodendron australe* and exotic species.

Due to the close proximity of residences within the estuarine reaches of Collins Creek, owl call playback was undertaken within the freshwater reaches. No threatened owl species were recorded, however, potential foraging habitat for Sooty Owl, Powerful Owl and Barking Owl is present at this site.

4.3.8 Bellambi Gully

The estuarine reaches of Bellambi Gully provide excellent potential foraging habitat for amphibians, microchiropteran bats, terrestrial, estuarine and coastal birds, and birds of prey. Structural complexity is quite high at the entrance bar, with a mixed assemblage of saltmarsh species, beach grasses and coastal dune vegetation. The coastal dune vegetation includes an intact understorey of Common Reed, Coastal Banksia and Coastal Tea Tree on the northern side of the gully, and Common Reed on the southern side of the gully. However, there are no hollow-bearing trees or stags to provide potential roosting and/or nesting habitat for birds, mammals and bats. There is dense riparian vegetation, predominantly Common Reed, through to the freshwater reaches that gives a good leaf litter cover and provides potential foraging habitat for reptiles. There are fallen logs within the coastal vegetation on the northern side of the gully that would provide potential refuge habitat for amphibians and reptiles. There are no SEPP 44 listed koala feed tree species within the estuarine reaches.

There is a large area (approximately 200 metres x 10 metres) of saltmarsh on the southern side of the entrance bar, including four young Grey Mangroves, which together provide a small area of potential habitat for estuarine invertebrates and avifauna.

Bellambi Gully connects to a large freshwater/brackish wetland area, consisting of a large waterbody fringed by Common Reed and Broad-leaf Cumbungi, grading into coastal dune vegetation. Together with the areas of estuarine vegetation, this site provides excellent foraging habitat for a range of amphibian, bird, reptile and bat species. The dense reed and wetland area also represents potential habitat for the threatened Australasian Bittern (*Botaurus poiciloptilus*) and Black Bittern, however given that this wetland area is relatively small and fragmented, it is considered unlikely that this represents important habitat for threatened species.

The Common Reed that fringes both sides of the gully provides potential habitat for common amphibians such as Eastern Common Froglet and Striped Marsh Frog, both of which were recorded during this survey. The freshwater/brackish wetland area provides potential habitat for the threatened Green and Golden Bell Frog. Diurnal searches for the species were undertaken and, whilst no Green and Golden Bell Frogs were recorded during the survey, potential habitat for this species is available at this site.

The creekline provides potential foraging habitat for insectivorous species such as common microchiropteran bats, birds and reptiles. Several microbats were observed at this site at dusk. The entrance bar and shallow areas of the creek provides potential foraging habitat for a range of common coastal species. A number of common bird species were recorded within the estuarine reaches including Black-shouldered Kite, Silver Gull, Dusky Moorhen, Intermediate Egret (*Ardea intermedia*), Pied Cormorant and Pacific Black Duck.

West of the freshwater wetland, riparian vegetation consists of an approximately five metre wide area of Common Reed fringing both sides of the creek. Fauna habitat values decrease, as riparian vegetation is limited. This area is likely to only provide marginal habitat for common amphibian and bird species.

Due to the proximity of residences to the estuarine reaches of Bellambi Gully, no owl call playback was undertaken at this site. However, potential foraging habitat for Sooty Owl, Masked Owl, Powerful Owl and Barking Owl is present at this site and within the freshwater reaches.

4.3.9 Bellambi Lagoon

The estuarine reaches of Bellambi Lagoon provide excellent potential foraging habitat for amphibians, microchiropteran bats, terrestrial, estuarine and coastal birds and birds of prey, and marginal habitat for ground-dwelling and arboreal mammals. Structural complexity is high at the entrance bar on the northern side of the lagoon, with a mixed assemblage of saltmarsh species, beach grasses and coastal dune vegetation that includes an intact understorey. There are several hollow-bearing trees and stags within the coastal dune vegetation on the northern side of the lagoon that would provide potential roosting and/or nesting habitat for birds, mammals and bats. The hollow-bearing trees and stags are mostly within Coastal Banksia, and one hollow in a Bangalay (*Eucalyptus botryoides*).

There is dense riparian vegetation lining the north, west, and most of the southern edges of the lagoon including saltmarsh, Swamp Oak Forest and freshwater reeds that give good leaf litter cover and provide potential foraging habitat for reptiles. There are fallen logs on the northern and western sides of the lagoon that would provide potential refuge habitat for amphibians and reptiles. Several freshwater pools provide potential habitat for amphibians within the Swamp Oak Forest. One SEPP 44 listed koala feed tree species, Swamp Mahogany, occurs at a low density within the coastal dune vegetation on the northern side of the lagoon, however due to fragmentation of the eucalyptus forest and lack of historical records at the site, it is considered highly unlikely that Koala would utilise the site.

Saltmarsh species fringe the southern side of Bellambi Lagoon. One Grey Mangrove occurs on the southern side of the lagoon, and several others occur at a low density on the islands within the lagoon and along the western edge of the lagoon. These areas of mangroves and saltmarsh provide potential habitat for estuarine waders and invertebrates.

Bellambi Lagoon has several small islands vegetated with saltmarsh species, reeds and Swamp Oak. These islands provide excellent foraging and nesting habitat for estuarine and terrestrial birds. Dusky Moorhen, Purple Swamphen and Pacific Black Duck were observed nesting on the islands during the site inspection.

The Common Reed and Swamp Oak Forest on the north and western edges of the lagoon provide potential habitat for common amphibians such as Eastern Common Froglet, Eastern Dwarf Tree Frog (*Litoria fallax*) and Striped Marsh Frog, all of which were recorded during this survey. Several dense stands of Broad-leaf Cumbungi and freshwater pools are located within the Common Reed and Swamp Oak forest that provides potential habitat for Green and Golden Bell Frog. There are historical records for Green and Golden Bell Frog at Bellambi Lagoon. Diurnal searches and call playback for the species were undertaken at two locations at Bellambi Lagoon, and whilst no Green and Golden Bell Frogs were recorded during the survey, potential habitat for this species is available at this site. Potential habitat for Australasian Bittern and Black Bittern is also present at this site, within the dense Common Reed and Broad-leaf Cumbungi wetland area.

There is a historical record of Swift Parrot (*Lathamus discolor*) on the eastern edge of Bellambi Lagoon within the Swamp Oak/ Bangalay Sand Forest. Swamp Mahogany (*Eucalyptus robusta)*, a preferred feed tree species of Swift Parrot (Pizzey and Knight 2003) occur within the Sand Bangalay forest, and it is considered that this area of Swamp Oak/Sand Bangalay Forest represents an area of potential foraging habitat for Swift Parrot.

The lagoon provides potential foraging habitat for insectivorous species such as common microchiropteran bats, birds and reptiles. Several microbats were observed at this site at dusk, and numerous individuals of Grey-headed Flying-fox were recorded flying overhead and foraging at the lagoon after dusk. The lagoon provides potential foraging habitat for a range of common coastal species. A large number of common bird species were recorded within the estuarine reaches including Spur-winged Plover, Silver Gull, Dusky Moorhen, Pied Cormorant, Pacific Black Duck, Chestnut Teal (*Anas castanea*), Australian Pelican (*Pelecanus conspicillatus*) and Little Egret (*Egretta garzetta*).

Due to the close proximity of residences within the estuarine reaches of Bellambi Lagoon, no owl call playback was undertaken at this site. However, potential foraging habitat for Sooty Owl, Powerful Owl and Barking Owl is present at this site.

4.3.10 Tom Thumb Lagoon

The estuarine reaches of Tom Thumb Lagoon (TTL) provide excellent habitat for amphibians, coastal and estuarine birds, microchiropteran bats and birds of prey. Structural complexity is high, with extensive areas of saltmarsh, mudflats, mangroves, Swamp Oak Forest, and reedlands. The areas of saltmarsh and mangroves connect to planted areas of Swamp Oak Forest and Paperbark Forest (*Melalueca* spp.) with intact shrub and groundcover layers, however there are no hollow-bearing trees or stags to provide potential roosting and/or nesting habitat for birds, mammals and bats within the estuarine reaches. Leaf litter levels are generally high, and would provide foraging habitat for reptiles. There are fallen logs throughout the estuarine area that would provide potential refuge habitat for amphibians and reptiles. There are no SEPP 44 listed koala feed tree species within the estuarine reaches.

Extensive areas of saltmarsh and mudflats occur within TTL, and smaller areas within J.J. Kelly Park, that would provide potential foraging habitat for estuarine wading birds and invertebrates. Two species of mollusc, *Salinator fragilis* and *Ophicardelus ornatus/quoyi,* have been previously recorded in TTL (SWC and WCC 1993) and were recorded during this survey. A large number of birds were recorded in TTL during the survey, however given the areas of extensive habitat available it is surprising that more species and individuals weren't recorded. Species recorded included Pacific Black Duck, Chestnut Teal, Grey Teal (*A. gracilis*), Royal Spoonbill (*Platalea regia*), Dusky Moorhen, White-faced Heron (*Egretta novaehollandiae*) and Intermediate Egret.

It is also likely that the eastern native water rat (*Hydromys chrysogaster*) occurs in TTL (SWC and WCC 1993).

There are scattered Grey Mangroves throughout TTL and J.J. Kelly Park, and a dense stand of Grey Mangroves at the southeast arm of the lagoon that would provide potential roosting habitat for a range of birds including kingfishers, ibis, spoonbills and honeyeaters.

The areas of reedland and Common Reed provide potential habitat for common amphibians such as Eastern Common Froglet and Striped Marsh Frog, both of which were recorded during the survey. TTL also provides potential foraging habitat for insectivorous species such as common microchiropteran bats, birds and reptiles. Several microbats were recorded at this site at dusk.

Call playback for Green and Golden Bell Frog and Red-Crowned Toadlet was undertaken at three locations within the estuarine reaches of TTL and J Kelly Park. Diurnal searches for the species were also undertaken. Whilst no threatened amphibians were recorded, potential habitat for Green and Golden Bell Frog is present at this site within the dense Broad-leaf Cumbungi and Common Reed stands. It should be noted that after extensive searching and call playback, no Green and Golden Bell Frog have been recorded at this site in previous studies. An honours thesis by Threlfall (2006) involved undertaking surveys for GGBF once a month during the daytime from September 2005 to February 2006, and on three occasions at night. No GGBF were found despite using call playback techniques.

No owl call playback was undertaken at this site due to the close proximity of the roads and amount of noise at the site. However, potential foraging habitat for Sooty Owl, Powerful Owl and Barking Owl is present at this site. There is a historical record of Little Shearwater (*Puffinus assimilis*) in the catchment, however it is considered that only limited potential habitat is available for this species at this site.

4.4 Results: Macroinvertebrate Surveys

A total of 1505 animals, representing 50 families, were collected from edge habitat, while 1575 animals, representing 44 families, were collected from pool rock habitat.

4.4.1 Habitat Assessment and Water Quality

A summary of the habitat assessment and water quality parameters recorded at each site is provided in Appendix D, together with the ANZECC (2000) trigger values for slightly disturbed ecosystems in south-east Australia. The water quality parameters detailed in Appendix D should be treated with caution, as water quality parameters can change rapidly over time and single readings cannot accurately represent the range of change though time that parameters may exhibit (for example temperature).

Generally, all sites had limited riparian vegetation and high levels of invasion by exotic species. All sites had 100 % riparian vegetation cover, however in more modified sites such as Collins Creek and Slacky Creek, riparian vegetation was dominated by groundcover consisting of introduced species and mown grasses. The creeks with the lowest levels of exotic species in the riparian vegetation were Flanagans

Creek and Bellambi Lagoon. All sites were located in residential areas, apart from Tom Thumb Lagoon, which was located in an industrial area. Site photographs are provided below.

Photo 1: Flanagans Creek

Photo 2: Slacky Creek

Photo 3: Whartons Creek

Photo 4: Collins Creek

Photo 5: Bellambi Gully

Photo 6: Bellambi Lagoon

Photo 7: Tom Thumb Lagoon

Temperature varied between all sites surveyed, however this is more likely a reflection of the time of day the sample was recorded. All sites recorded pH vales within the normal range of estuaries (ANZECC 2000).

Water with conductivity values < 1500 *u*S/cm are generally considered freshwater (ANZECC 2000). Bellambi Lagoon and Tom Thumb Lagoon were both brackish sites. However, as freshwater habitats upstream of Bellambi Lagoon and Tom Thumb Lagoon were limited to channelised stormwater drains, the macroinvertebrate samples were obtained from the brackish reaches of the estuaries.

All sites had turbidity values greater than ANZECC (2000) trigger values. This may be due to wind-induced resuspension or the input of turbid waters from the catchment.

An adequate supply of dissolved oxygen is essential for the survival of aquatic organisms. Collins Creek, Bellambi Lagoon and Tom Thumb Lagoon all had sites that recorded very low dissolved oxygen values (< 6 mg/L), below the ANZECC (2000) trigger values. This may be due to a number of reasons, such as lack of flow, algal blooms, eutrophication, high biological oxygen demand (BOD) and/or water temperature.

4.4.2 Macroinvertebrate Assemblages - Edge Habitat

Analysis of macroinvertebrate assemblages from edge habitat was undertaken using PRIMER V6. The data were analysed by non-metric multi-dimensional scaling (nMDS) and cluster analysis based on macroinvertebrate abundance, as presented in Figure 4.1 and Figure 4.2.

Overall the estuaries support two distinct macroinvertebrate assemblages. The macroinvertebrate assemblages at both sites on Whartons Creek, Flanagans Creek, Bellambi Lagoon and one site from Slacky Creek were relatively similar to each other indicating that they support assemblages with similar composition in terms of family abundance and diversity. Bellambi Gully and one site from Slacky Creek supported assemblages that are considered similar to each other. The remaining sites, one from Collins Creek and one from Tom Thumb Lagoon, were dissimilar to the other sites and to each other. A stress value of 0.09 indicates that the analysis provides an accurate representation of the data, and can be interpreted with confidence (Clarke and Warwick 2001).

Figure 4.1 nMDSplot, edge habitat

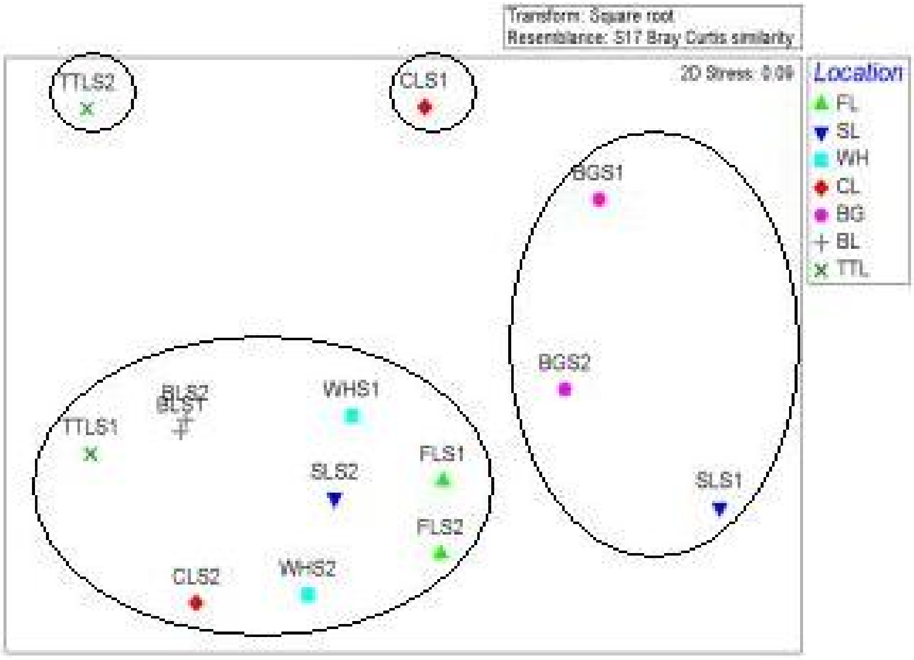
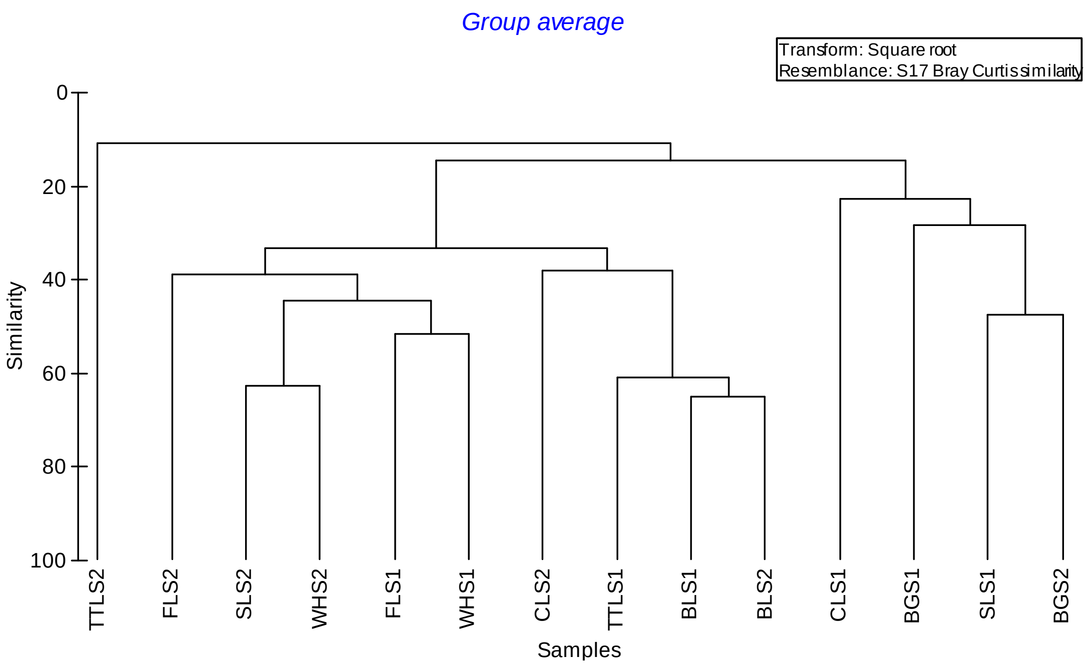


Figure 4.2 Cluster analysis, edge habitat



4.4.3 Macroinvertebrate Assemblages - Pool Rock Habitat

Primer V6 was also used to analyse macroinvertebrate assemblages from pool rock habitat. The nMDS and cluster analysis results for pool rock habitat, based on macroinvertebrate abundance, indicate that assemblages formed four groups of similar structure, as presented in Figure 4.3 and Figure 4.4.

The largest group of similar assemblages included both sites at Whartons Creek, Slacky Creek, Collins Creek and one site from Flanagans Creek. Another group included both sites from Bellambi Lagoon and Tom Thumb Lagoon, as would be expected given that these sites were both sampled in their brackish reaches, as freshwater sites were inaccessible. Both sites from Bellambi Gully formed the third group and one site from Flanagans Creek formed the fourth group of similar macroinvertebrate assemblages. A stress value of 0.05 indicates this analysis provides an accurate representation of the data, and can be interpreted with confidence (Clarke and Warwick 2001).

Figure 4.3 nMDS plot, pool rock habitat

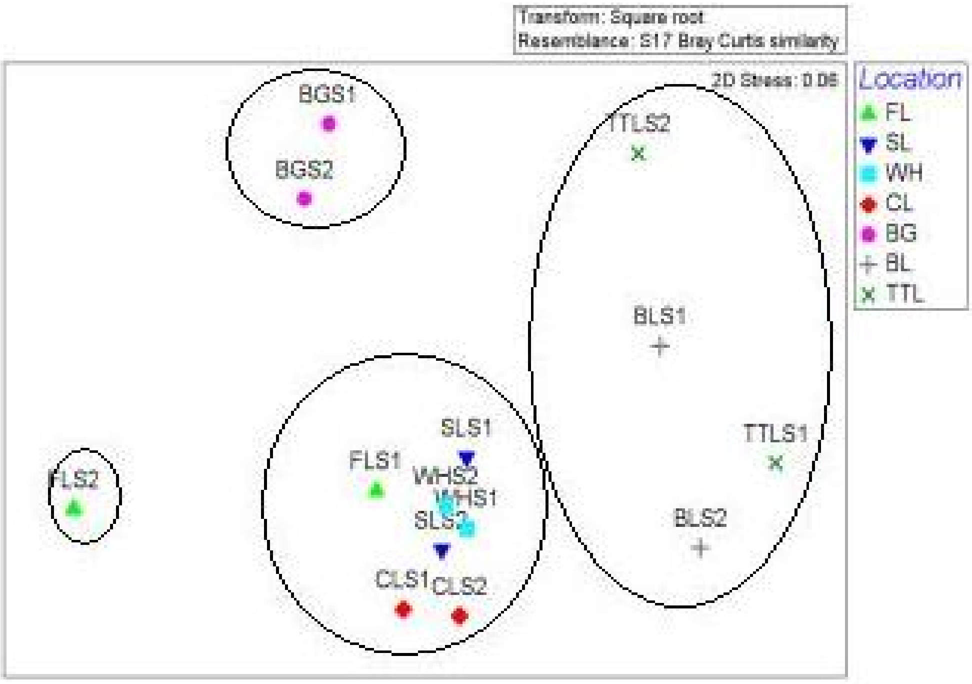
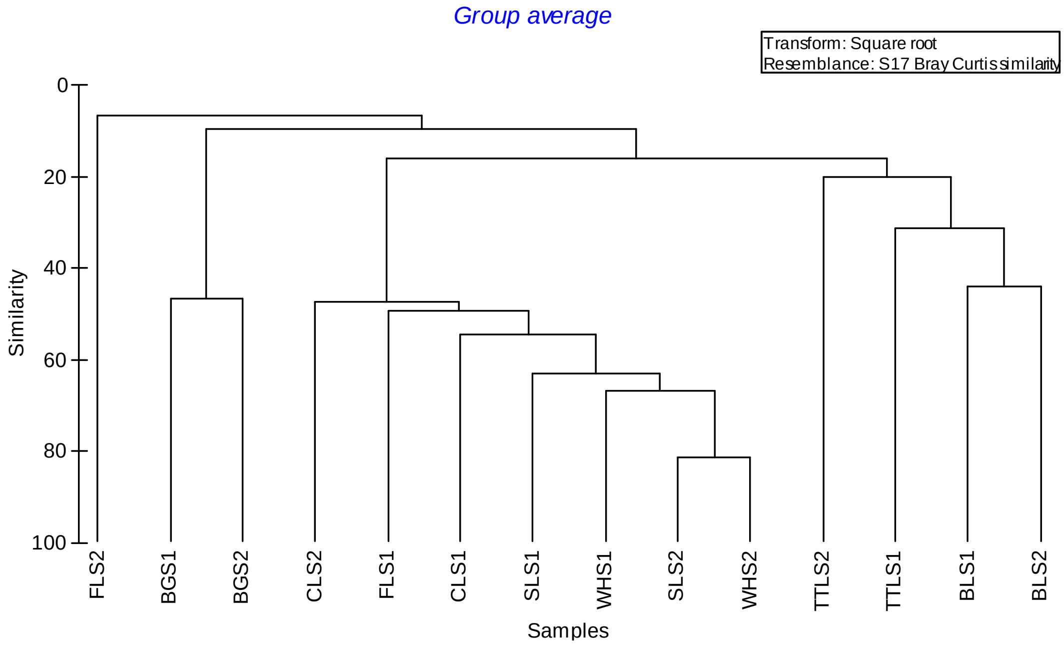


Figure 4.4 Cluster analysis, pool rock habitat



The analyses for both edge and pool rock habitat indicate that Flanagans Creek, Whartons Creek and Slacky Creek are most similar to each other, and that Bellambi Lagoon and Tom Thumb Lagoon are also very similar to each other but different to Flanagans Creek, Whartons Creek and Slacky Creek. Bellambi Gully appears to be quite dissimilar to all other creeks.

4.4.4 Family Diversity - Edge Habitat

Of the edge habitat samples, the highest diversity was recorded at Flanagans Creek. Whartons Creek, Collins Creek and Bellambi Gully had similar levels of family diversity, while Slacky Creek, Bellambi Lagoon and Tom Thumb Lagoon recorded the lowest family diversity, as detailed in Figure 4.5.

4.4.5 Family Diversity - Pool Rock

Of the pool rock habitat samples, the highest diversity was recorded at Flanagans Creek. Whartons Creek, Collins Creek and Bellambi Lagoon recorded similar levels of family diversity, while Slacky Creek, Bellambi Gully and Tom Thumb Lagoon recorded the lowest family diversity, as presented in

Figure 4.5 Mean (+/- SE, n = 2) family diversity, edge habitat

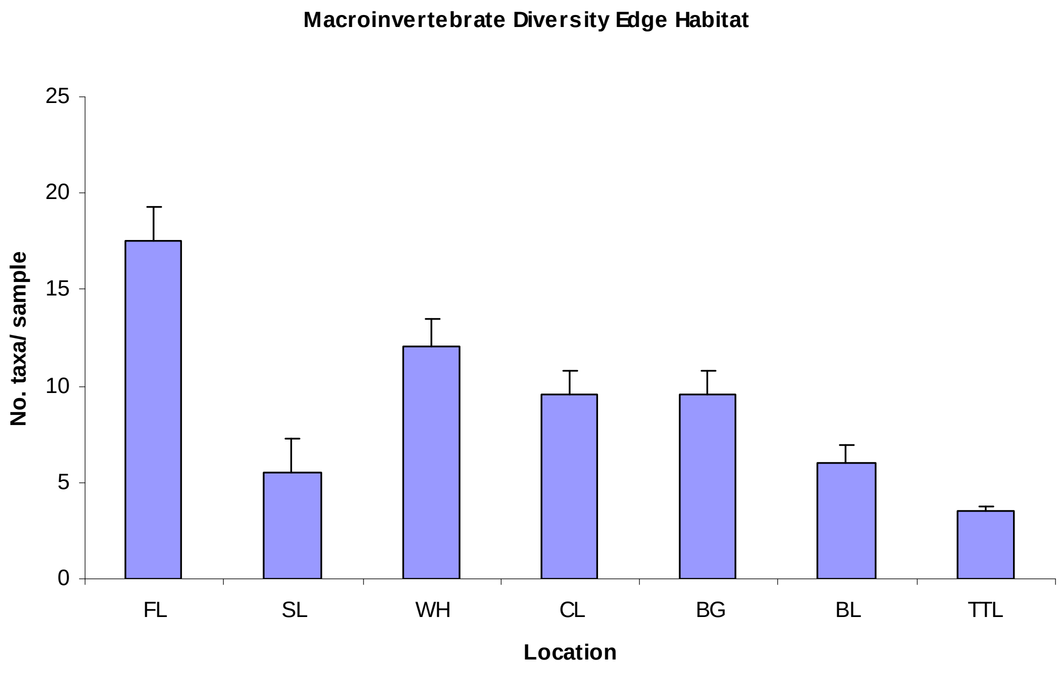
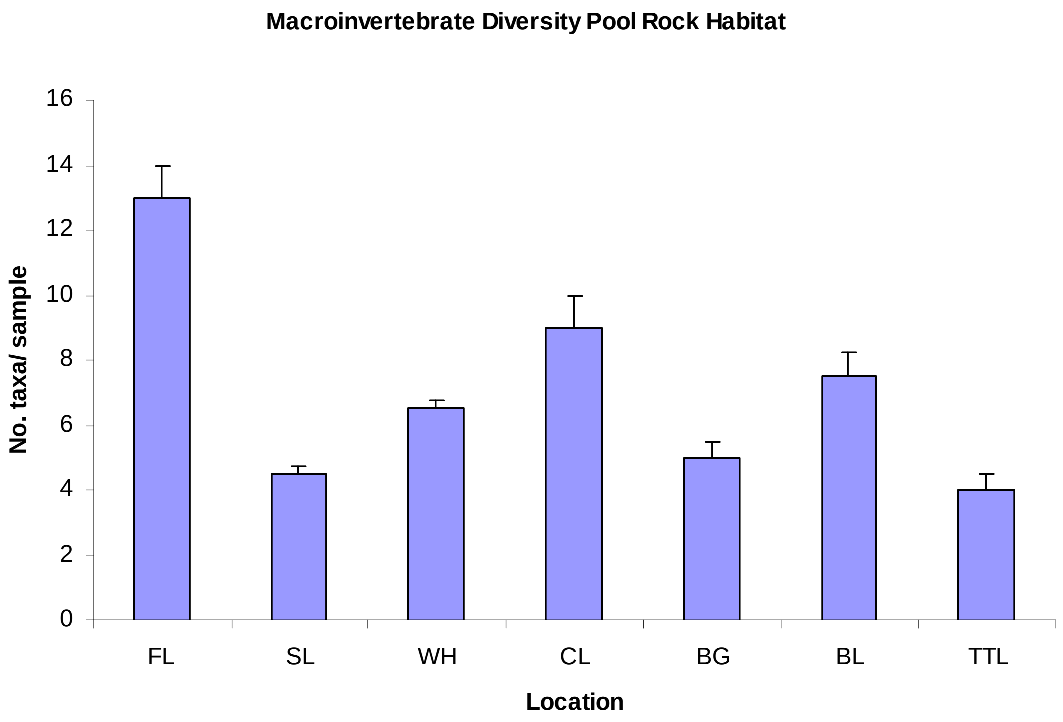


Figure 4.6 Mean (+/- SE, n = 2) family diversity, pool rock habitat



4.4.6 Flanagans Creek

Flanagans Creek had the highest diversity of all creeks sampled for both the edge habitat (18) and pool rock habitat (13). A high diversity of families were recorded in edge habitat including Gerridae, Hydrometridae, Veliidae, Hydrobiidae, Chironomidae, Leptoceridae, Atyidae, Calamoceratidae and Order Collembola. Two families of caddisflies (Trichoptera) were also recorded in the edge habitat. Many caddisfly larvae are sensitive to water quality, and for this reason a high diversity of caddisfly larvae are used to indicate good water quality and stream health (Gooderham and Tsyrlin 2002). One stonefly (Plecoptera) family was recorded in the edge habitat sample. Stoneflies are also very sensitive to water quality, and the number of families occurring in a waterway can be used as an important indicator of water quality and stream health (Gooderham and Tsyrlin 2002). One mayfly (Ephemeroptera) family was recorded in edge habitat. Most mayfly families require good water quality, although some families are more tolerant than others (Gooderham and Tsyrlin 2002).

A high diversity of families were recorded in pool rock habitat including Psephenidae, Glossiphoniidae, Helicophidae, Tasimiidae, Giripopterygidae, Hydrobiidae and Leptoceridae. Five families of caddisflies (Trichoptera) were recorded in pool rock habitat.

4.4.7 Slacky Creek

Slacky Creek had relatively low family diversity in both edge and pool rock habitat. Families recorded in edge habitat included Gerridae, Veliidae, Hydraenidae, Hydrobiidae and Chironomidae.

Families recorded in pool rock habitat included Simuliidae, Ecnomidae, Hydrobiidae and Chironomidae. One family of caddisfly (Trichoptera) was recorded in pool rock habitat.

The families present were both relatively low in diversity (six for edge habitat and four for pool rock habitat), and relatively pollution tolerant, indicating that water quality might be poorer than in Flanagans Creek.

4.4.8 Whartons Creek

Whartons Creek had higher family diversity in edge habitat than in pool rock habitat. Families recorded in the edge habitat included Simuliidae, Elmidae, Ceratopogonidae, Hydrobiidae and Chironomidae. One family of caddisfly (Trichoptera) and mayfly (Ephemeroptera) was recorded in edge habitat.

Families recorded in the pool rock habitat included Lymnaeidae, Hydrobiidae and Chironomidae and Order Collembola.

Although the diversity of families was slightly higher than observed in Slacky Creek, the lower overall diversity still indicates generally poor water quality and/or habitat.

4.4.9 Collins Creek

Collins Creek had similar family diversity in edge habitat and pool rock habitat. Families recorded in edge habitat included Glossiphoniidae, Corixidae, Chironomidae and Class Conchostraca. One family of caddisfly (Trichoptera) was recorded in edge habitat.

Families recorded in pool rock habitat included Paramelitidae, Petaluridae, Oniscidae, Hydrobiidae and Glossiphoniidae. One family of caddisfly (Trichoptera) was recorded in pool rock habitat.

Collins Creek had the second most diverse pool rock assemblage but this was still substantially poorer than observed at Flanagans Creek.

4.4.10 Bellambi Gully

Bellambi Gully had higher family diversity in edge habitat than in pool rock habitat. Families recorded in the edge habitat included Chironomidae, Stratiomyidae, Veliidae, Simuliidae and Dytiscidae. Two families of caddisflies (Trichoptera) were recorded in edge habitat.

Families recorded in the pool rock habitat included Simuliidae, Psephenidae, Ecnomidae, Tasimiidae and Chironomidae. Two families of caddisflies (Trichoptera) were recorded in pool rock habitat.

The diversity recorded was generally low and indicative of poor water quality and/or habitat.

4.4.11 Bellambi Lagoon

Bellambi Lagoon had higher family diversity in pool rock habitat than in edge habitat. Families recorded in the brackish edge habitat included Hydrobiidae, Sphaeromatidae and Class Conchostraca.

Families recorded in the brackish pool rock habitat included Hydrobiidae, Corixidae, Sphaeromatidae and Class Conchostraca.

Bellambi Lagoon had a generally low diversity, which may be attributable to sampling in brackish conditions or poor water quality and/or habitat.

4.4.12 Tom Thumb Lagoon

Tom Thumb Lagoon had relatively low family diversity in both edge and pool rock habitat. Families recorded in the brackish edge habitat sampled included Hydrobiidae, Talitridae, Chironomidae and Sphaeromatidae.

Families recorded in the brackish pool rock habitat included Hydrobiidae, Talitridae and Sphaeromatidae.

TTL had the lowest diversity of all estuaries for both edge and pool rock habitat. This was consistent with sampling in brackish conditions and may also be partly attributable to sewage overflows in the western arm and stormwater flows in the northern arm.

4.4.13 Comparison with AWT Survey

AWT Survey Results

Macroinvertebrate assemblages have been previously sampled by AWT (1999a) in Hargraves Creek, Stanwell Creek and Stoney Creek as part of the Priority Sewerage Program Environmental Impact Statement. A total of 90 taxa were identified in the AWT study, which were predominantly insects. Analysis of macroinvertebrate assemblages indicated that the fauna at township sites (i.e. sites exposed to sewage outflows) differed from reference sites (AWT 1999a). Some fauna typically associated with poor water quality and polluted environments were commonly recorded at township sites, for example the introduced snails *Physa acuta* and *Potamopyrgus antipodarum* (Family Hydrobiidae) (AWT 1999a). These species typically occur in waterways with high nutrient levels, as they primarily feed on the associated biofilms such as algal growth attached to the stream substrate (AWT 1999a). However, some pollution sensitive taxa, for example Leptophlebiid mayflies, were recorded from north township and reference sites (AWT 1999a).

Family Richness

Figure 4.7 presents the edge habitat family richness data recorded for Hargraves Creek, Stanwell Creek and Stoney Creek by AWT (1999a), as well as the edge habitat family richness data for Flanagans Creek, Slacky Creek, Whartons Creek, Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon collected in this study to allow comparisons between family richness across the ten creeks. Note that AWT (1999a) surveyed in both autumn and spring in 1998, and both the autumn and spring data are displayed for Hargraves Creek, Stanwell Creek and Stoney Creek. It should also be noted that the data for Hargraves, Stanwell and Stony Creeks (AWT 1999a) are eight years old may or may not be reflective of the conditions and diversity at the present time.

Flanagans Creek has the highest family diversity of all ten creeks. Hargraves Creek, Stanwell Creek and Stoney Creek had similar levels of diversity as Whartons Creek, Collins Creek and Bellambi Gully. Slacky Creek, Bellambi Lagoon and Tom Thumb Lagoon have the lowest family diversity.

Figure 4.8 presents the pool rock habitat family richness data recorded for Hargraves Creek, Stanwell Creek and Stoney Creek by AWT (1999a), as well as the pool rock habitat family richness data collected at Flanagans Creek, Slacky Creek, Whartons Creek, Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon in this study to enable comparisons between family richness across the ten creeks. Flanagans Creek has the highest family diversity of all ten creeks. Whartons Creek, Collins Creek and Bellambi Lagoon have similar family diversity, greater than Hargraves Creek, Stanwell Creek and Stoney Creek. Hargraves Creek, Stanwell Creek and Stoney Creek have the lowest levels of diversity, similar to Slacky Creek, Bellambi Gully and Tom Thumb Lagoon.

Figure 4.7 Total (n = 2) family diversity, edge habitat

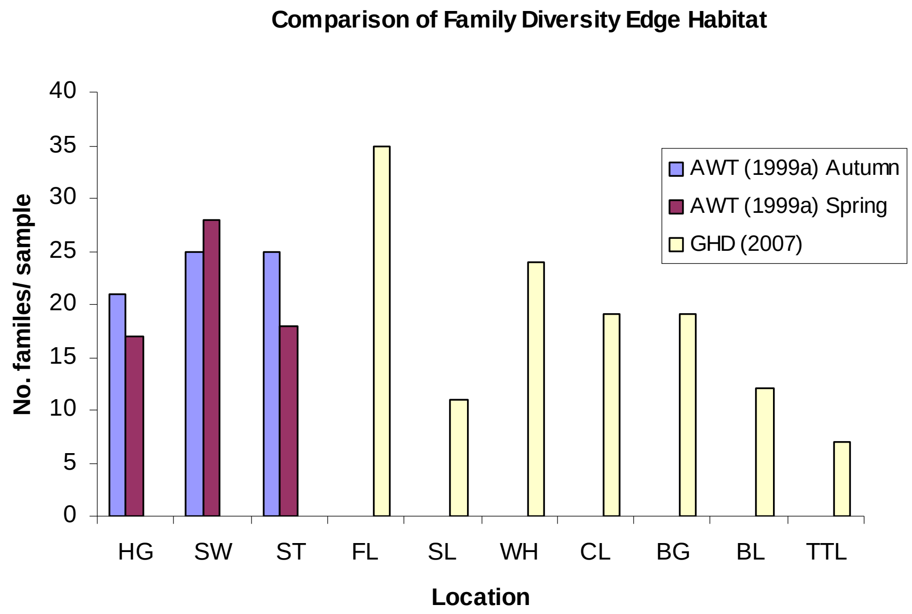
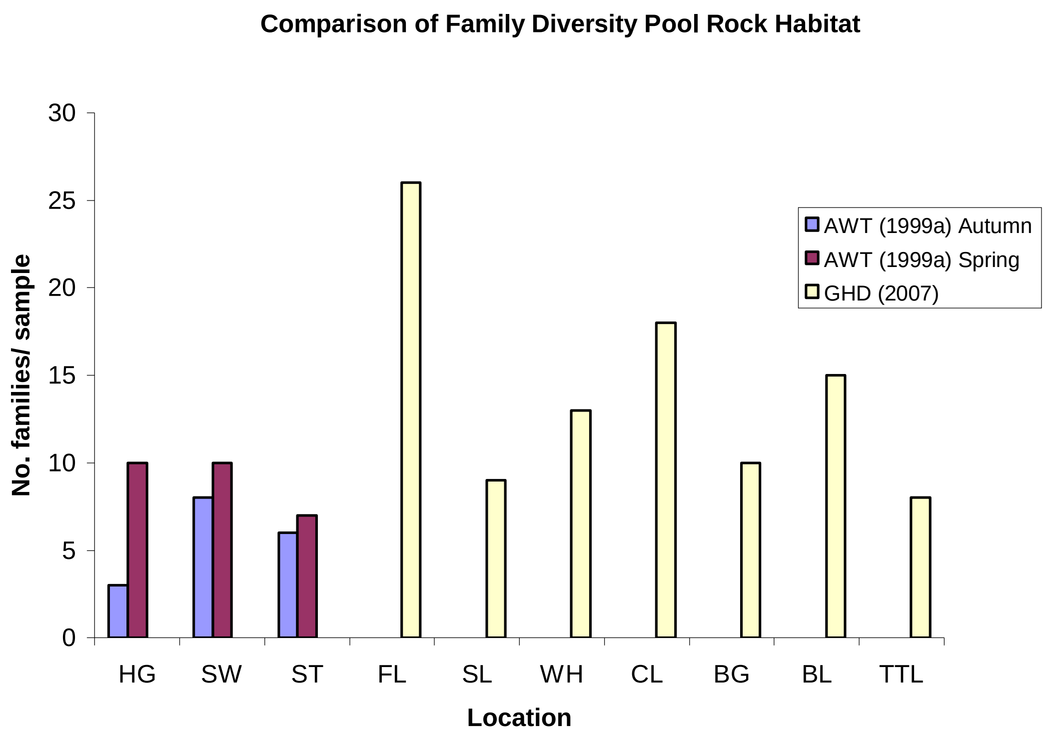


Figure 4.8 Total (n = 2) family diversity, pool rock habitat



EPT Richness

Ephemeroptera, Plecoptera and Tricoptera (EPT) families are freshwater macrovinertebrates that are sensitive to various forms of pollution, including heavy metals and organic loading (BOD), and can therefore be used as indicators of water quality and river health. In the absence of any other factor (such as the availability or otherwise of suitable habitat), the proportion of EPT families in a macrovinvertebrate sample is generally indicative of water quality, with a high proportion indicating better water quality. As EPT families are absent from estuarine waters this score is not applicable to the samples collected from Bellambi Lagoon and Tom Thumb Lagoon.

Table 4.5 compares edge habitat EPT richness data recorded for Hargraves Creek, Stanwell Creek and Stoney Creek by AWT (1999a), with the edge habitat EPT richness data recorded at Flanagans Creek, Slacky Creek, Whartons Creek, Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon by GHD. Data for Hargraves Creek, Stanwell Creek and Stoney Creek were obtained from AWT (1999a). The autumn data from AWT (1999a) were used rather than the spring data, as GHD surveyed in autumn.

In edge habitat, Hargraves Creek, Stanwell Creek and Stoney Creek have EPT richness percentages much greater than the creeks surveyed by GHD. Flanagans Creek and Bellambi Gully recorded the highest EPT family diversity in the current study, however this was still lower than the EPT family diversity recorded at Hargraves Creek, Stanwell Creek and Stoney Creek by AWT (1999a).

In pool rock habitat, Hargraves Creek, Stanwell Creek and Stoney Creek again have EPT richness percentages much greater than the creeks surveyed by GHD. Flanagans Creek and Bellambi Gully recorded the highest EPT family diversity in this survey by GHD, however this was still lower than the EPT family diversity recorded at Hargraves Creek, Stanwell Creek and Stoney Creek by AWT (1999a).

Table 4.5 EPT Families

Location	Edge Habitat			Pool Rock Habitat		
	Total Families	Total EPT Families	EPT	Total Families	Total EPT Families	EPT
Hargraves Creek	21	5	24%	3	1	33%
Stanwell Creek	21	8	38%	8	3	38%
Stoney Creek	25	7	28%	6	2	33%
Flanagans Creek	35	4	11%	26	5	20%
Slacky Creek	11	0	0%	9	1	11%
Whartons Creek	24	2	8%	13	0	0%
Collins Creek	19	1	5%	18	1	6%
Bellambi Gully	19	2	10%	10	2	20%
Bellambi Lagoon	12	0	N/A	15	0	N/A
Tom Thumb Lagoon	7	0	N/A	8	0	N/A

4.4.14 SIGNAL 2 Score

SIGNAL 2 scores provide an indication of factors potentially affecting freshwater macroinvertebrates at a site, such as water quality or habitat (DEW 2004). Table 4.6 provides a broad guide for interpreting the health of a site according to it's SIGNAL 2 score. The Signal 2 results for Bellambi Lagoon and Tom Thumb Lagoon should be treated with caution as the samples were collected from the estuarine reaches rather than from the freshwater reaches (which consisted of a concrete channel devoid of any habitat).

Table 4.6 Guide to Interpreting SIGNAL 2 Scores

SIGNAL 2 Score	Habitat Quality
Greater than 6	Healthy habitat
Between 5 and 6	Mild pollution
Between 4 and 5	Moderate pollution
Less than 4	Severe pollution

(Source: Gooderum and Tsyrlin 2002)

Figure 4.9 and Figure 4.10 compare SIGNAL 2 scores recorded for Hargraves Creek, Stanwell Creek and Stoney Creek by AWT (1999a) with the SIGNAL 2 scores recorded at Flanagans Creek, Slacky Creek, Whartons Creek, Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon by GHD. The autumn data from AWT (1999a) were used rather than the spring data, as GHD surveyed in autumn.

In edge habitat, the SIGNAL 2 score for all creeks surveyed by GHD indicated severe pollution. The SIGNAL 2 score indicated healthy habitat for Hargraves Creek, indicated mild pollution for Stanwell Creek, and indicated moderate pollution for Stoney Creek.

In pool rock habitat the majority of SIGNAL 2 score for all creeks surveyed by GHD indicated severe pollution apart from Flanagans Creek, which indicated mild pollution, and Bellambi Gully, which indicated moderate pollution. The SIGNAL 2 score indicated severe pollution for Hargraves Creek, indicated healthy habitat for Stanwell Creek and indicated moderate pollution for Stoney Creek.

Figure 4.9 Signal 2 Scores, edge habitat

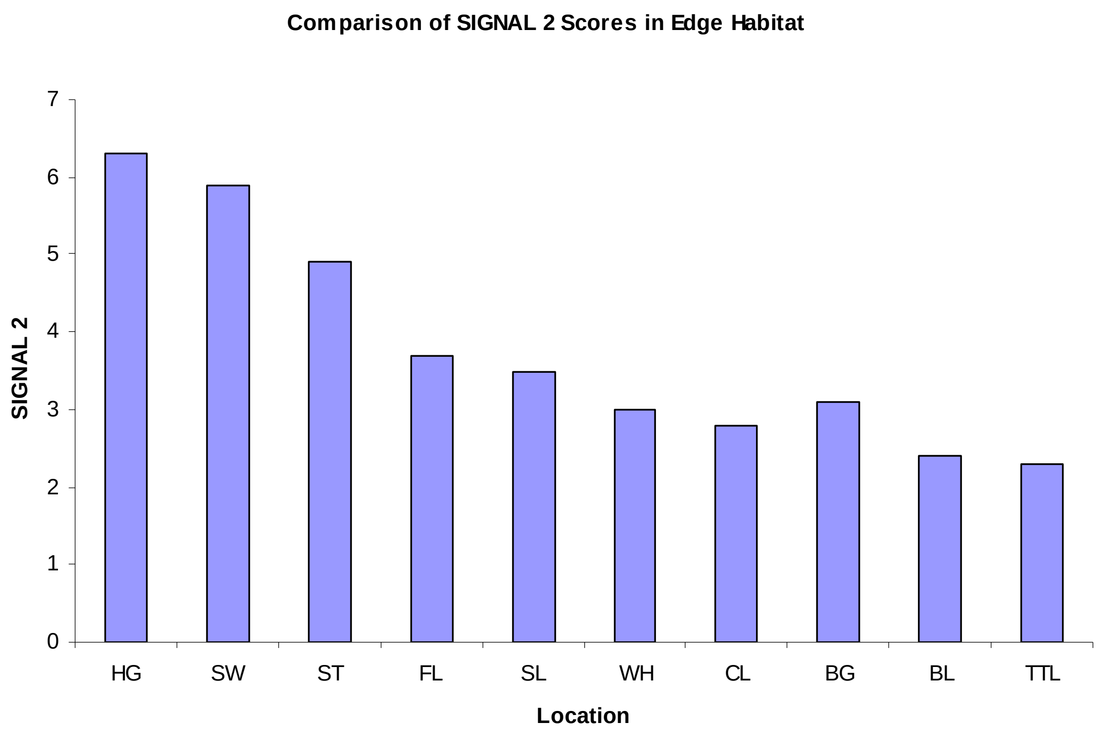
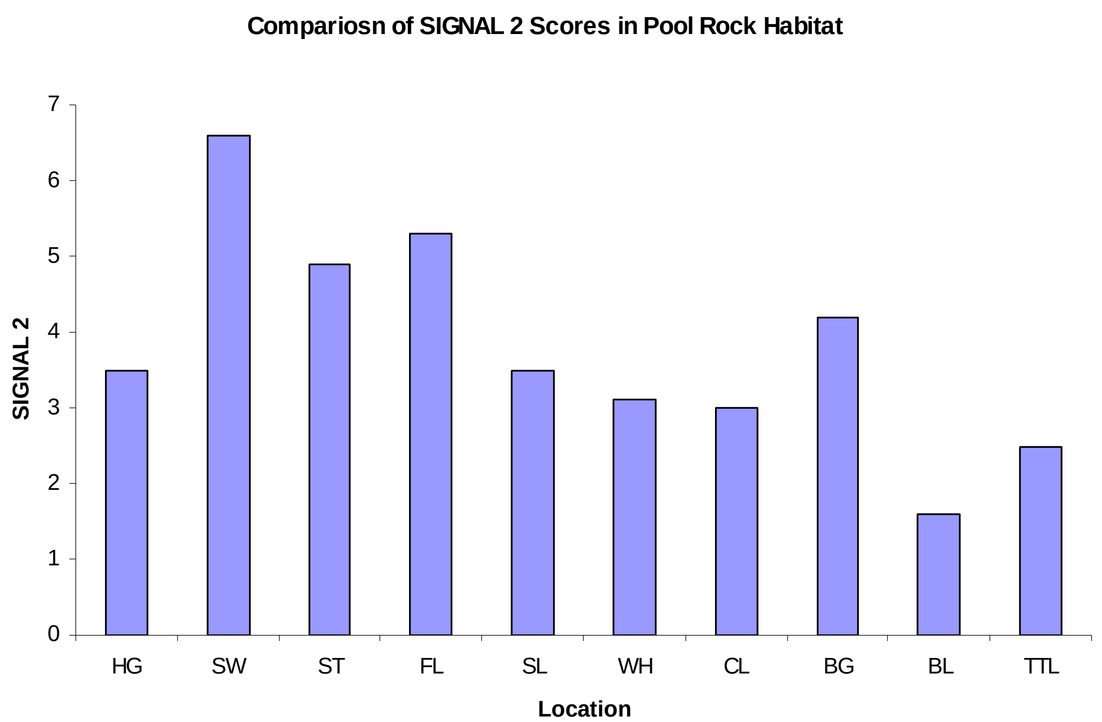


Figure 4.10 Signal 2 Scores, pool rock habitat



4.4.15 Discussion of Macroinvertebrate Restults

The water quality data recorded by GHD during the fish survey at Flanagans, Whartons and Collins Creeks and Tom Thumb Lagoon, presented in Section 5 (refer Tables 5.4–5.7), plus the water quality data collected by WCC and presented in Section 3, provide an indication of the likely water quality experienced in each estuary. However, the data should be treated with caution as water quality parameters can exhibit variability through time, and isolated readings cannot accurately represent the range that parameters may exhibit (for example temperature). More detailed water quality assessments would be required to assess water quality within the catchments through time. Once this data is available, an assessment could be made on the impacts water quality may be having on the diversity of macroinvertebrate assemblages in the catchments.

It should be noted when comparing macroinvertebrate family richness, % EPT families and SIGNAL 2 scores of the data recorded by AWT (1999a) with the data collected in this study that eight years has passed since the AWT (1999a) survey, and the data collected by AWT may or may not be reflective of the conditions and diversity at Hargraves, Stanwell and Stony Creeks at the present time. The comparison between all ten creeks should therefore be treated with caution and with the knowledge that the data for Hargraves, Stanwell and Stony Creeks are eight years old.

Some water quality sensitive families (EPT families) were recorded by GHD, particularly in Flanagans Creek and Bellambi Gully. However, the percent EPT families were low (between 10% and 20%, much lower than the percent EPT families (30-40%) recorded by AWT (1999a)), and as noted by Gooderham and Tsyrlin (2002), some EPT families are relatively tolerant to adverse water quality, and the mere presence of EPT families does not indicate high water quality. A high diversity of EPT families is an indication of good water quality and creek health (Gooderham and Tsyrlin 2002). No creeks surveyed by GHD had a diversity or EPT % indicative of good water quality and creek health.

The SIGNAL 2 scores calculated from this study indicate severe pollution within edge habitats of all the creeks surveyed by GHD, and severe pollution in pool rock habitat in all creeks surveyed by GHD with the exception of Flanagans Creek and Bellambi Gully. This result may be due to high levels of urban development within the catchments, poor water quality or loss of riparian vegetation. The habitat assessment undertaken by GHD indicated that all macroinvertebrate sampling sites had highly modified riparian zones and high levels of weed invasion. This is likely to be influencing the diversity of macroinvertebrate assemblages.

The SIGNAL 2 scores calculated by AWT (1999a) differed between habitats in the same (autumn) sampling event, in some cases varying between severe pollution and healthy habitat at the same site. This emphasises the need for higher replication of samples than undertaken in these studies, to gain a better understanding of the patterns of diversity. A higher number of samples taken at each site and habitat would give a more accurate representation of family richness and macroinvertebrate assemblages.

A strong seasonal influence was detected in macroinvertebrate assemblages by AWT (1999a), with differences recorded between autumn and spring samples for family diversity, EPT richness and SIGNAL 2 scores. The data collected in this survey may therefore not be representative of macroinvertebrate diversity through time. It is recommended that future sampling designs aim to incorporate an estimate of natural variability in macroinvertebrates through time by stratifying sampling to include multiple samples throughout the seasons and year.

Information gathered during this macroinvertebrate survey indicates that Flanagans Creek, Slacky Creek, Whartons Creek, Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon have been impacted to a high degree by anthropogenic pressures within the catchments. It is recommended that:

» riparian revegetation and weed control be undertaken within the catchments of the creeks to improve habitat quality;

» long-term water quality monitoring be undertaken in the catchments to examine long-term trends in water quality and assess possible impacts that water quality may be having on aquatic fauna;

» macroinvertebrate sampling at the creeks be repeated in the future to assess trends in creek health though time; and

» water quality in the catchments is improved through measures to improve stormwater management, reduce sewage overflows and more closely monitor and restrict trade waste discharges.

4.5 Conclusions and Recommendations

4.5.1 Significance

Several areas of ecological significance occur in the estuaries surveyed, including:

» Areas of Coastal Saltmarsh EEC recorded at Hargraves Creek, Stanwell Creek, Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon;

» Areas of Swamp Oak Floodplain EEC recorded at Stanwell Creek, Bellambi Lagoon and Tom Thumb Lagoon;

» An area of Bangalay Sand Forest EEC recorded at Bellambi Lagoon;

» Mangroves recorded at Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon;

» Seagrasses recorded at Bellambi Lagoon;

» Estuarine areas of potential habitat for the threatened Green and Golden Bell Frog at Hargraves Creek, Stanwell Park, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon;

» Estuarine areas of potential habitat for the threatened Sooty Oystercatcher at Stanwell Creek;

» Estuarine areas of potential habitat for the threatened Swift Parrot at Bellambi Lagoon;

» Estuarine areas of potential habitat for the threatened Australasian Bittern and Black Bittern at Bellambi Gully;

» The Swamp Oak Forest and Bangalay Sand Forest at Bellambi Lagoon that contains hollow-bearing trees, providing potential nesting habitat for birds, bats and mammals;

» The Bangalay Sand Forest (which includes flowering eucalypts) that would provide potential foraging habitat for a variety of birds, bats and mammals;

» The Swamp Oak Forest at Stanwell Creek, Bellambi Lagoon and Tom Thumb Lagoon that would provide potential foraging habitat for a variety of birds and mammals;

» Potential foraging habitat for a range of owls and birds of prey was identified within the catchments of all estuaries surveyed; and

» Lagoons with dense riparian vegetation that would provide important fauna foraging habitat for a range of amphibians, bats, reptiles and birds at Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon.

Additionally, a macroinvertebrate family list was developed for all estuaries (apart from Hargraves Creek, Stanwell Creek and Stoney Creek). This family list can serve a baseline data set for the estuaries, and enable future comparisons. The diversity of water-quality sensitive families recorded at Flanagans Creek indicates generally moderate to good water quality and stream health at this site. Merrin and Chafer (2000) also noted that water quality in Flanagans Creek was good as there has been little urban development along the creek line.

4.5.2 Conservation

Conservation efforts should initially be focused on the larger areas of EECs at Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon, areas of seagrass and mangroves, and areas of higher fauna habitat value recorded in this survey. Conservation efforts could include research and monitoring of EECs, investigation into the effect of anthropogenic impacts, and monitoring and management of sites for invasion of exotic species.

4.5.3 Revegetation and Weed Control

Revegetation

Riparian vegetation provides a diversity of refuge and foraging habitat for terrestrial, riparian and aquatic species. Hargraves Creek, Collins Creek, Bellambi Lagoon and Tom Thumb Lagoon have had riparian vegetation replanted, which has improved fauna habitat values for these sites. Revegetation programs to increase the riparian corridor at Stanwell Creek, Stoney Creek, Flanagans Creek, Slacky Creek and Whartons Creek would improve fauna habitat values at these sites, and provide a buffer against further erosion. It is recommended that native, endemic species suitable for estuarine lagoons be used in the revegetation, similar to those species used at Collins Creek.

Weed Control

Table 4.7 identifies the declared noxious weeds recorded in this survey and details the requirements for controlling these species prescribed under the Illawarra District Noxious Weeds Authority (IDNW) Management Plans.

Table 4.7 Noxious Weeds Recorded and Control Policies

Scientific Name	Common Name	NW Act 1993 Class Description	Illawarra District Noxious Weeds Authority (IDNW) Management Plans	Estuary with this weed
Asparagus aethiopicus	Asparagus 'Fern'	5 - The requirements in the Noxious Weeds Act for a notifiable weed must be complied with.	All Class 5 weeds will be inspected for as part of the annual nursery and aquaria inspection program to ensure they are not being sold or distributed. If found being sold plants are to be immediately withdrawn from sale. Where infestations of Class 5 weeds on private/public land are reported to the IDNWA the location of the infestation is to be recorded and where agreement is reached control undertaken by the owner/occupier of the infested land.	HG, SW, ST, SL, CL, BL
Baccharis halimifolia	Groundsel Bush	3 - The plant must be fully and continuously suppressed and destroyed.	All Class 3 weeds on Public Land and Vacant Crown Land will be fully and continuously suppressed and destroyed.	FL, SL, WH, CL, TTL
Chrysanthemoides monilifera subsp. rotundata	Bitou Bush	4 - The growth and spread of the plant must be controlled according to the measures specified in a management plan published by the local control authority.	The growth and spread of all Bitou Bush plants on private lands and all light and medium infestations on public lands must be fully controlled by undertaking any one, or any combination, of the use of herbicides or physical/manual control. These control measures must be implemented on an annual basis until all plants are destroyed. Heavy infestations on public land must be contained, prevented from spreading, have appropriate biological controls applied and be gradually reduced in density and distribution over the life of this plant. Note that biological control agents used in isolation will not achieve this level of control.	CL, BG, BL, TTL
Opuntia stricta	Prickly Pear	4* - The growth and spread of the plant must be controlled according to the measures specified in a management plan	The growth and spread of all Prickly Pears must be fully controlled by undertaking any one, or any combination, of the following control measures, including use of herbicides and	WH

Scientific Name	Common Name	NW Act 1993 Class Description	Illawarra District Noxious Weeds Authority (IDNW) Management Plans	Estuary with this weed
		published by the local control authority and the plant may not be sold, propagated or knowingly distributed.	biological control. These control measures must be implemented on an annual basis until all plants are destroyed.	
Cortaderia selloana	Pampas Grass	4 - The growth and spread of the plant must be controlled according to the measures specified in a management plan published by the local control authority.	All council lands infested with this weed are to be controlled annually with specific programs undertaken in September each year. Infested private properties are to be inspected annually initially until infestation levels are reduced to a manageable level, and then inspected every second year until fully controlled or eradicated.	BG, BL
Rubus fruticosus	Blackberry	4 - The growth and spread of the plant must be controlled according to the measures specified in a management plan published by the local control authority and the plant may not be sold, propagated or knowingly distributed.	High level action plans will be implemented throughout the district on an annual basis. Operational programs will complement inspectorial programs so that all roads and reserves within inspectorial areas are treated. Particular emphasis will be afforded to inspecting areas where Blackberry is of limited distribution and agricultural productivity is at greatest risk. Nurseries will be inspected annually to prevent the sale of any weedy Blackberry.	SW, ST, BG, BL
Lantana camara	Lantana	4-5 - The requirements in the Noxious Weeds Act for a notifiable weed must be complied with.	All ornamental varieties of Lantana (*Lantana camara*) are required to be fully controlled on both private & public lands. Lantana camara will be required to be fully controlled only in those localities identified in Schedule 1 of the Weed Control Class 4 Lantana Management Plan. A systematic approach to control will be implemented such that planning and enforcement will be undertaken in a south to north direction. All urban areas throughout Wollongong will be inspected each autumn as time and resources permit. Nurseries will be inspected annually to	All

Scientific Name	Common Name	NW Act 1993 Class Description	Illawarra District Noxious Weeds Authority (IDNW) Management Plans	Estuary with this weed
			prevent sale of ornamental varieties of Lantana. Lantana is declared a Class 5 notifiable noxious weed throughout the Whole of the State of NSW and as consequence must not be sold, propagated or knowingly distributed.	

4.5.4 Potential Threats

Potential threats to the flora and fauna values of the lagoons include:

- Decline and/or weed invasion of riparian vegetation;
- Decline and/or weed invasion in areas of EEC;
- Loss of fauna and riparian habitat through urban development;
- Inappropriate levels of, or impacts from, recreational use (i.e. Bellambi Lagoon dunes);
- Introduced fauna preying on native fauna;
- Urban runoff containing high levels of nutrients that may have an impact on algae blooms within the estuaries;
- Industrial and/or contaminated runoff entering Tom Thumb Lagoon; and
- Impacts on water quality from sewage, industrial and residential sources.

4.5.5 Recommendations

The following actions are recommended in order to maintain and/or improve the value of the estuaries:

- Revegetation of riparian areas at Stanwell Creek, Stoney Creek, Flanagans Creek, Slacky Creek and Whartons Creek to increase the width/depth and length of the riparian corridor. It is recommended that native, endemic species suitable for estuarine lagoons be used in the revegetation, similar to those species used at Collins Creek;
- Monitoring for decline, and/or invasion by exotic species, of the large areas of Coastal Saltmarsh EEC (Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon), Swamp Oak Forest EEC (Bellambi Lagoon and Tom Thumb Lagoon) and Sand Bangalay Forest EEC (Tom Thumb Lagoon), similar to the current WCC program at Tom Thumb Lagoon;
- Active monitoring and management of exotic species at all estuaries surveyed;
- Investigation into nutrient inputs and cycling within the catchments of the lagoons surveyed, and the role nutrients have in generating algal blooms within the estuaries. This would be particularly important for Bellambi Gully as algae blooms appear to be threatening the seagrass beds in this estuary;

- Further macroinvertebreate surveys to monitor long-term creek health, with sampling undertaken throughout different seasons though the year; and
- Investigation into the possible contamination of Tom Thumb Lagoon from the adjacent decommissioned landfill site.

5. Processes Studies – Fish Communities

5.1 Material and Methods

5.1.1 Field sampling

Field sampling was conducted at Flanagans Creek, Whartons Creek, Collins Creek, and Tom Thumb Lagoon between 12 and 16 March 2007, as detailed in Table 5.1. A one-day sampling effort was allocated to each waterway. Sampling involved a combination of active and passive sampling methods. Fishing was carried out under the conditions set by GHD's NSW Fisheries Scientific permit (P06/0110-1.0). All fish were identified to species, weighed and measured before being returned to water.

Table 5.1 Sampling events

Site	Date Sampled	Estuarine Lagoon Area
Flanagans Creek	12-3-2007	1.1 ha
Whartons Creek	14-3-2007	0.1 ha
Collins Creek	15-3-2007	0.5 ha
Tom Thumb Lagoon	13-3-2007	7.7 ha

5.2 Weather Data (Australian Bureau of Meteorology)

On the Sunday prior to, and the Monday and Tuesday during the sampling period, very heavy rainfalls occurred in the Wollongong area. A total of 48.9 mm of rain fell over the three-day period, as detailed in Table 5.2.

Table 5.2 Field Survey Weather Data

Date	Day	Temperature		Rainfall mm
		Min°C	Max°C	
11-3-07	Sunday	20.2	25.5	11.8
12-3-07	Monday	19.2	21.8	32.7
13-3-07	Tuesday	17.0	23.6	4.4
14-3-07	Wednesday	15.3	25.0	0.0
15-3-07	Thursday	15.7	25.9	0.0
16-3-07	Friday	17.9	26.7	0.0
17-3-07	Saturday	17.8	27.3	0.0

5.3 Water Quality and Habitat Assessment

In addition to fish sampling, aquatic habitat assessment and water quality analyses were conducted at each site. Habitat values such as algal cover, mangrove cover, seagrass cover, open sand habitat, emergent and overhanging vegetation, logs and other woody debris, substrate and depth, were recorded at each sampling location.

In situ water quality parameters including temperature (ºC), conductivity (µS/cm), turbidity (NTU) and pH were measured using a TPS 90FL-T water quality meter.

5.4 Active Sampling Methods

A seine net (5m x 2m, 2 mm stretched mesh) was hauled at each site to sample small mid-water and benthic fish species. The net was weighted at the bottom and had a series of floats along the headrope. Each seine trawl was standardised to approximately 10m. After each trawl the ends were carefully brought together and the contents of the seine were emptied into a large aerated tank where fish were held for processing. Multiple replicates from each site were sampled to target different habitats. Such habitats included:

- Stands of emergent and submerged vegetation (requiring great care during retrieval to prevent fish escaping);
- Areas adjacent to snags, woody debris and structure;
- Areas underneath overhanging vegetation;
- Open water;
- Seagrass beds; and
- Mangroves.

5.5 Passive sampling Methods

The passive sampling effort was standardised at 336 net hours per site.

5.5.1 Fyke Nets

Two large-mesh single wing fyke nets, two small-mesh single wing fyke nets and two dual wing fyke nets were deployed at each site and left set overnight for a 12 hour period to sample the diversity of structural habitat available to fish (i.e. open water, amongst or against vegetation and woody material).

Large-mesh fyke nets have a central wing (8 m x 0.65 m) attached to the first supporting hoop (diameter = 0.65 m) with a stretched mesh size of 20 mm.

Small-mesh fyke nets have a central wing (8 m x 0.65 m) attached to the first supporting hoop (diameter = 0.65 m) with a stretched mesh size of 0.8 mm

Dual-wing fyke nets have two wings (each 2.5 m x 1.2 m), with a first supporting hoop (diameter = 0.65 m) fitted with a stretched mesh size of 20 mm.

5.5.2 Bait Traps

Fifteen bait traps were baited, deployed and left set over night.

Bait traps have a funnelled opening at each end (0.22m x 0.22m x 0.4m, with 2 mm stretched mesh) and were set close to emergent vegetation, submerged macrophytes and woody debris to sample fish normally associated with such structures.

5.5.3 Gill Nets

A series of gill nets made of nylon monofilament were used to provide a wall of diamond-shaped mesh that entangles fish around the head or body. The nets used during this survey consisted of four mesh sizes (19 mm, 40 mm, 63 mm, 80 mm stretched mesh size) with a 25 m length of hung net for each net. The nets were arranged in varying sequence to maximise catch and avoid biases.

Each net was 25 x 2 m and was weighted at the base so they could be set in flowing water. Fish commonly caught in gill nets include highly mobile species, fish with spines and benthic fish. Gill nets are most efficient at sampling large to medium-sized fish, in deep and/or turbid water.

5.6 Analysis

5.6.1 Multivariate

To examine the similarities of the fish communities throughout the estuaries sampled, multivariate analyses using PRIMER version 5.0 was undertaken. Similarity matrices were created using the Bray-Curtis similarity index for abundance data. Data were fourth root transformed to equalise the contribution of rare and common taxa. In order to view the similarity relationships, hierarchal clustering with group average linking was used.

5.6.2 Univariate

Total species, total abundance, proportion of total native species and proportion of total native abundance were calculated for each estuary. The average was calculated in order to provide a benchmark of the current fish communities. Proportions of total catch were also calculated for each species.

5.6.3 Length Histograms

Total length histograms were used to investigate the size classes of different species held in each estuary.

5.7 Previous Studies

A previous study, conducted by the Centre for Estuarine and Coastal Catchment Studies (CECCS) in 1998, identified a total of 18 species from Slacky Creek, Stanwell Creek, Bellambi Lagoon, Bellambi Creek and Stoney Creek as detailed in Table 5.3 . Belllambi lagoon was the most diverse system studied with 11 species.

Table 5.3 Fish species surveyed by CECCS (1998)

Common Name	Scientific Name	Stanwell Creek	Stoney Creek	Slacky Creek	Bellambi Creek	Bellambi Lagoon
Dwarf Flat-head Gudgeon	*Philypnodon sp.*	X				X
Flathead Gudgeon	*Philypnodon grandiceps*	X		X	X	X
Longfinned Eel	*Anguilla reinhardtii*	X	X		X	
Sand Mullet	*Myxus elongatus*	X		X	X	X
Sea Mullet	*Mugil cephalus*	X		X	X	X
Mosquito Fish	*Gambusia hobrooki*				X	X
Common Jollytail	*Galaxias maculatus*		X		X	
Sand Whiting	*Sillago ciliata*		X		X	
Eastern Fortescue	*Centropogon australis*	X				X
Smooth Toadfish	*Tetractenos glaber*	X			X	
Tarwhine	*Rhabdosargus sarba*	X				
Smallmouth Hardyhead	*Atherisoma microstoma*				X	X
Tamar River Goby	*Afurcagobius tamerensis*				X	X
Firetail Gudgeon	*Hypseleotris gallii*					X
Ogilbys Hardyhead	*Antherinosoma ogilbyi*					X
Sandy Sprat	*Hyperlophus vittatus*					X

5.8 Study Sites

5.8.1 Flanagans Creek

Flanagans Creek is a coastal creek with a catchment of 266 ha. The Flanagans Creek lagoon covers approximately 1.1 ha and opens to Thirroul Beach. At the time of the survey Flanagans Creek was open to the ocean, with tidal seawater running into the lagoon during high tide. During low tide, fresh stormwater flushed through the lagoon. There was heavy rain prior to sampling with 32.7 mm falling in a short period of time.

Flanagans Creek Site 1 (56309412 E, 6201012 N)

Situated at the mouth of the lagoon, site 1 was characterised by shallow water (0.55m) with a width of 3m. The substrate at this site was composed of a sand base with 100% coverage of decaying organic matter. This site was predominantly open water habitat with no aquatic vegetation in the immediate area.

Flanagans Creek Site 2 (56309349 E, 6201031 N)

Site 2 was situated approximately 15 m west of Site 1. This site consisted of a shallow, open water habitat with less than 20% aquatic vegetation cover around the littoral zone. The substrata at this site largely consisted of silt and sand. Site 2 was characterised by a thick detritus cover providing an abundance of cover for benthic species. The average depth was 0.4m with a width of approximately 15m. The aquatic vegetation around the littoral zone largely consisted of Phragmites. A stormwater pipe situated on the southern bank entered the lagoon at this point.

Flanagans Creek Site 3 (56309344 E, 6201048 N)

This site was located approximately 40m west of Site 2. The water depth was >1.5m with a width of approximately 5m. This channelised site had a Phragmites cover of 20%. The substrate consisted of clay and silt.

Flanagans Creek Site 4 (56309291 E, 6201661)

Similarly to Site 3, Site 4 was very channelised with a depth >1.5m and a width of approximately 2.5m. Located a further 40m west of Site 3, the banks were relatively steep. Around the littoral zone, there was dense growth of Phragmites, providing and abundance of cover and habitat for aquatic organisms. The dominating substrate included fine silt with a detritus cover >70% providing an abundance of organic material.

5.8.2 Whartons Lagoon

Whartons Lagoon is an estuarine creek that opens into a small lagoon before opening to Bulli Beach. The catchment area is approximately 211 ha, with a wetland area of 0.1 ha. At the time of sampling, the mouth of the lagoon was open to the sea. Although water was not rushing through the wetland, there was a slight current passing though the lagoon. Anecdotal reports from observers indicated that prior to the lagoon opening, it appeared stagnant.

Wharton Lagoon Site 1 (56309063 E, 6198092 N)

Situated at the mouth of the lagoon, Site 1 was characterised by shallow water (0.4m) with a width of 3 meters. The substrate at this site comprised of an open sand base. There was no aquatic vegetation or physical structure at this site. A large stormwater outlet was located on the Northern bank of the site. At the time of the survey this outlet was not discharging. The overall visibility of the water was good with no algae on the substrate or suspended in the water column. This site was predominantly open water habitat with no aquatic vegetation in the immediate area.

Wharton Lagoon Site 2 (56309016 E, 6198103 N)

Situated 30 meters upstream of Site 1, Site 2 was characterised by steep banks. The water depth was greater than 1.5 meters. The lagoon was 5 meters wide at this point. Similarly to Site 1, there were no snags or woody debris. Rock fill dumped to provide support to the nearby footbridge was the only structure available at this site. The substrate largely consisted of silt (90%) with sand (10%). This site was largely open water habitat with less than 5% Phragmites cover fringing the littoral zone.

Whartons Lagoon Site 3 (56709005 E, 6198126 N)

Site 3 was located 40 meters West of Site 2. This site consisted of deep water fringed by a dense thicket of Phragmites on the Northern bank. The Southern bank was characterised by overhanging trees. Similarly to previous sites, Site 3 was largely an open water habitat with less than 20% total cover of aquatic vegetation. The width of the lagoon at this point was approximately 7 meters.

Whartons Lagoon Site 4 (456708952 E, 6198152 N)

Site 4, was characterised by 100% canopy cover and an abundance of woody debris. The average depth was 1m. The site was much narrower compared to previous sites with a width of 3m. The substrate consisted of clay and silt.

5.8.3 Collins Creek

Sampled on 15 March 2007, Collins Creek is a coastal lagoon that opens up into an estuarine lagoon of approximately 0.5ha in area. The lagoon entrance was open at the time of the survey.

Collins Creek, Site 1 (56308897 E, 6197443 N)

Situated at the mouth of the lagoon, Site 1 was characterised by shallow water (0.5 meters) with a width of 4 meters. The substrate at this site comprised of 70% sand and 30% bedrock base with 30% detritus cover. This site was predominantly open water habitat with no aquatic vegetation in the immediate area. The visibility was clear, however at the time of the survey there was an abundance of algae in the water column.

Collins Creek, Site 2 (56308840 E, 6197495 N)

Situated 70 meters upstream from Site 1, Site 2 had a depth greater than 1.5 meters. The lagoon at this site was 4 meters wide. This site was largely open water habitat with less than 20% total cover of aquatic vegetation. The dominant vegetation type was Phragmites. There was an abundance of algae suspended in the water column. The substratum at this site was entirely bedrock with 100% detritus cover. A disused shopping trolley provided the only structure within the water. There was no woody debris or larger snags.

Collins Creek, Site 3 (56308767 E, 6197502 N)

Site 3 was located approximately 70 meters upstream of Site 2. Characterised by an abundance of aquatic vegetation, Phragmites, and very channelised geomorphology, the depth at this site was greater than 1.5 meters, with a width of 4 meters. There was low flow at this site and similar to the previous site, the water column was thick with suspended algae. The substrata at this site was predominantly bedrock with a silt and detritus layer covering approximately 80%.

Collins Creek, Site 4 (56308702 E, 6197512 E)

Site 4, located approximately 100 m upstream of Site 3; was again characterised by dense Phragmites cover on the littoral zone. The channel at this site was slightly narrower than at previous sites with a width of 2.5 meters, and a depth greater than 1.5 meters deep. There was very little flow at this site however foaming was present in and around the vegetation.

5.8.4 Tom Thumb Lagoon

Tom Thumb Lagoon is a 7.7 ha remnant coastal wetland that once extended over an area of up to 500 ha and is the largest estuarine wetland to be surveyed during this project. The site is an estuarine channel that has areas of adjacent salt marshes and mangroves. The lagoon drains a catchment of 353 ha and has a complex history of disturbance from development of the Port Kembla industrial site and inner harbour. Tom Thumb Lagoon receives the majority of stormwater generated by the Wollongong CBD.

Tom Thumb Lagoon can be separated into two arms. For the purpose of this study these are referred to as Tom Thumb Lagoon itself (running east-west) and Garangaty waterway (running north-south through J J Kelly Park. The Garangaty waterway receives stormwater runoff from the CBD, while Tom Thumb Lagoon services a small catchment, receives little stormwater runoff, but does receive sewage overflows in wet weather.

Tom Thumb Lagoon is constantly open to the sea, receiving regular flushing and inundation through tidal pulses.

Tom Thumb Lagoon, Site 1 (56306560 E, 6186691 N)

Site 1 was located in Garangaty waterway upstream of it's confluence with Tom Thumb Lagoon, and was characterised by areas of mudflats and sparse mangroves. When disturbed, gas bubbled from the mud. There was low flow through this section, although the flow increased in the afternoon due to an influx of stormwater from Wollongong CBD, generated by an intense and very localised rain event. Foam was visible on the water surface. There were no algae suspended in the water column or on the substratum.

Tom Thumb Lagoon, Site 2 (56306599 E, 6186688 N)

Situated approximately 300m upstream of Site 1 on Garangaty waterway, Site 2 was a channel habitat with an average depth of 0.5m at mid tide. The width of the channel at this site was approximately 20m. Thick stands of mangroves were present along the Western bank with cleared land and Phragmites on the Eastern bank. The substratum at this site was largely comprised of anoxic mud with rubble rock fill.

Tom Thumb Lagoon, Site 3 (56306632 E, 6186679 N)

Site 3 was located on Tom Thumb Lagoon approximately 60 meters upstream of it's confluence with the Garangaty waterway, and was flanked by mudflats on both sides. The channel was 4m wide and had an average depth (mid tide) of 0.4 meters. Similar to Site 1, the substrata consisted of anoxic mud that was sludge-like in appearance when disturbed. The flow though this section was lower and slower than that of the Garangaty waterway. Dense mangroves were present on the mudflats fringing the channel. Within the channel itself, there was no vegetation or structure.

Tom Thumb Lagoon, Site 4 (56306545 E, 6186702 N)

Site 3 was located on Tom Thumb Lagoon approximately 100m upstream of Site 2. The site consisted largely of an open water channel habitat fringed by dense mangroves on either bank.

5.9 Water Quality

The results of the in-situ water quality monitoring are detailed in Table 5.4 to Table 5.7 and discussed below.

5.9.1 Flanagans Creek

As the water flowed from the west (freshwater influence) toward the lagoon opening (saltwater influence), there was a two-fold increase in electrical conductivity. Results from the most upstream site (Site 4) returned an Electrical Conductivity (EC) value of 652 µS/cm. The EC value increased to 1474 µS/cm near the lagoon opening. These results indicate that at the time of the study, Flanagans Creek was primarily a freshwater system. Floating debris including rubbish, leaves and timber flowing through the lagoon at the time of the survey indicated that the water flowing through the lagoon was stormwater runoff from the surrounding residential area.

pH followed a similar trend to EC. The pH decreased from 8 to 6.9 as the water moved toward the lagoon opening. The lower pH at the lagoon entrance may reflect localised reduction in pH associated with direct inflow of water from the stormwater pipe near Site 2, since the pH of seawater is typically around 8.

Table 5.4 Water Quality for Flanagans Creek

Flanagans Creek	Site 1	Site 2	Site 3	Site 4
pH	6.9	7.7	8.1	8.0
Electrical Conductivity, µS/cm	1474	1039	653	652
Turbidity NTU	9	6	7	9
Temperature ^{o}C	20	20	20	20
Dissolved Oxygen mg/L	5.5	6.3	5.5	4.5

5.9.2 Collins Creek

As the water flowed toward the lagoon opening, there was a gradual increase in pH from 7.7 to 8.4. Similarly, there was a gradual increase in dissolved oxygen. The electrical conductivity concentrations were relatively consistent along the length of the lagoon with the results indicating that Collins Creek was a freshwater system at the time of the survey. Electrical conductivity values ranged from 1046 µS/cm to 1134 µS/cm.

Table 5.5 Water Quality for Collins Creek

Collins Creek	Site 1	Site 2	Site 3	Site 4
pH	8.4	8.2	7.9	7.7
Electrical Conductivity µS/cm	1100	1134	1084	1046
Turbidity NTU	5	9	4	3
Temperature ^{o}C	26.7	25.5	25.3	25.1
Dissolved Oxygen mg/L	8.6	6.5	6	5

5.9.3 Whartons Creek

The water quality of Whartons Creek was relatively consistent across all sites sampled. The EC ranged between 708 µS/cm and 795 µS/cm indicating that, similar to Flanagans and Collins Creek, this system contained freshwater at the time of the survey. It should be noted that it is difficult to determine whether this the natural state of the creek or a result of the massive stormwater input into the system.

The dissolved oxygen levels were notably low with the concentrations ranging between 4.2 mg/L and 5.0 mg/L. After storm events it is common for oxygen levels to decrease due the influx of organic mater washed into the system.

The pH levels were stable across the sample sites with the highest level recorded at site 4. pH ranged from 7.9 to 7.6.

Table 5.6 Water Quality for Whartons Creek

Whartons Creek	Site 1	Site 2	Site 3	Site 4
pH	7.7	7.6	7.6	7.9
Electrical Conductivity µS/cm	795	784	706	716
Turbidity NTU	12	11	11	17
Temperature ^{o}C	25.9	25.6	25.9	24.0
Dissolved Oxygen mg/L	4.2	4.2	5.0	4.2

5.9.4 Tom Thumb Lagoon

The Garangaty waterway (Sites 1 and 2) receives stormwater runoff from the entire Wollongong CBD. As a result, the water running through this waterway consisted entirely of fresh stormwater that fell during the time of the survey. As this freshwater flowed towards the ocean, it became mixed with seawater from the incoming tide. This resulted in an increase of electrical conductivity between Sites 1 and 2. The electrical conductivity ranged from 2320 µS/cm to 994 µS/cm.

In contrast the water quality of Tom Thumb Lagoon itself (Sites 3 and 4) was largely marine with a corresponding EC ranging from 29700 to 28200 µS/cm.

The turbidity of the entire Tom Thumb Lagoon system was slightly higher than that of other lagoons studied under the scope of this project. With a turbidity greater than 40 NTU measured in both channels, the increased levels most likely reflect the tide-affected mud substrata that was characteristic of this site.

The dissolved oxygen levels within Garangaty waterway were notably lower that that of Tom Thumb Lagoon itself. As this waterway receives a high volume of stormwater runoff, it is likely that the mass input of organic matter is the cause for a lower dissolved oxygen content.

The pH levels were relatively stable across Sites 1, 2 and 3 with the lowest level recorded at Site 4.

Table 5.7 Water Quality for Tom Thumb Lagoon

Tom Thumb Lagoon	Site 1	Site 2	Site 3	Site 4
pH	8.6	8.3	8.1	7.7
Electrical Conductivity µS/cm	2320	994	29700	28200
Turbidity NTU	44	32	43	25
Temperature ^{o}C	28.2	27.7	28.7	29
Dissolved Oxygen mg/L	5.9	6.4	8.4	8.6

5.10 Diversity and Abundance of fish

The results of the fish survey are detailed in Table 5.8 and Figure 5.1 to Figure 5.7.

A total of 2738 fish, representing 15 species, were sampled during the study period. The most abundant species caught across all sites were the Flathead Gudgeon *(Philypnodon grandiceps)*, contributing to 40% of the total catch (Table 4.8). Commercially significant species such as the Yellowfin Bream (*Acanthopagrus australis)*, the Sand Mullet *(Myxus elongatus)* and the Sea Mullet (*Mugil cephalus)* were locally abundant contributing 8%, 10% and 4% respectively to the overall percentage.

The only non-native species sampled from the four estuaries was the Mosquito Fish (*Gambusia holbrooki*). Only 19 individuals were sampled across all sites.

Three species were common to all estuaries. These included Sea Mullet, Sand Mullet and Flathead Gudgeon. The Longfinned eel (*Anguilla reinhardtii*) was present in three of the four estuaries.

The fish community within Tom Thumb Lagoon was found to be significantly different to those in the Flanagans, Whartons and Collins Creek systems. Tom Thumb Lagoon is permanently open to the ocean through Port Kembla, thus tidal pulses heavily influence the lagoon. This is reflected in the fish community, as the majority of the species found within this lagoon also were predominantly marine species. Tom Thumb lagoon displayed the highest species diversity.

Table 5.8 Total Species Sampled

Common Name	Scientific Name	Habitat [1]	Flanagans Ck	Tom Thumb Lagoon	Whartons Ck	Collins Ck
Yellowfin Bream	*Acanthopagrus australis*	M, E		212		
Glass Perchlet	*Ambassis jaksoniensis*	E	1	160		
Longfinned Eel	*Anguilla reinhardtii*	F	1		2	4
Smallmouth Hardyhead	*Atherinosoma microstoma*	E			4	129
Three-bar Porcupinefish	*Dicotylichthys punctulatus*	M		2		
Mosquito Fish	*Gambusia holbrooki*	F	3			16
Luderick	*Girella tricuspidate*	M, E		2		
Flat-tail Mullet	*Liza argentea*	E	2			
Sea Mullet	*Mugil cephalus*	M, E	1	107	5	4
Flat-backed Goby	*Mugilogobius platynotus*	E		683		
Sand Mullet	*Myxus elongatus*	M, E	2	168	28	92
Bullrout	*Notesthes robusta*	M, E				1
Flathead Gudgeon	*Philypnodon grandiceps*	F	305	4	224	575
Gudgeon	*Philypnodon sp.*	F	2	1		
Black Sole	*Synaptura nigra*	M	1			

Note: [1] F – Freshwater, M – Marine, E - Estuarine

Figure 5.1 Total number of Individuals sampled in each system

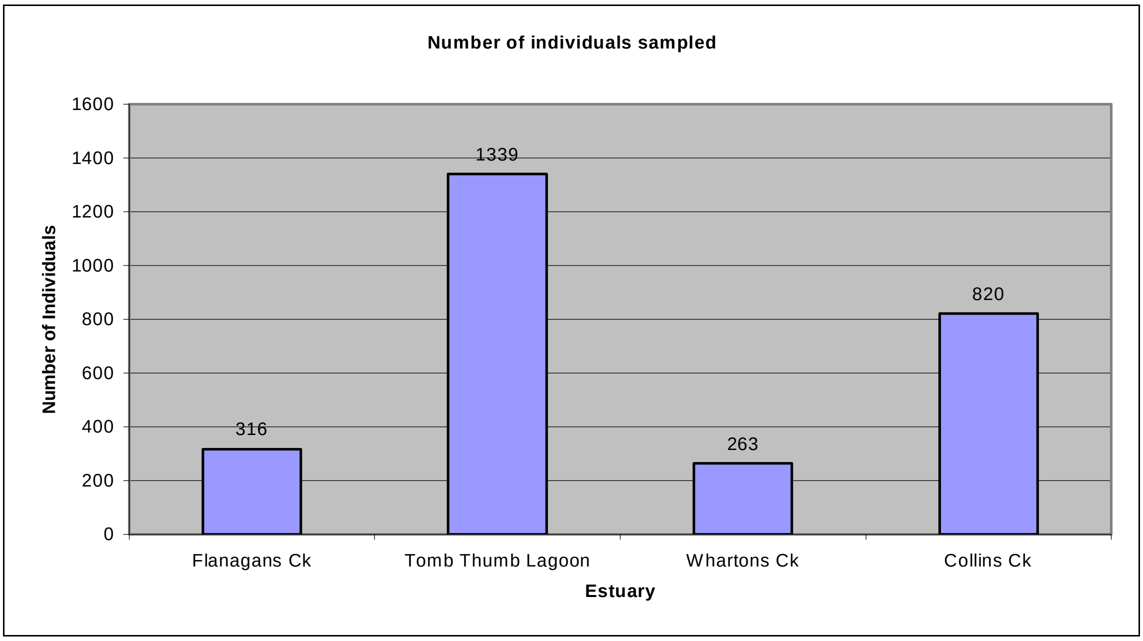


Figure 5.2 Number of Species sampled in each system

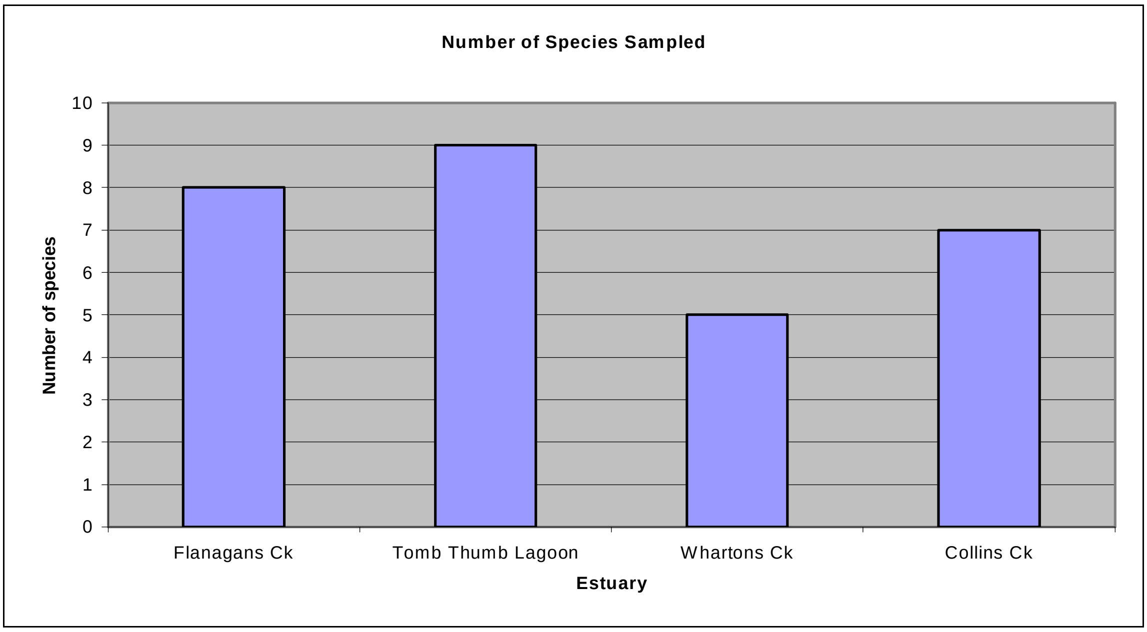
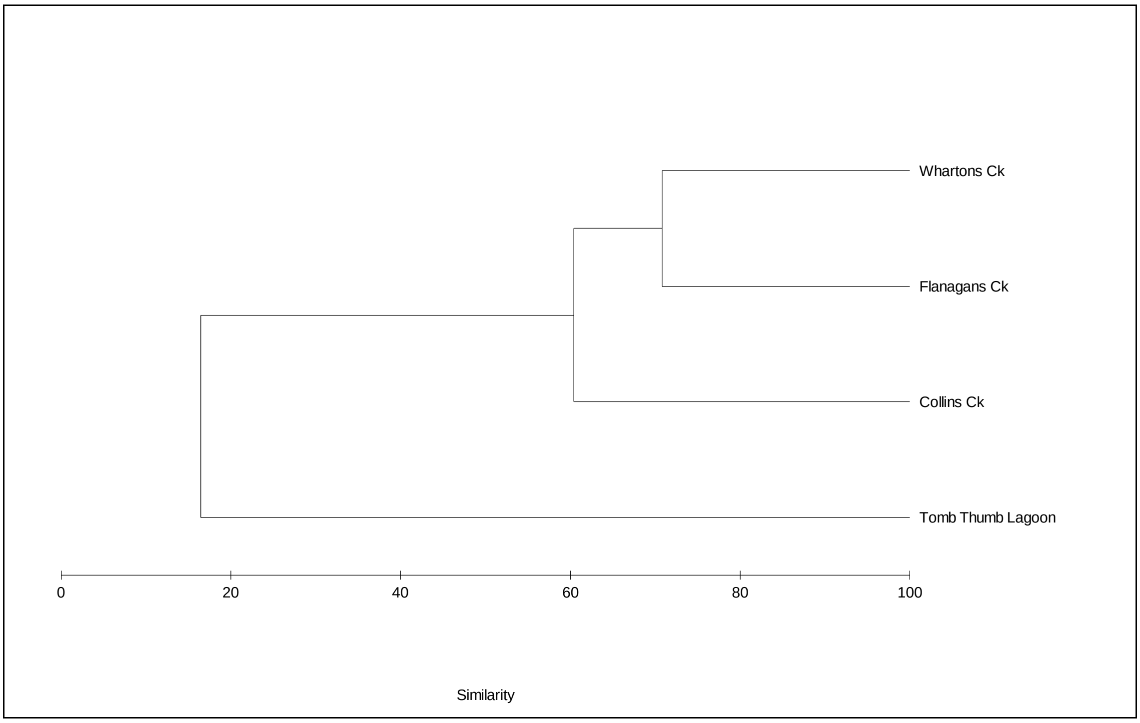


Figure 5.3 Dendogram of hierarchical clustering



5.10.1 Collins Creek

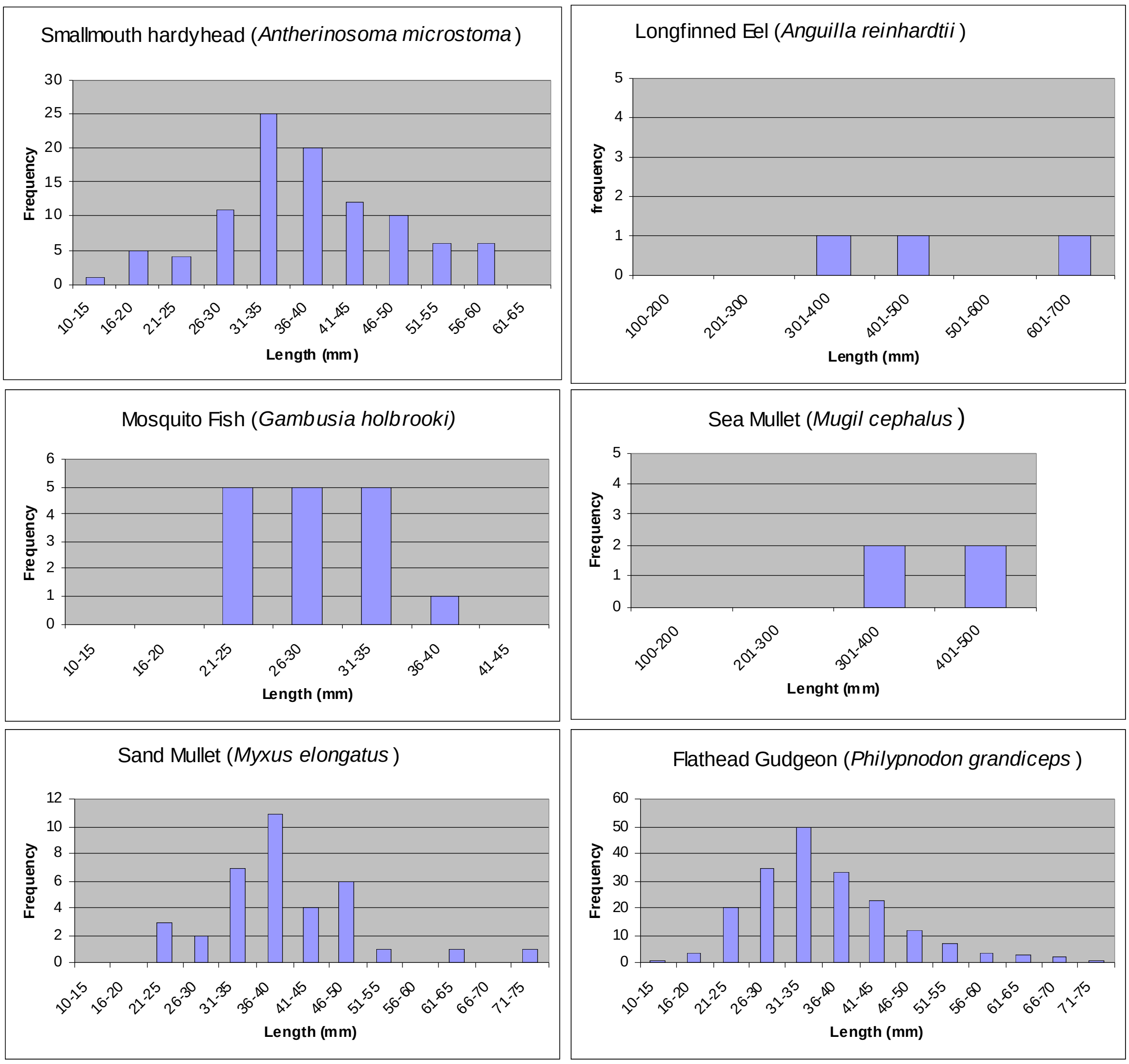
Diversity and Abundance of fish

A total of 820 individuals, comprising seven species, were sampled from Collins Creek. Native species accounted for 98% of the total number of fish caught. Mosquito Fish was the only introduced species sampled. This small number of exotic species does not appear to have had an adverse impact on the native community present, as the numbers of native fish sampled were significantly greater.

The dominant fish species sampled from this lagoon was the Flathead Gudgeon, contributing 70% of the overall abundance. The second most abundant species sampled was the Smallmouth Hardyhead (*Atherinosoma microstoma*), contributing a further 15%. The remaining 15% of the overall abundance contains five species including two species of mullet *Myxus elongatus* (Sand Mullet) and *Mugil cephalus* (Sea Mullet) plus *Anguilla reinhardtii* (Long-finned eel), all of which are of commercial value.

The size class distribution of Flathead Gudgeon, Smallmouth Hardyhead and Sand Mullet indicate that these species all have viable populations within the Collins Creek Estuary. Specimens of Flathead Gudgeon ranged from 15mm to 75mm with an average of 36 mm. Smallmouth Hardyhead presented a similar size class, from 15mm to 60mm with an average size 38 mm.

Figure 5.4 Species abundance, Collins Creek



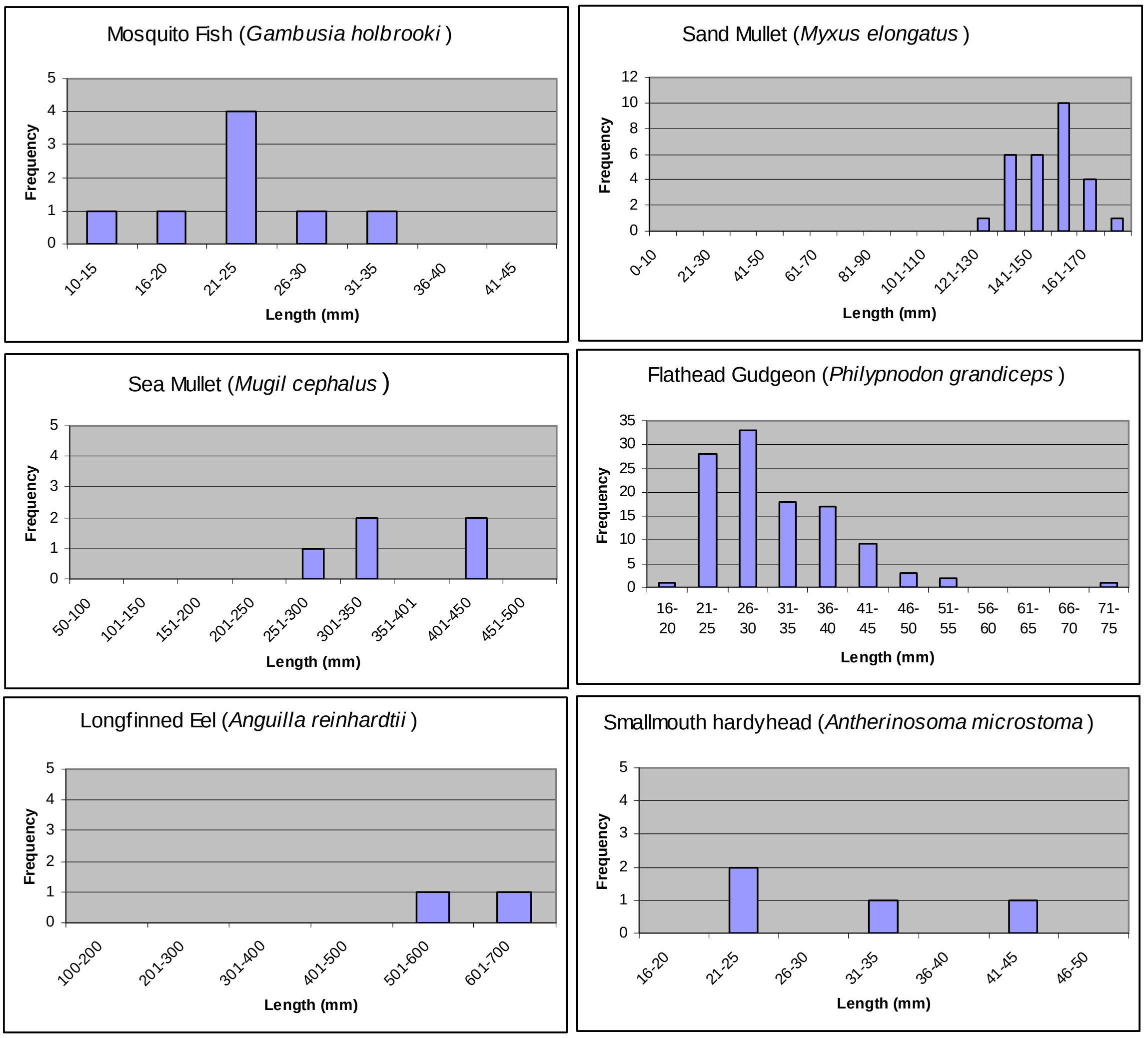
5.10.2 Whartons Creek

Diversity and Abundance of fish

Samples taken from Whartons Creek returned 263 individuals of five species. Whartons Creek was the least diverse system with 95% of the total abundance attributed to only two species, Flathead Gudgeon and Sand Mullet, with respective contributions of 85% and 10%. The remaining 5% included Sea Mullet, Longfinned Eel and Smallmouth Hardyhead.

The size class distributions indicate that the Mosquito Fish has established a small breeding population, and that the Flathead Gudgeon population is also viable. With a size class ranging from 21 mm to 75 mm, the sand mullet population appears to be mostly comprised of juvenile specimens. As this lagoon was open at the time of the survey, it is possible that the sand mullet are recent arrivals into the estuary.

Figure 5.5 Species abundance, Whartons Creek



5.10.3 Flanagans Creek

Three hundred and sixteen (316) individuals from eight families were sampled from Flanagans Creek. Similar to Whartons and Collins Creek, Flathead Gudgeon was the dominant species sampled with 305 individuals accounting for 96% of the total abundance. The Dwarf Flathead Gudgeon (*Philypnodon sp*.) contributed a further 0.65%.

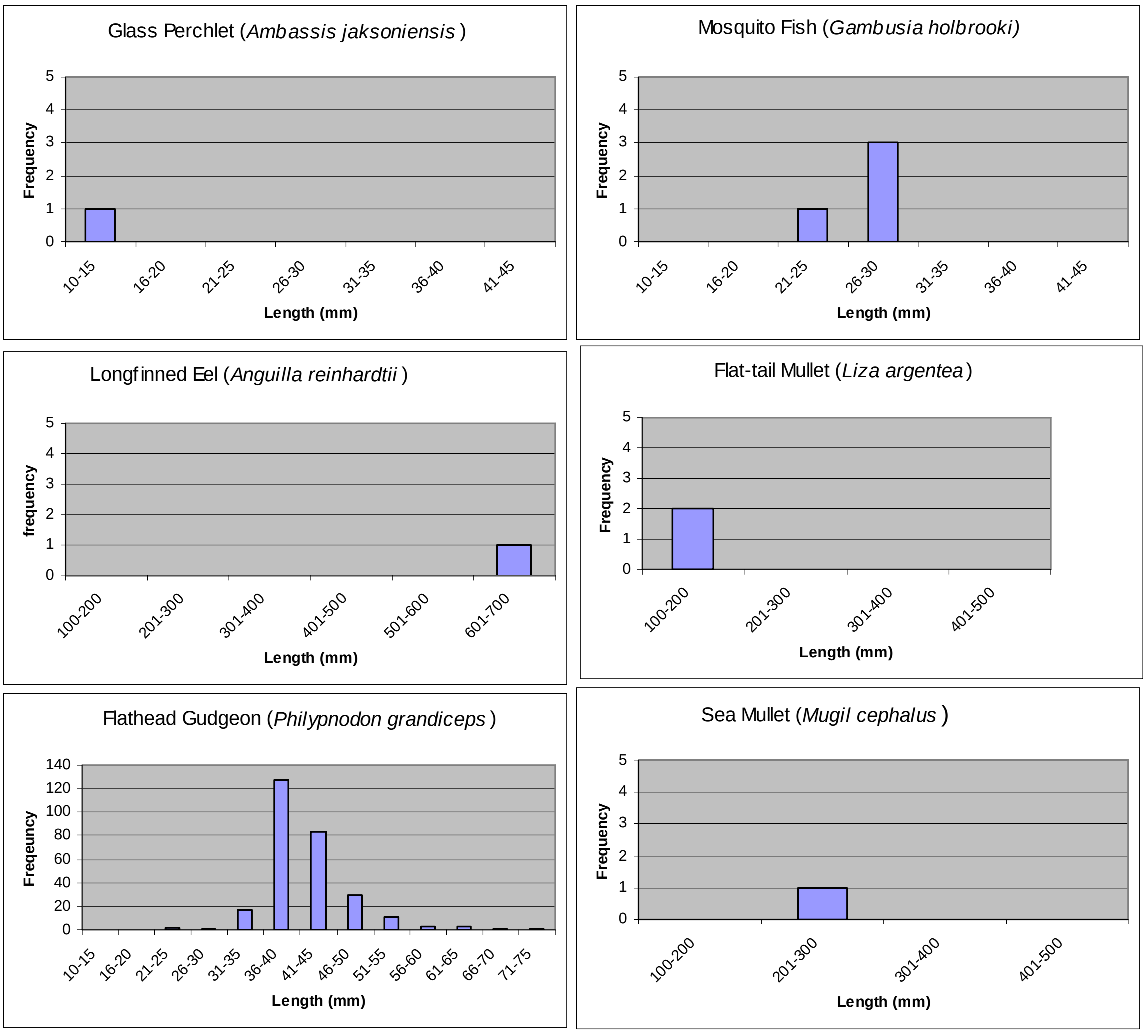
Synaptura nigra (Black Sole) was identified in this estuary. In total, four species of commercial value were identified. These included Longfinned Eel, Sea Mullet, Sand Mullet and the Black Sole.

Flathead Gudgeon ranged from 24 mm to 70 mm in length with the majority of individuals falling into the 36-40 mm size class. The lack of individuals less than 20 mm in length, and the high abundance of adults (36-40 mm) suggests that, unlike the population found in Collins Creek, recent recruitment has not occurred in this system. Possible reasons for this include the lack of spawning triggers, increased predation, the lack of adequate habitat and sampling bias. However, as this survey was based on a one off sample event, these reasons are difficult to determine.

It is possible that fish of the less than 20 mm size class were effected by the high flow volumes present at the time of the survey and sought refuge in slow flowing water in dense vegetation (which is difficult to sample), and were therefore not captured during the survey. It is considered to be unlikely that they were flushed out to sea.

It is of note that, during the survey, one large mud crab, with an estimated carapace width of 10 cm, and one Australian Long-Necked Turtle, were observed at this location.

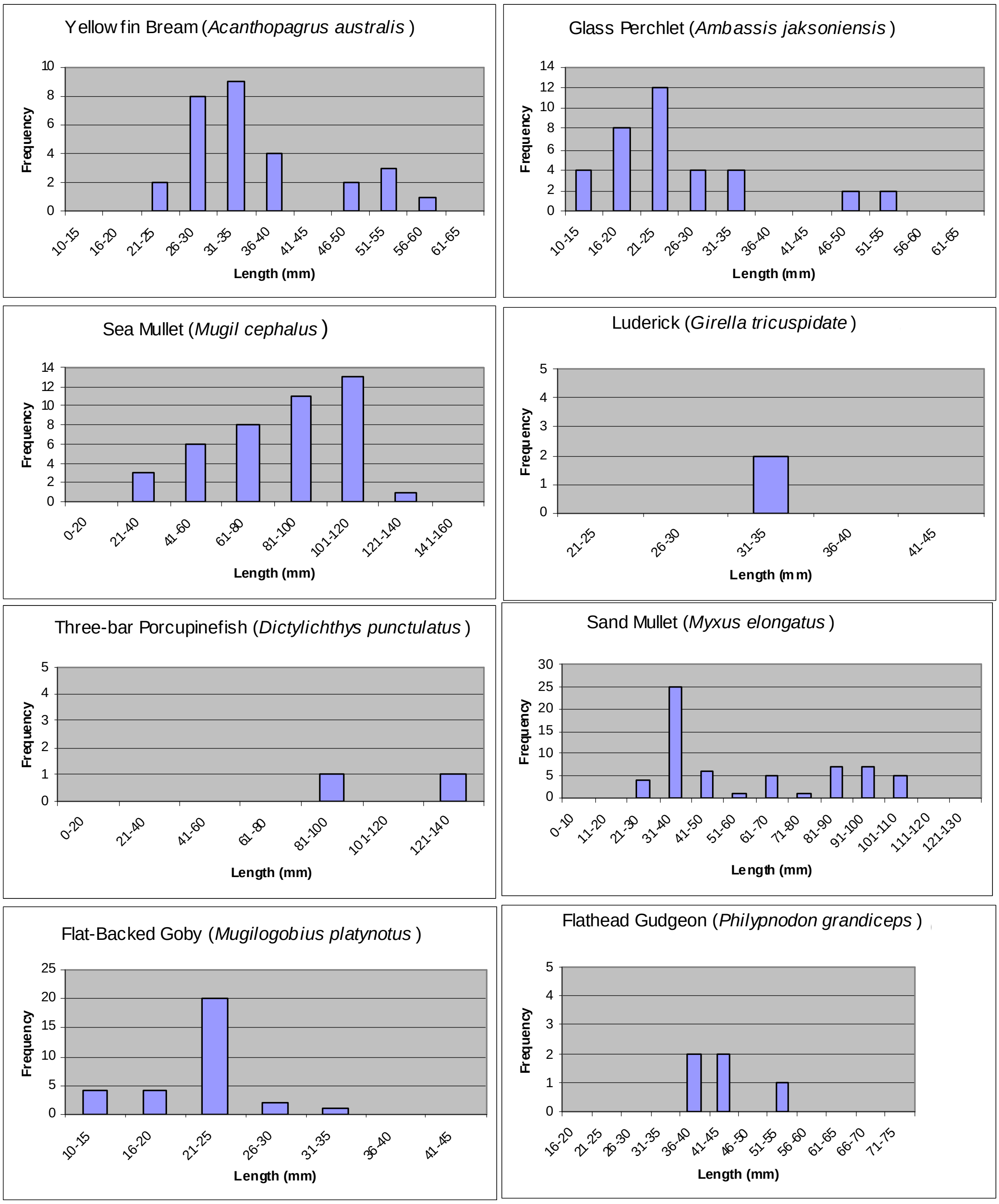
Figure 5.6 Species abundance, Flanagans Creek



5.10.4 Tom Thumb Lagoon

Tom Thumb Lagoon was the most diverse estuary sampled as part of this project with 1339 individuals belonging to nine species. The most abundant species was the Flat-backed Goby (*Mugilogobius platynotus*) accounting for 51% of the total catch. Individuals of all size classes were represented indicating a viable population. The maximum and minimum lengths for this species were 32 mm and 14 mm respectively, with an average of 21 mm.

Figure 5.7 Species abundance, Tom Thumb Lagoon



A number of highly valued commercial species were present. Commonly known as Yellowfin Bream, *Acanthopagrus australis* is a species of considerable commercial importance and was the second most abundant species (15% of the total abundance). All specimens sampled were juveniles with a maximum length of 56 mm. The majority of the individuals sampled were between 31 mm - 35 mm with an average length of 35 mm. This size class suggests that Tom Thumb Lagoon provides an important nursery habitat for this species, and is important to the sustainability of the greater Port Kembla population.

Although only 2 specimens were found, accounting for only 0.14% of total abundance. *Girella tricuspidate* (Luderick) were sampled from Tom Thumb Lagoon. Similar to that found with Yellowfin Bream, specimens collected of Luderick were all juvenile, falling into the 31 mm – 35 mm size class.

Combined, Sea Mullet and Sand Mullet accounted for 20% of the overall abundance. Size classes varied for these two species. The average length of Sea Mullet was 82 mm with maximum and minimum of 135 mm and 31 mm respectively, while for Sand Mullet, the mean length was 57 mm with a minimum of 28 mm and a maximum of 107 mm. Both populations are likely to be viable.

Ambassis jaksoniensis (Glass Perchlet) accounted for 11% of the total catch for Tom Thumb Lagoon. The average length of Glass Perchlet was 25 mm with a maximum and minimum of 14 mm and 54 mm. The size class distribution data indicates that the population in Tom Thumb Lagoon is viable.

Flathead Gudgeon were also present, with an abundance of only 4 individuals or 0.2%. The abundance of this species was not as high as observed in other estuaries during this project.

5.11 Commercial Species Sampled

5.11.1 Sea Mullet (*Mugil cephalus*)

Sea mullet are a marine fish occurring in coastal habitats, but also occur in estuaries and occasionally venture into freshwater. They are common in tidal estuaries and bays. Sea mullet occur worldwide, mainly in warm temperate and tropical regions. They are found throughout all coastal waters of Australia and are abundant in southern Queensland and NSW. During late autumn mature fish group in estuaries and begin their annual northward spawning migration. Spawning occurs out at sea and the fry move back into estuaries. Sea mullet feed by vacuum-cleaning the rich surface of muds with their soft lips, digesting out the edible elements of the surface film (Edgar 1997).

5.11.2 Longfinned Eel (*Anguilla reinhardtii)*

Longfinned eel are reported to attain 2 m in length and more than 16 kg in weight, although generally individuals are much smaller, with lengths of less than 1 m more common. Principally carnivorous, although some plant material is eaten, large adults take a variety of prey ranging from insects to fish, although fish appear to be the main component of the diet (McDowall 1996). Feeding patterns follow the seasons and feeding is most intense at night during spring and summer. Upstream migration of the juveniles (known as glass eels) occurs from January to May and the eel spends most of its life cycle in freshwater before migrating downstream to spawn at sea when sexually mature (Allen *et al 2003).* Full details of the life cycle of the Longfinned eels are still not fully understood. They are believed to spawn in the Coral Sea near New Caledonia (Allen *et al 2003*) and the transparent larvae (known as *leptocephali*) may spend 2 to 3 years at sea being transported southwards by the East Australian Current. They then change into glass eels with no pigmentation, they lose their teeth, cease feeding for a period and move into estuarine areas (McDowall 1996). Movement into fresh water is accompanied by increased size and rapid colouring and they are now known as elvers. Upstream migration appears to be in response to a number of factors including falling salinity and rising water temperatures. Migration usually occurs at night, the young eels remaining close to the banks and avoiding fast flowing water (McDowall 1996).

5.11.3 Yellowfin *Bream (Acanthopagrus australis)*

This species inhabits coastal and estuarine waters of eastern Australia from the Gulf of Carpentaria in Queensland to Gippsland in Victoria. They are most abundant in estuaries, but also inhabit inshore reefs to a depth of about 35 m and waters adjacent to ocean beaches and rocky headlands (Allen *et al* 2003). They can be found in rivers, upstream to the limit of brackish waters but rarely enter fresh water. Bream form into shoals of several hundred fish, and during spawning season (winter) the larger fish tend to group in schools of similar sized fish. Yellowfin bream are known to associate with a variety of substrates from sand and mud to rocky sections of riverbed. (Kuiter 1996)

5.11.4 Luderick (*Girella tricuspidate)*

Luderick live in river mouths, estuaries, off ocean beaches near rocky outcrops, and rock walls. Luderick only live in waters off eastern Australia and the north island of New Zealand. In Australia their distribution ranges from Hervey Bay in Queensland, southwards to Victoria, northern, eastern and western Tasmania and into South Australia as far west as Kangaroo Island. Luderick found in estuarine areas feed on dark green thread-like algae growing on rubble beds and stable bottom mud in shallow muddy water (Hutchins & Swainston 1986). They use dense beds of eelgrass as a refuge. Luderick found in coastal waters feed mainly on ulva growing on surf-washed rocks. Those fish living in estuaries tend to be dark olive brown with dark, narrow, vertical bars on their bodies and a purplish tinge. Luderick from more open waters are much paler with silvery bellies and their bodies have a bronze sheen (Kuiter 1996). The dark bars on these fish are more pronounced. Luderick grow to about 71 cm (5 kg). They are sexually mature at 4 years of age and around 25-26 cm in length

5.12 Discussion

In coastal lagoon systems such as Whartons, Flanagans and Collins Creeks, and Tom Thumb Lagoon, variations in physical factors such as salinity, precipitation, evaporation, wind and sea connections determine the structure of the local fish community through limiting or favouring individual species (Staunton-Smith *et al. 2004*).

Coastal lagoons vary widely in their opening/closing characteristics including the frequency of opening, and the length of time they remain open. Historically, the artificial opening of these lagoons has been undertaken with little regard to the impact on their long-term ecological health. It has since been found that artificial openings may lead to a loss of riparian vegetation and wetland habitat. In the short term, artificial openings under certain environmental conditions may lead to catastrophic events such as anoxia (Loneragan, *et al* 1999).

Depending on the intensity of the rainfall, the volume of runoff generated, and in-stream flows, lagoon openings can create an intense flow out to sea. Freshwater species can be dragged out to sea and die during such an event (Watts & Johnson 2004). Some individuals may manage to hide upriver and return after salinity stabilizes, or they may seek refuge in slower flowing and densely vegetated areas at the margins of the lagoon. Small lagoons such as Collins, Whartons and Flanagans Creeks are likely to be the most affected in such situations. Larger lagoons such as Tom Thumb Lagoon provide some level of buffering to short term changes in biotic factors.

The survey identified that Collins, Flanagans and Whartons Creeks were predominantly freshwater systems with the majority of species sampled coming from freshwater origins. The CECCS study indicated that many species are likely to be resident all year round in estuary. As this study was based on a one off sampling event It is difficult to determine if these species are the resident population that normally reside within these lagoons, or if they have been washed down from the upper catchment. It is possible that marine/estuarine species that might normally occur may have either actively or passively moved out of the lagoon to avoid the fresh water pulse caused by the heavy rains (Robertson *et al 1990)*.

Estuarine fish assemblages vary in time and space, largely because estuaries have varying environmental characteristics and serve as nurseries for many productive and dependent marine species (Pombo *et al* 2002). Previous studies on coastal lagoons have indicated that species diversity is positively correlated with lagoon size (Griffiths & West 1999). With a lagoon area of 7.7 ha, Tom Thumb Lagoon was the largest estuary sampled during this project and, notably, it was the most diverse system sampled. Without further investigation, however, it is not possible to determine if the estuary size was the determining factor for its diversity. Larger lagoons provide a greater level of fish habitat and are generally found to contain significantly more species than smaller lagoons with bare substrata. However, Tom Thumb Lagoon was the only lagoon containing mangroves, and contained a higher number of species compared to other lagoons that were relatively denuded of structure.

Both fish abundance and species diversity provide managers with a good indication of the health of a particular system (Whitfield 2005). The estuarine lagoons sampled during this project are highly influenced by abiotic variables that affect recruitment, distribution, and the survival of species. Most fish commonly found in coastal lagoons use these areas for feeding and growth. The fish assemblages sampled throughout this study were relatively consistent between Whartons, Flanagans and Collins Creeks, while the fish assemblage of Tom Thumb Lagoon was notably different. The majority of species of commercial importance caught in these lagoons were juveniles, with many appearing to be recent recruits. The nursery function of these lagoons, especially Tom Thumb Lagoon, is likely to be crucial in the ongoing sustainability of many species in the local area.

Longfinned Eel were the only large piscivorous predator sampled during this survey, however it is often suggested that there are few piscivorous fishes in shallow estuarine habitats. Information on the dietary habits of predatory fishes from estuaries remains limited to broad summaries that lack quantitative detail on the fish components of the diet. To better define the assemblage of piscivorous fishes relevant to the functioning of shallow water nurseries, a broader scale survey would need to be undertaken on more than one sampling event.

The principal estuarine water quality parameters that are known to affect fish distribution are salinity, temperature, turbidity, pH and dissolved oxygen. Sediment characteristics, substrata and vegetation cover also affect fish distribution through their influence on habitat and prey availability (Powell *et al 2002*). The spatial distribution of salinity within Tom Thumb Lagoon varied greatly with high salinities in the entrance and western (non-stormwater receiving) arm. Without conducting a second survey in this lagoon, anecdotal evidence is sufficient to suggest the variation in salinity was highly related to localised rainfall. This is also supported by the presence in this lagoon (only) of species such as Yellowfin Bream, which do not tolerate long term freshwater environments, suggesting that salinity is more typically brackish to saline. The survey suggests that the fish fauna contained in Tom Thumb Lagoon are tolerant of fluctuations in salinity.

In recent years there has been an increasing concern about human impact on the coastal lagoon ecosystem (Roessig *et al. 2004*). Such ecosystems may be affected by a variety of human activities, both direct and indirect, such as coastal engineering works/ development, pollution, eutrophication and global warming (Robins *et al* 2005). In order to analyse these possible human interferences a knowledge of the dynamics of the system is necessary.

The management of urban runoff is one of the most important factors that needs to be addressed in the management of small coastal lagoons. It has long been acknowledged that intermittently open lagoons suffer the effects of pollution from urban runoff and stormwater drains. Stormwater can effect the health of fish populations and also influence the degree of recruitment (Griffiths & West 1999). Road surfaces generate pollutant loads that exceed the assimilative capacity of the aquatic environment, while contaminants of urban runoff can include gross pollutants, nutrients, heavy metals, pesticides, herbicides and petroleum hydrocarbons, each of which can have catastrophic impacts on aquatic systems. Since the current study only investigated *in situ* water quality parameters, a program of ongoing water quality monitoring of these waterways is recommended to evaluate the potential impacts of stormwater infiltration and urban runoff on the water quality of the creeks.

5.13 Implications for Estuary Management

The fishery survey results indicate that the most diverse and abundant fish community is that in Tom Thumb Lagoon, and that this community contains high value marine commercial species representative of estuaries that are permanently open to the ocean. Tom Thumb Lagoon provides the best fishery habitat of the four estuaries studied as part of this project, with extensive areas of mangroves providing nursery habitat. The large expanse of tidally inundated mudflats and saltmarsh also provide habitat for important fish prey species such as crabs and other invertebrates, providing a rich food resource for the fish. The daily tidal interchange also provides a continuous interaction of saline, brackish and fresh waters that would assist in replenishing water quality and flushing out nutrients and other potential pollutants.

The fish communities at Collins, Whartons and Flanagans Creeks were all similar, and relatively consistent with fish communities typically associated with ICOLLs. The relatively limited diversity and abundance would be related to the limited tidal flushing that these systems receive, together with the lack of suitable nursery habitat (mangroves, seagrasses, saltmarsh) and tidally inundated mud flats that provide a rich food resource.

Key management strategies to conserve and enhance the existing fishery resource include:

» Protect, conserve and enhance important fish nursery habitats (mangroves, seagrasses, saltmarsh, snags, etc) where they already exist, and consider the creation of these habitats in suitable estuaries where they do not exist (if viable environmental conditions exist); and

» Improve water quality through the investigation and management of point source pollutants, sewage overflows, trade waste discharges and stormwater quality.

6. Processes Studies – Geomorphological Assessment

6.1 Geomorphology of Estuaries

In Australia, four main types of estuaries have been recognised and documented. These are wave-dominated, tide-dominated, intermittently closed estuaries and open ocean embayments (Roy *et al.*, 2001; Heap *et al.*, 2004). The estuary classifications are based on widely agreed geological criteria on the depth and shape of the incised valley and the type of entrance conditions that control tidal exchange (Roy *et al.,* 2001).

The estuaries present on the NSW coast are predominantly wave-dominated barrier estuaries that are distinguished by relatively high wave energy compared to tidal energy at the mouth (Nichol, 1991; Roy, 1994; Zaitlin *et al.*, 1995; Kench, 1999; Roy *et al.*, 2001; Heap *et al.*, 2004). More specific forms of estuaries have been recognised within this category, including micro-tidal drowned river-valley estuaries, open oceanic embayments, wave-dominated barrier estuaries and (saline) coastal lagoons (Roy et al., 2001; Heap et al., 2004) as detailed in Figure 6.1 (Sloss, 2001 after Roy et al., 2001).

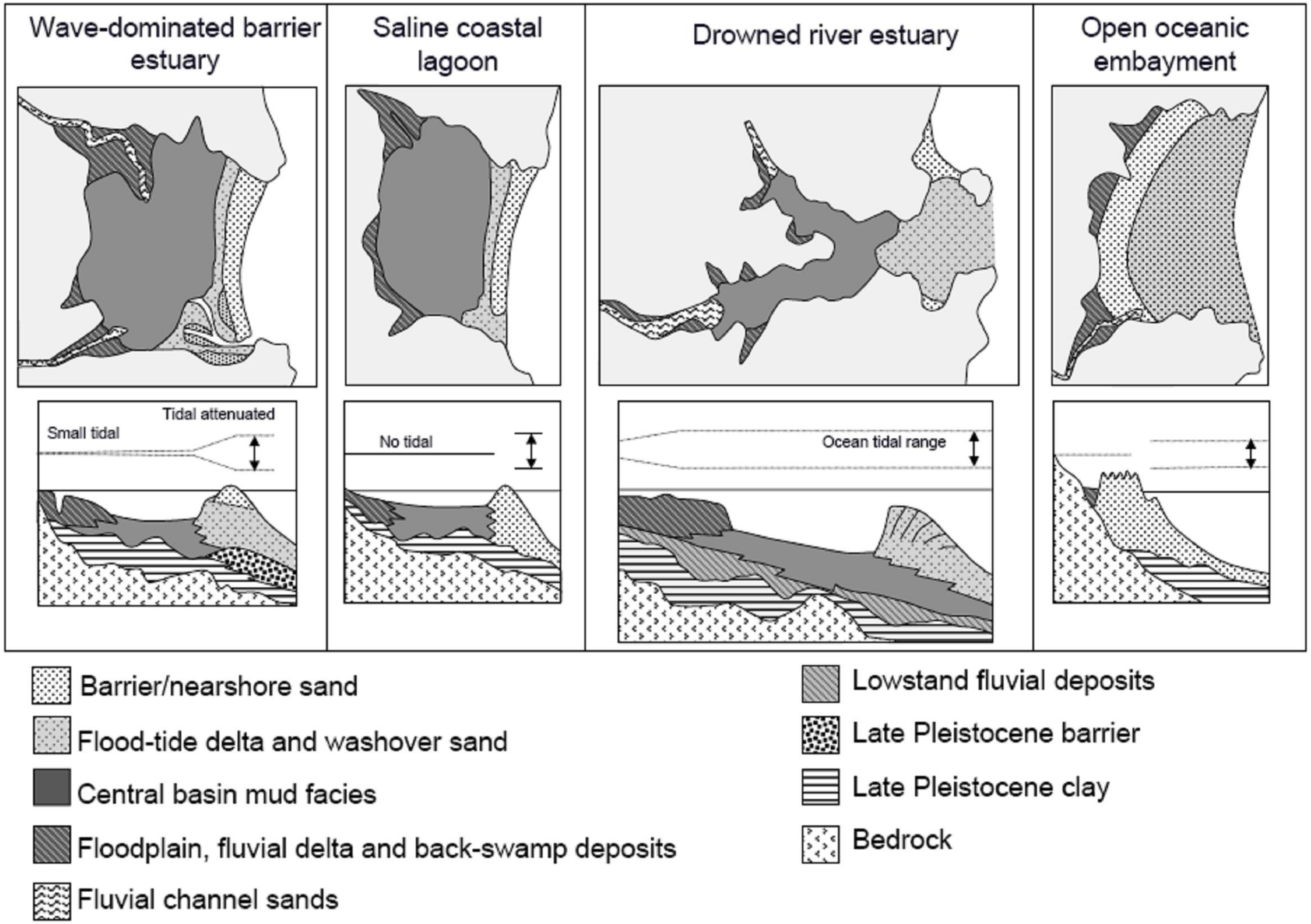
The ultimate control on the type of estuary present today is sea level (Kench, 1999; Zaitlin *et al*., 1995). Today's estuarine morphologies are defined by historical sea levels that determine the estuary shape, depth and barrier size through the influence of previous geomorphic conditions (Dalrymple *et. al.* 1992; Roy, 1994).

6.2 Coastal Dynamics

S-SE wind and wave directions dominate the southern NSW coastline resulting in a tendency for a northward littoral drift to occur along the shorelines. This often results in the formation of bay-head beaches and barrier systems with deflated and narrower southern portions of beaches occupying bedrock-bound embayments and broader beaches and barriers to the north (Langford-Smith and Thom, 1969; Roy *et al*., 1980). These features are characteristic of the Wollongong coast.

The dominant process influencing the morphology and functioning of NSW coasts is the action of waves, particularly during storm events. The tidal influence on this area of the Australian coast in minimal as the area is characterised as a micro-tidal zone. It is not unusual then, that the majority of estuaries located on the NSW south coast are characteristically wave-dominated in their form, with fluvial input being the variable factor in determining their final morphology and functioning.

Figure 6.1 Estuary type and geomorphology on the NSW coast



6.3 ICOLLs

An ICOLL is an intermittently closed and open lake or lagoon (also known as a coastal lagoon or strandplain associated creek) and falls under the wave-dominated barrier estuary classification (Haines *et al*., 2006). ICOLLs display many similarities to barrier estuaries in morphology, functioning and development (Woodroffe, 2002). Instead of being permanently open to the sea, ICOLLs may be periodically closed off by the action of tides or waves moving sand at the entrance of the estuary. Some estuaries have little fluvial influence so they are permanently closed to the sea as the consistent action of waves on the entrance barrier prevents it from becoming unblocked. The majority of estuaries along the Wollongong coast can be classified as ICOLLs, with the exception of Tom Thumb Lagoon and Lake Illawarra in the southern extent of the region.

ICOLLs (coastal lagoons and creeks) evolve on wave-dominated coastlines by the partial or total closure of small coastal embayments by a post-glacial sand barrier or flooding of beach ridges (Harris *et al*., In Press). Fluvial input into ICOLLs is generally low or negligible, however in every other way, they experience the same or similar evolutionary processes as other wave-dominated barrier estuaries. Infilling in ICOLLs is slow and the majority of sediment is comprised of marine sands that are deposited in the estuary when the entrance is open (Boyd *et al*., 1992).

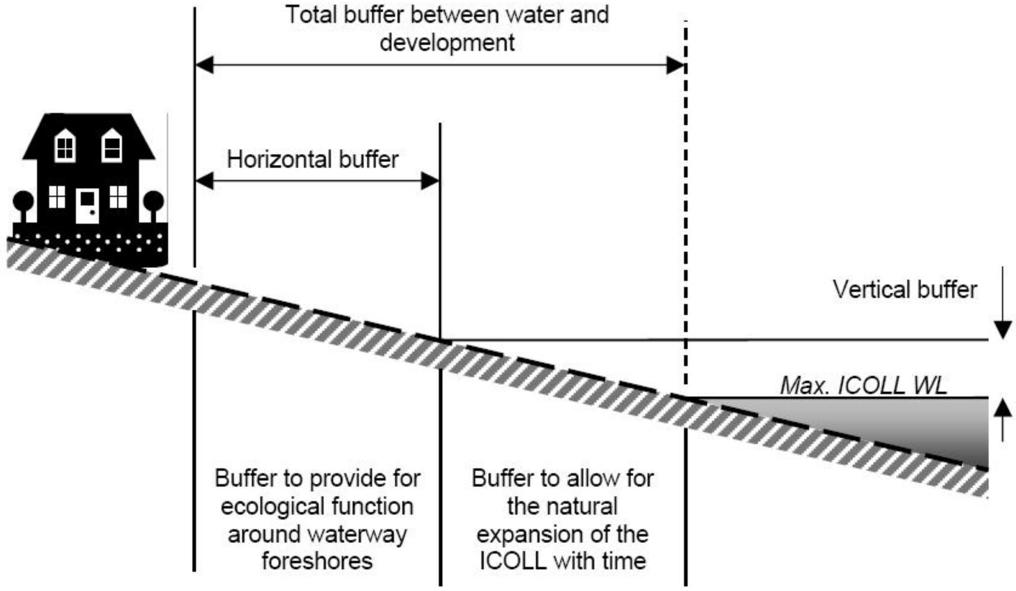
The catchment for ICOLLs is limited to the immediate surrounding hinterland. ICOLLs and coastal creeks are narrow, generally shallow water bodies that develop on prograding coastal sequences formed from beach ridges, dunes and barriers. Wave energy and tide energy within the systems are very low as tidal waters are often unable to penetrate the closed, very narrow or intermittent entrances. Low or non-existent river flow is conductive to very low energy conditions within the estuary, except during flood events.

6.3.1 ICOLL Management Implications

The distinguishing feature between ICOLLs and other estuary types is the variable condition of their entrances, which also makes them the most sensitive type of estuary to human influences (HRC, 2002; Boyd et al, 1992). It has been estimated that more than 50% of NSW ICOLLs experience temporary entrance modification, mainly through artificial entrance breakout to prevent inundation of surrounding land to minimise economic or social impacts (Haines, 2006). Interruption of the natural hydraulic regime of ICOLLs can modify other physical, biological and chemical processes which can result in adverse impacts such as terrestrialisation of estuarine wetlands and foreshores (Haines, 2006).

ICOLLs are often situated in areas of heavy urbanisation or agriculture, with foreshore land use encroaching on areas that would otherwise accommodate natural water level variability. This often requires measures such as entrance modification to maintain the economic viability of the land at the expense of natural systems. Maintaining the natural function of ICOLLs requires the allowance of an adequate buffer zone between development and the estuary. Due to the fact that the hydrological regimes of ICOLLs differ greatly from other estuary types, planning developments based upon distance from a 'Mean High Water' level are inappropriate for the variable water levels experienced in ICOLLs (Haines, 2005). The true nature of the waterway can only be defined by its maximum water level, which is dependent on the maximum berm height achieved prior to breakout. Haines (2005) suggests a buffer distance based on accommodating the natural water level fluctuations of ICOLLs whilst incorporating contingency for future level rise due to climate change, as well as providing a horizontal buffer to maintain and promote ecological function. Figure 6.2 shows this type of buffer configuration.

Figure 6.2 Optimal ICOLL Buffer Configuration (Haines, 2005)



It is now widely accepted in the global scientific community that the global climate is changing due to increases in atmospheric 'greenhouse' gas concentrations (IPCC, 2001), and, due to the inertia of the system, the effects of this will be experienced in the next few decades regardless of any mitigation attempts (Lord & Gibbs, 2004). Climate change has great potential to impact upon ICOLLs in NSW. Predicted sea level rise will increase berm heights through normal coastal processes, which will in turn raise the maximum water level of ICOLLs, further threatening encroached developments. ICOLLs that currently are artificially manipulated for flood mitigation purposes will require more frequent and systematic openings to ensure the equivalent protection of assets, increasing the level of regulation imposed upon the waterway. This type of practice is counter to the principles of Ecologically Sustainable Development (ESD), a key component of the NSW Costal Policy (1997). Reducing the artificial opening of coastal lagoons is also identified by the Healthy Rivers Commmision as an integral goal of their Coastal Lakes Strategy (HRC,2002).

In addition to intrinsic environmental values, ICOLLs also generate ecological, social and economic benefits for the surrounding communities and the population as a whole. Historically, economic and social issues have been the driving factors in most estuarine management decisions, with sectors such as tourism and commercial fisheries reliant upon coastal estuaries. Often there is significant pressure to maintain estuary character more favourable to these industries than that of maintaining natural hydrological cycles (Haines, 2006).

With the pressures imposed upon ICOLLs by future coastal development growth and climate change, careful management will need to be undertaken with particular regard for the natural variation of ICOLL conditions and future change if the environmental amenity of these important coastal features.

6.4 Wollongong Estuaries

The following contains a brief description of the form, class and dominant characteristics of the ten Wollongong estuaries assessed in this report. Appendix F contains aerial and site photos of each estuary (Figures F1-F10).

6.4.1 Hargraves Creek

Hargraves Creek is a very small coastal creek (ICOLL) that has limited fluvial input, except in periods of flooding. The creek itself is perpendicular to the beach and displays a narrow linear morphology in its upper reaches. This estuary has a characteristic lagoon located close to its mouth, with a small flood-ebb delta present. The lagoon however would have limited interactions with tidal and wave processes, except in king-tide or storm events.

6.4.2 Stanwell Creek

Stanwell Creek is a slightly larger estuary that is also classified as an ICOLL (coastal creek). The lagoon is the main feature of this estuary, with some evidence of rocky features on the bottom sediments. These features may have been deposited in the calmer waters of the lagoon from erosion of the creek channel during flooding events, or may be bedrock features that can be found underlying the transgressive sand sheets. Although the potential for fluvial input is increased due to the relatively large catchment size in comparison with other lagoons, fluvial inputs appear to be limited with the notable lack of a fluvial delta at the landward end. The dominant forces acting on this lagoon would be small wind waves that form on the limited water surface area, however there appears to be a greater potential for some tidal exchange to occur, especially at high tide on the beach platform, which would allow more regular flushing of the estuary. The lack of a prominent flood-ebb delta on the seaward edge suggests however that the marine influence is dominated by the action of waves consolidating the beach barrier, rather than tidal influence on the estuary.

6.4.3 Stony Creek

Stony Creek is a very small ICOLL (coastal creek) formed on a mostly rocky substrate composed of the underlying bedrock. The small creek channel has limited fluvial inputs except during flood events and the estuarine lagoon is shallow and narrow in morphology. The lagoon is largely linear and is situated perpendicular to the beach barrier. No flood-ebb delta is visible which suggest limited tidal influence into the estuary. Wave processes that push sand up into the estuary mouth and consolidate the beach barrier dominate the system.

6.4.4 Flanagans Creek

Flanagans Creek is a small ICOLL (coastal creek) that is dominated by wave processes acting on the estuary mouth. The estuary displays a highly modified, narrow, linear morphology that is characteristic of coastal creeks and is positioned perpendicular to the beach barrier. The fluvial inputs into the lagoon are characteristically low as evidenced by the lack of a fluvial delta.

6.4.5 Slacky Creek

The Slacky Creek estuary consists of a small, narrow, linear lagoon that is positioned perpendicular to the beach barrier. The morphology of the lagoon is similar to that of Flanagans Creek, Whartons Creek and Collins Creek with the estuary classified as an ICOLL (coastal creek) as it only intermittently open to the ocean at its mouth. The dominant process acting on the estuary is that of waves which push-up sand towards the mouth of the estuary consolidating the beach barrier. Sand may be pushed into the estuary mouth during storm events. The fluvial-marine exchange is evident by a small flood-ebb delta present at the mouth of the lagoon.

6.4.6 Whartons Creek

Whartons Creek is a very small ICOLL (coastal creek) positioned perpendicular to the beach barrier. The estuary is comprised of a small, shallow lagoon that is cut-off from the ocean by the beach. Tidal processes would very rarely penetrate the lagoon, except during king-tide and storm events. Wave action may bring sand into the lagoon during storm events. Fluvial processes are negligible in the estuary due to the limited catchment area, with no fluvial delta present.

6.4.7 Collins Creek

Collins Creek is classified as an ICOLL (coastal creek) as it is only periodically open to the ocean in flooding events or storm events that have sufficient energy to open the entrance of the lagoon. The morphology of the lagoon is linear running perpendicular to the beach that it is bounded by. The creek contains a shallow, narrow estuarine lagoon and an alluvial forest in the shallow depositional environments. The creek is predominantly wave influenced as the mouth is controlled by the action of waves forcing sand into the area and further consolidating the entrance until a flood or storm event occurs. As the catchment area is isolated to the adjacent hinterland, fluvial influence is low, however, due to limited tidal flushing events the creek is highly vulnerable to sedimentation and pollutant accumulation as it is situated in a highly urbanised catchment.

6.4.8 Bellambi Gully

Bellambi Gully is an ICOLL (coastal lagoon) and is similar in morphology to Bellambi Lagoon. The lagoon lies parallel to the sand dune barrier. A tidal channel runs along the western and southern sides of the lagoon exiting to the ocean to the south. The lagoon itself has been modified and is only linked to the tidal channel and the upstream catchment via two connecting channels. These are elevated between one (1) and two (2) metres above the invert of the tidal channel and limit the intrusion of saline, tidal waters into the lagoon. As a result the waters of the lagoon border on fresh to brackish and tidal flushing events are extremely limited. Additionally, tidal flushing appears to be further limited with the wave processes dominating the morphology of the estuary entrance. Bellambi Point projects quite significantly from the coast to the south of the entrance, protecting the entrance area from wave attack from the dominant S – SE swell direction. As a result marine sands accrete in the area and have directed the entrance along the back of the beach, causing it to travel several hundred metres before exiting into the ocean at the north of Bellambi Point.

6.4.9 Bellambi Lagoon

Bellambi Lagoon is an ICOLL (coastal lagoon) and is one of the largest of the estuaries studied in this report. The lagoon displays typical coastal lagoon morphology, in that it sits parallel to the beach barrier, with its entrance at the southern end of the lagoon. The lagoon itself has undergone intense modification in recent years after sandmining took place after European settlement. The estuary is usually closed, with infrequent opening events creating a small flood-ebb delta at the marine-dominated edge of the estuary. The estuary is subject to micro-tidal influences, however it is still a wave-dominated estuary. The central lagoon basin is shallow and contains two small and one large sand island, which have been artificially created. Fluvial inputs into the lagoon are low except in high rainfall and flood episodes. The extensive barrier to the estuary consists of a series of accreted parallel sand dunes that are broken only at the estuary opening. The morphology of the estuary provides for significant environments such as estuarine saltmarsh and swamp communities and alluvial forest to be present.

6.4.10 Tom Thumb Lagoon

Tom Thumb Lagoon is classified as a remnant saline coastal lagoon. Much of the original lagoon has been reclaimed for use as the Port Kembla Steelworks and Harbour area. The estuary was originally 500 ha in area but now has been reduced to just 50 ha due to past infilling. Tom Thumb Lagoon is comprised of an estuarine channel, remnant saltmarsh and tidal mudflats. The lagoon remains permanently open to the sea and is mainly influenced by micro-tidal environments common to the NSW coast and small localised wave activity at the mouth from ship movements in the protected harbour. Before development, the estuary would have been bounded by a sand barrier and consisted of a large, moderately deep, central basin influenced predominantly by fluvial processes. The lagoon now consists of straight, formalised estuarine channels that do not reflect its original form. A fluvial bay-head delta is no longer present in the system, however a small marine flood-ebb delta is present at the mouth of the estuary, which is characteristic of marine inputs into the system.

6.5 Bank Erosion Assessment

6.5.1 Assessment Methodology

An assessment of bank erosion was undertaken through a field inspection along the banks of each of the ten estuaries over the period 21 to 22 February 2007. Identified bank erosion was assessed based on the level of activity as described in Table 6.1. GPS co-ordinates for each erosion site were documented for subsequent GIS mapping.

Table 6.1 Erosion Categories and Description

Erosion Category	Description
Stable	Banks are stable and are generally well vegetated or have been stabilised artificially.
Minimally Active	Banks display minor, localised erosion or evidence of past erosion. Generally active only in high to extreme flow events.
Moderately Active	Banks exhibit minor to moderately severe erosion over lengths greater than 5 metres. Generally active in moderate to high flow events.
Highly Active	Banks exhibit moderate to severe erosion over lengths greater than 5 metres. Generally active over all flow events.

6.5.2 Results and Recommendations for Erosion Management

The following discussion provides a summary of the field observations and recommendations for bank erosion management. Sites where significant erosion was identified have been provided a site code, and their characteristics and management recommendations have been addressed in more detail. All references to left and right banks are made looking downstream.

The figures provided in Appendix F (F1–F10) display the distribution of the erosion categories along the banks of each estuary as well as photographs of representative bank conditions.

Hargraves Creek

As detailed on Figure F1 (Appendix F), the banks of Hargraves Creek are largely stable and for the most part bank conditions can be improved through establishment of a vegetated riparian zone. However, three sites were identified that display moderately to highly active bank erosion. These are detailed below.

Site H1

The freshwater reach of Hargraves Creek upstream of the lagoon is relatively steep and exhibits moderately to highly active bank erosion even though the banks are well vegetated. The channel bed consists of cobble-sized sediment indicating that stream energy in this reach is high. It is suspected that past works to constrain flows has increased channel capacity and flow energy, exacerbating channel instability in this reach. Evidence for these works is located along the right bank in the downstream extent of this reach in the form of spoil-like piles acting as a levee type structure. There is also evidence of regular human access to the creek, limiting the generation and growth of understorey vegetation.

Apart from acting as a source of sediment to the estuary, the erosion at this site is not threatening any high value assets. Additionally, due to the high stream energies in this reach, controlling erosion here will likely require considerable intervention at high cost and risk. Hence, direct erosion control is not recommended, however, fencing to control access and improvements in understorey vegetation may reduce the rate and extent of erosion through this reach.

Site H2

This site is located in the upstream extent of the lagoon and exhibits active erosion of the right bank over a distance of approximately 40 metres. The erosion at this site may be exacerbated by confinement of flow through the footbridge crossing as well as uncontrolled access to the foreshore. Additionally, the growth of Typha and Phragmites spp. along the left bank constrains low to moderate flows against the right bank promoting bank erosion.

Direct erosion control measures are not recommended at this site as it does not pose a threat to any assets. Erosion along this site is likely to be reduced through establishment of a fenced and vegetated riparian zone.

Site H3

This site exhibits erosion of the embankment to the beach as a result of regular access between the beach and the beach reserve. Construction of a formal access way and revegetation of the remaining section of the eroding embankment is recommended.

Stanwell Creek

The right bank of Stanwell Creek Lagoon, and both banks immediate upstream of the causeway are generally stable, as detailed on Figure F2 (Appendix F). Establishment of a vegetated riparian zone would improve ecological associations along the right bank in the middle to lower section of the lagoon.

The left bank, however, exhibits active erosion of varying degrees along the lagoon section as detailed below.

Site SW1

This site exhibits moderately active erosion for approximately 50 metres downstream of the causeway. The dominant erosion process is suspected to be bank undercutting during moderate to high flow events. The erosion along this site poses a threat to Beach Road. Downstream of this site the bank conditions improve, however there still exists the potential for erosion and further risk to the road.

As the road limits the potential to establish a vegetated riparian zone, direct control works to address the erosion through placement of rock toe protection is recommended. If space allows, revegetation of the upper bank with understorey and shrub species is recommended. This should be extended downstream through the minimally active zone.

Site SW2

This site is located along the lower left bank of the lagoon and exhibits highly active bank erosion. The bank erosion here is likely the result of regular access to the lagoon foreshore, however, flows and wind generated waves may contribute to ongoing erosion. Rock protection has been placed along the upstream section of the bank where erosion has threatened the car parking area.

Establishment of a vegetated riparian zone is limited along this site by the car parking area along the upstream extent and unrestricted foreshore/beach access in the downstream extent. Hence, it is recommended that the existing rock protection be extended downstream. This should be supplemented with revegetation and fencing to control access along the downstream section.

Stoney Creek

Having no developed coastal plain, the estuary of Stoney Creek is almost entirely bounded by bedrock and does not exhibit any erosion issues as detailed on Figure F3 (Appendix F). However, establishing riparian vegetation along the lower left bank is recommended to improve ecological conditions in the upper lagoon through shading and habitat provision.

Flanagans Creek

The banks of Flangans Creek are generally stable to minimally active with the left bank exhibiting evidence of past undercutting and slumping. Moderately active erosion is limited to two short sections along the right bank, as detailed on Figure F4 (Appendix F). As no assets are currently being threatened by erosion along these sections, no direct control works are required. Instead, it is recommended a vegetated riparian zone be established to improve bank stability and ecological associations. As the high left bank is bounded by grassed parkland, benching of this bank to reduce erosion potential during high magnitude events is considered feasible.

Slacky Creek

As seen on Figure F5 (Appendix F), the lower estuary of Slacky Creek displays several sections of moderately to highly active bank erosion. These sites are detailed below. For the other sections of bank, there are considerable opportunities to improve riparian vegetation associations.

Site S1

This site exhibits moderately to highly active erosion of an outside bend. The erosion process here is dominated by bank undercutting and slumping associated with moderate to high flow events. Effective erosion control would require direct stabilisation works in the form of rock toe protection and upper bank reshaping in association with revegetation. However, as a large area of grassed parkland flanks the area, the erosion is not threatening any assets. Hence, addressing the erosion here is not a high priority.

Site S2

This site displays moderately active erosion of an outside bend along the right bank upstream of Blackall Street and along both banks downstream. Improved stability could be achieved upstream of the bridge through establishment of a vegetated riparian zone. It is likely that erosion downstream of the bridge is exacerbated by eddies generated during flow events as the channel widens immediately downstream of the road and footbridge crossings. To effectively address the erosion, these banks may require either direct protection or reshaping prior to revegetating. However, as the erosion is not threatening any assets, such works are not considered a high priority. Nevertheless, the erosion should be monitored to ensure it does not impact on the road and footbridge crossings.

Whartons Creek

The estuarine section of Whartons Creek is relatively stable with only the section of the left bank between the entrance to Bulli Beach Holiday Park and the downstream footbridge exhibiting moderately active erosion, as detailed on Figure F6 (Appendix F). As this erosion does not present an immediate threat to assets, restricting access and revegetation of this section will be effective in improving the overall stability of this section. Upstream of the holiday park entrance the banks are generally stable with only localised areas of minor to moderate erosion present. While the banks of the estuary entrance downstream of the footbridge have been protected with gabion baskets, revegetation would supplement these works along the left bank.

Collins Creek

The banks of the Collins Creek estuary are predominantly stable and bounded by grassed parkland and playing fields, as detailed on Figure F7 (Appendix F). Hence, all sections downstream of Kulgoa Road present excellent opportunities to improve ecological associations through riparian revegetation and management with the aim to provide a continuous riparian zone linking the entrance to the well-vegetated channel upstream of Kulgoa Road. As seen in Figure 3.7 (Appendix F), only the banks in the vicinity of the footbridge exhibit some minor instability. However, the banks in the lower profile here consist of bedrock and have limited potential to erode further. While the northern arm is essentially a drainage swale, it is well vegetated with Typha, Phragmites and other grasses and acts as a pollutant and sediment trap. Hence, any revegetation along the northern arm should be limited to the upper bank profile and above.

Bellambi Gully

As seen on Figure F8 (Appendix F), the banks of Bellambi Lagoon are generally stable with only limited minimally active erosion along the left bank towards the entrance. This erosion is considered 'natural' and does not require works to address it. However, monitoring of the erosion in the vicinity of the footbridge is recommended to ensure it does not impact on the footbridge in the future.

Dumped rubbish was also observed along the left bank of the tidal channel upstream of the footbridge. A community education and engagement program to improve the riparian vegetation associations along the tidal channel may assist in discouraging future dumping of waste in this location.

Bellambi Lagoon

The banks of Bellambi Lagoon are largely stable, however, moderately active erosion of the dunes at the entrance was identified, as detailed on Figure F9 (Appendix F). Along the right bank this erosion is associated with the area being used as an access to the beach. Creating a formal access way and revegetating the remaining disturbed area is recommended to address the erosion here. The large dune that bounds the left bank of the entrance is experiencing erosion. This is suspected to be primarily driven by wave attack during ocean storm events, however catchment flow events and unrestricted access to the dunes are likely to be contributing. It is not practical to fence the dunes to control access at this location due to the processes operating. Hence management actions are limited to public education and signage to discourage inappropriate activities that can lead to dune destabilisation.

Tom Thumb Lagoon

While no moderately to highly active bank erosion was identified within Tom Thumb Lagoon, scour and channelisation is evident across the floor of the saltmarsh flat in the western arm, as detailed on Figure F10 (Appendix F). This has created a landscape of elevated areas colonised with saltmarsh and lower mudflat areas that are regularly inundated by the tides. The scour is likely to be exacerbated by the confinement caused by the landfill area to the north and the railway to the south of this area, constraining flood event flows and resulting in elevated flow velocities and energy. Additionally, the reported decline in saltmarsh might also have exacerbated the scour by creating bare earth areas that can be more readily eroded during flow events.

It is not known whether the proportion of scoured areas to saltmarsh has increased with time. If so, this may be contributing to the observed decline of saltmarsh in the western arm through decreasing the elevation to which tides reach due to an increasing waterway capacity. This assumes that for any given tide event only a certain volume of water enters the system due to hydraulic controls (causeway, bridges) further downstream. Decreased tidal heights would therefore reduce the frequency and duration of saltmarsh inundation by saline waters.

The banks of the northern arm exhibit minimally active erosion that is generally localised to the lower bank where tidal inundation prevents the growth of vegetation. There is some evidence of sedimentation in the form of mid-channel and bank attached bars in the upstream sections of the northern arm. The source of this sediment was not determined, however, the deposits may just be a product of localised reworking of the channel bed to create a pool, bar and riffle morphology.

Industrial waste materials such as slag and washed coal refuse comprise portions of the channel and bed structure, which if disturbed could potentially cause contamination of the estuary.

6.5.3 Erosion in Upstream Catchments

In addition to the assessment of estuary bank erosion, this investigation has attempted to identify significant erosion sites along streamlines in the upstream catchment of each estuary. Table 6.2 lists identified and potential erosion sites in the upstream catchments of each estuary. Apart from one reported site (Site Number 8), these have been identified from either the field investigation or through aerial imagery analysis. In the case of the latter, it is recommended that these sites be verified through field investigation. As a priority, verification should cover the streamlines of Bellambi Gully and Bellambi Lagoon catchment where 12 of the 24 potential erosion sites have been identified. Of the other sites, it is recommended that Site Number 6 along Whartons Creek be further assessed for erosion control works as it exhibits an erosion head that will retreat upstream and further destabilise banks. Additionally, the reported Site Number 8 should be investigated due to the community concerns here.

Table 6.2 Erosion Sites in Upstream Catchments

Site	Estuary	Easting	Northing	Source	Comment
1	Hargraves	314319	6211007	Field	Minor erosion of right bank downstream of Old Coast Road.
2	Hargraves	312618	6211229	Imagery	Significant area of ground disturbance upstream of Stanwell Tops. Potential sediment source.
3	Flanagans	308466	6201365	Field	Short reach subject to recent riparian vegetation removal and minor erosion.
4	Slacky	308030	6199247	Field	Minor left bank erosion and in channel sedimentation.
5	Slacky	307970	6199414	Field	Approximately 100 m of minimally active, localised erosion of both banks. Some inchannel deposition of tailings like sediment. May indicate erosion of upstream fill deposits.
6	Whartons	308493	6198438	Field	Erosion head with moderately active erosion downstream.
7	Whartons	307937	6198731	Imagery	Potential erosion in reach highly constrained by development.
8	Whartons	307043	6198551	Report	Reported large erosion site along tributary of Whartons Creek adjacent to Corrie Road.
9	Collins	308442	6197303	Imagery	Potential erosion, especially on outside of bends, throughout reach downstream of railway crossing to a private access road bridge.
10	Collins	308178	6197360	Imagery	Potential erosion on outside of bend.
11	Collins	308004	6197417	Imagery	Potential erosion for approximately 100 m downstream of Thirroul Street.
12	Collins	307700	6197594	Imagery	Potential left bank instabilities over a 100 m reach downstream of footbridge at Woonoona High.
13	Bellambi Gully	306524	6197011	Imagery	Potential localised bed and bank erosion.
14	Bellambi Gully	307858	6195852	Imagery	Potential bank instabilities upstream of rail crossing for 20 metres.

Site	Estuary	Easting	Northing	Source	Comment
15	Bellambi Gully	306619	6196213	Imagery	Short reach of active bank erosion.
16	Bellambi Gully	307381	6196145	Imagery	Potential bank erosion 50 metres upstream and downstream of footbridge.
17	Bellambi Gully	306926	6196264	Imagery	Waterway is extremely constrained by development and is potentially eroding over a 200 m section downstream of Princes Highway.
18	Bellambi Gully	307971	6195410	Imagery	Potential moderate to highly active erosion of both banks upstream of Gladstone Street.
19	Bellambi Gully	307687	6195387	Imagery	Potential moderate left bank erosion for 100 m upstream of Brompton Road.
20	Bellambi Gully	307477	6195538	Field	Minor bank erosion downstream of culverts under Northern Distributor.
21	Bellambi Gully	306811	6195684	Imagery	Creek is highly constrained by development between Princes Highway and Northern Distributor. Likely to be experiencing moderate to high degrees of channel instability.
22	Bellambi Lagoon	306837	6195238	Imagery	Potential moderate right bank erosion over approximately 30 metres.
23	Bellambi Lagoon	306913	6195174	Imagery	Moderate to severe localised erosion.
24	Bellambi Lagoon	307451	6194903	Imagery	Moderate erosion of left bank extanding for approximately 100 m upstream of footbridge at end of Louks Street.

6.5.4 Erosion Management Priorities

Based on this assessment, of the sites detailed in the previous sections, the following are considered priority sites/actions for erosion management:

» Stanwell Creek (SW1 and SW2) as future ongoing erosion is threatening road and car parking facility assets;

» Whartons Creek (Upstream Catchment Site 6) as ongoing bed erosion will extend the length of bank instability at this site; and

» Undertake field investigations to verify the potential upstream catchment erosion sites identified in the Bellambi Gully and Bellambi Lagoon catchments.

For the other sites, a prioritisation process should be undertaken according to the importance of other considerations. That is, consideration of the importance of ecological, social and economic aspects of the site. This may, for example, include the existence of threatened species, the importance of certain habitats, the local community's interest (such as Landcare group activity or cultural significance) in the site, the potential to build on past riparian/foreshore rehabilitation activities and extend on existing vegetated riparian areas, the protection of estuaries with good water quality values, or the importance of the site for recreational activities.

6.6 Hydrological Study

6.6.1 Introduction

The Illawarra region of NSW experiences high intensity localised storm events and associated flash flooding with discharges comparable to the largest rainfall-runoff floods worldwide (Reinfelds and Nanson, 2004). In the last 50-60 years high magnitude events causing substantial property damage to urban areas have occurred with a historical frequency of around eight years (Reinfelds and Nanson, 2001, in Reinfelds and Nanson, 2004). This may be due to the fact that the Illawarra catchment is becoming increasingly urbanised, leading to increases in the frequency and magnitude of discharge peaks, while decreasing the time to reach peak flows. This results in the enlargement of upstream channels and the downstream deposition of high volumes of eroded sediment.

Stream Channel Profiles

The Illawarra escarpment produces steep stream profiles, falling between 200-300 m/km until rapidly reducing to less than 5 m/km on the costal plain (Nanson and Young, 1981, in Reinfelds and Nanson, 2004). This steep profile and rapid gradient transition have been linked to the tendency of Illawarra streams to decrease in channel capacity downstream from the escarpment to the coastal plain, to have dense vegetative cover, and large floodplains to accommodate floodwaters. This means that the actual stream channels have limited capacity to convey flood discharges, and the floodplains become the more important flood conveyance mechanism. This is reflected in the geomorphological characteristics of the Illawarra streams, which display compound channel morphologies as a result of the common recurrence of high magnitude events. Compound channel streams typically have an inner 'active channel' formed and maintained by frequent small flows, and a larger 'macro channel' related to the higher and more infrequent flood volumes.

The unimportance of the low flow channel in comparison to the macro channel in conveying flood discharges was confirmed after the 1998 flood event, when low flow channels were observed to have been extensively altered through deposition and erosion. The macro channels experienced scour in the same event, suggesting the channel morphology continues to be determined by high magnitude floods (Reinfelds and Nanson, 2004).

Spatial Characteristics of Illawarra Storms

The spatial behaviour of high magnitude storms also contributes to the flood characteristics observed in the Illawarra catchment. Recent studies into high magnitude storms (Grootemaat, 2000; Reinfelds and Nanson, 2001, in Reinfelds and Nanson, 2004) have shown that most intense storms in the Illawarra region exhibit non-stationary behaviour, producing higher intensities and associated discharges in the middle and lower catchment areas than the orographic rainfall gradient typical of escarpments would suggest. Because of this spatial variance in intense storm behaviour, Reinfelds and Nanson (2001) emphasise the need for caution in flood discharge estimation for the Illawarra catchment.

Modelling Wollongong Catchments

Large sediment and woody debris loads accompany high magnitude flood events and introduce uncertainties for hydraulic modelling due to debris accumulation, blockages and channel changes altering stream characteristics. The prolific growth of riparian vegetation observed in the Illawarra catchment also impacts on hydraulic modelling assumptions, and must be considered a dynamic influence when investigating conditions over extended time frames.

6.6.2 Wollongong Estuaries Flood Volumes

Estuary processes are closely linked to the hydrological processes that dominate catchment runoff, and impact upon aspects such as the frequency of the estuaries opening to the ocean, water quality and ecological health. From a catchment perspective the flushing of the estuary is dependent on the volume of runoff generated by the catchment in storm events, and the recurrence interval of these events determines the frequency at which flushing occurs. In practice the dynamic nature of coastal morphology such as berm height has a large impact on the flushing frequency of coastal estuaries, but for volume calculations the berm height has been assumed to be stationary.

6.6.3 Catchment Runoff Assessment

For each estuarine catchment the critical runoff volume generated by a one year Average Recurrence Interval (ARI) storm was calculated using a simple water balance model to incorporate infiltration and evaporation losses. The critical runoff volume is the peak runoff volume produced by a one year ARI event, and is identified by calculating runoff for a range of design storm durations. Typically the peak runoff volume is generated by long duration storm events greater than 12 hours. The rainfall excess required to completely displace the volume of each estuary was also calculated. The rainfall excess refers to the amount of rainfall that turns to runoff, i.e. the rainfall required to generate sufficient volume of runoff to flush the estuary (following saturation of the catchment).

Rainfall Data

The Wollongong design storm events were generated from Australian Rainfall and Runoff (AR&R) Intensity-Frequency-Duration (IFD) curves for a one year ARI, and the IFD tables can be found in Appendix G.

Loss Model

To accurately represent runoff process in a catchment, the losses due to infiltration need to be taken into consideration. The initial loss due to rapid infiltration at the beginning of a storm event and the continuing infiltration losses over the period of the storm both need to be taken into consideration when modelling rainfall-runoff relationships. The initial and continuing losses adopted for this catchment analysis were 30 mm and 2.5 mm/hr respectively. This data was based on AR&R Volume 1, Book 2, Table 3.2; Design Loss Rates for NSW.

Estuary Volumes

The estuary volumes used for analysis are calculated from estimates of average water depth based on field observations, and measurements of surface areas from aerial photography of the individual sites. The catchment data can be seen Table 6.3.

Table 6.3 Catchment Data

Estuary	Catchment Area (Ha)	Estuary Area (m^2)	Adopted Estuary Depth (m)	Estuary Volume (m^3)
Hargraves Creek	207.3	3300	1.2	3960
Stanwell Creek	757.6	13000	1.5	19500
Stoney Creek	425.2	1200	0.3	360
Flanagans Creek	181.4	4600	0.8	3680
Slacky Creek	285.3	5500	0.5	2750
Whartons Creek	210.8	2350	0.8	1880
Collins Creek	390.1	5000	0.8	4000
Bellambi Gully	426.8	28000	1.5	42000
Bellambi Lagoon	245.8	51000	0.5	25500
Tom Thumb Lagoon	226.0	54000	0.1	5400

Results

The calculation of runoff volumes for each catchment indicated that all catchments produce the critical runoff volume in the one year ARI 18 hour duration design storm event. The results for each estuary are detailed in Table 6.4.

Table 6.4 Estuary Runoff Results

Estuary	Critical Volume Storm Duration (Hours)	Critical Storm Runoff Volume (m^3)	Catchment Runoff - Estuary Volume Ratio	Rainfall Excess to Flush Estuary (mm)
Hargraves Creek	18	79700	20.1	1.9
Stanwell Creek	18	291000	14.9	2.6
Stoney Creek	18	163300	453.6	0.1
Flanagans Creek	18	69700	18.9	2.0
Slacky Creek	18	109600	39.9	1.0
Whartons Creek	18	81000	43.1	0.9

Estuary	Critical Volume Storm Duration (Hours)	Critical Storm Runoff Volume (m^3)	Catchment Runoff - Estuary Volume Ratio	Rainfall Excess to Flush Estuary (mm)
Collins Creek	18	149800	37.5	1.0
Bellambi Gully	18	163900	3.9	9.8
Bellambi Lagoon	18	94400	3.7	10.4
Tom Thumb Lagoon	18	86800	16.1	2.4

Table 6.4 indicates that the critical runoff volumes resulting from the one year ARI 18 hour design storm event for all catchments are considerably greater than the volume of the estuaries they flow into, and consequently would cause flushing of the system. It can also be seen that the rainfall excess required to produce runoff equal to or greater than each estuary's volume is quite low, ranging up to a maximum of 10.4 mm. When the initial loss of 30 mm and continuing losses of 2.5 mm/hr are taken into account, the rainfall excess corresponds to one year ARI design storms of between one and two hours duration (equivalent to approximately 30-45 mm rainfall) as the minimum required to produce the flushing volume. As discussed in more detail in Section 5.6.4, these results indicate that flushing of all 10 estuaries would be expected to occur in association with relatively frequent rainfall events, and would assist in minimising issues such as the eutrophication of estuarine waters by flushing nutrients from the system.

6.6.4 Evaluation of Flushing Events

During field investigation of the estuary sites it was noted that most estuaries had recently been open to the ocean. Rainfall records from the Bureau of Meteorology (BOM) indicated that prior to site visits, rainfall events of 11.8 mm and 32.7 mm were recorded at the University of Wollongong meteorological station on the 11th and 12th of February respectively. This event provides confirmation of the typical rainfall event likely to cause the estuaries to open; the rainfall on the 11th, whilst not sufficient to flush the estuary, would have increased the soil moisture such that the 32.7 mm falling the next day experienced fewer losses and hence produced higher runoff.

Figure 6.3 shows mean Wollongong rainfall data (for the period from May 2006 to April 2007) compared to observed rainfall from May 2006 to April 2007. It can be seen that while observed monthly rainfall for some months were very close to mean values, monthly data for other were much lower or higher than the average.

Analysis of rainfall events during the year from May 2006 to the end of April 2007 reveals seven rainfall events with a high probability of causing estuary flushing, and a further nine events with the potential to generate conditions for the estuaries to have at least opened to the ocean.

Table 6.5 shows the number of rainfall events in the period May 2006 to April 2007 identified to be of sufficient volume to flush the estuaries (24 hour rainfall exceeding 30 mm and/or several smaller consecutive events), and those events with the potential to cause the estuary to open resulting in partial flushing (≥25 mm total rainfall in three day period). It can be seen that probable flushing occurred quite regularly throughout the year, accompanied by consistent potential estuary opening events. The implications for estuarine health are positive, as the frequency of high intensity events in the Illawarra region indicates that this number of flushing and opening events generated from rainfall is not unusual and would be expected in an average year. Correspondence with the Bellambi Dune Bushcare group confirmed that in both March and April 2007 Bellambi Lagoon experienced an extended opening event, lasting for 3 weeks in March, and one week in April.

Figure 6.3 Observed and Mean Wollongong Rainfall

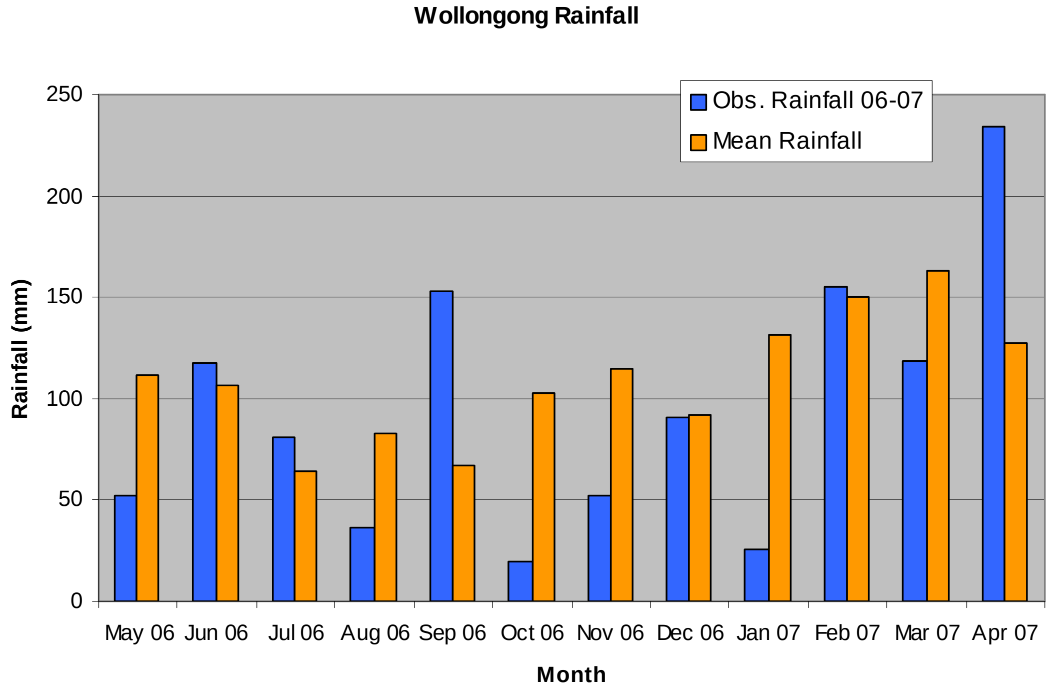


Table 6.5 May 2006 – April 2007: Significant Rainfall Events

Month	Number of Probable Flushing Events	Number of Potential Opening Events
May ‘06	0	1
Jun ‘06	1	1
Jul ‘06	0	2
Aug ‘06	0	1
Sep ‘06	1	0
Oct ‘06	0	0
Nov ‘06	0	1
Dec ‘06	1	1
Jan ‘07	0	0
Feb ‘07	2	0
Mar ‘07	1	1

Month	Number of Probable Flushing Events	Number of Potential Opening Events
Apr '07	1	1
Total	**7**	**9**

The potential impact of climate change on rainfall patterns in temperate regions is predicted to be an increase in the frequency and intensity of storm events, which in the storm dominated Wollongong catchments could lead to an increase in estuarine opening and flushing events. This may be offset to some degree by rising sea levels causing transgressive migration of barrier systems and an increase in berm height leading to larger runoff volumes being required to flush estuary systems.

7. Summary of Significant Issues

The estuary processes study identified the following issues as being of particular significance for the ongoing management of the estuaries, and the protection of their intrinsic environmental ecological, social and cultural heritage values:

- Revegetation of riparian areas at Stanwell Creek, Stoney Creek, Flanagans Creek, Slacky Creek and Whartons Creek to increase the width/depth and length of the riparian corridor. It is recommended that native, endemic species suitable for estuarine lagoons be used in the revegetation, similar to those species used at Collins Creek;
- Monitoring for decline, and/or invasion by exotic species, of the large areas of Coastal Saltmarsh EEC (Collins Creek, Bellambi Gully, Bellambi Lagoon and Tom Thumb Lagoon), Swamp Oak Forest EEC (Bellambi Lagoon and Tom Thumb Lagoon) and Sand Bangalay Forest EEC (Tom Thumb Lagoon), similar to the current WCC program at Tom Thumb Lagoon;
- Active monitoring and management of exotic species at all estuaries surveyed;
- Investigation into nutrient inputs and cycling within the catchments of the lagoons surveyed, and the role nutrients have in generating algal blooms within the estuaries. This would be particularly important for Bellambi Gully as algae blooms appear to be threatening the seagrass beds in this estuary;
- Investigation into the possible contamination of Tom Thumb Lagoon from the adjacent decommissioned landfill site;
- Implementation of measures to improve water quality in the estuaries, including improved stormwater and construction runoff management, a community education program and the improved management of sewerage systems and overflows (including the connection of all residences in the catchments of Hargraves, Stanwell and Stoney Creeks);
- Implementation of a comprehensive water quality monitoring program for all estuaries (excluding Tom Thumb Lagoon) to monitor faecal coliform levels plus basic physical and chemical parameters, including nutrients, with notification of the results on signs placed adjacent to the estuaries and on Council's website;
- The ongoing monitoring and maintenance, and where possible, improvement, of aquatic habitats of value for fishery nursery areas, including seagrass beds and mangroves;
- Implementation of targeted erosion protection and remediation works to minimise further erosion and the impact of high sediment loads on the estuaries;
- Education of the community via brochures, leaflets, the media and appropriately located signage, particularly regarding their ability to assist in the ongoing protection and management of the estuaries; and
- Education of the community via interpretative signage relating to the estuaries' ecological and cultural heritage values.

To assist in the effective development of a management plan and strategy that covers all issues, the significant issues identified during the processes studies are summarised by estuary in Table 7.1.

Table 7.1 Summary of Significant Issues

Estuary	Water Quality (WCC 2007 and AWT 1999)	Flora	Fauna	Aquatic Ecology	Bank Erosion / Hydrology
Hargraves Creek	Faecal contamination, particularly during wet weather periods. Faecal coliforms levels generally exceed the secondary recreational contact guidelines. Nutrient levels elevated in the downstream reach when compared to the upstream freshwater reach.	Decline and/or weed invasion of Coastal Saltmarsh (EEC). Presence of noxious weeds. Cleared riparian vegetation and replacement with Kikuyu grass.	Loss/damage to potential habitat for threatened amphibians (Green and Golden Bell Frog and Red-crowned Toadlet) and potential foraging habitat for threatened birds (Sooty Owl, Powerful Owl, Barking Owl) through urban development and human disturbance.	AWT (1999) macroinvertebrate study should be repeated to monitor current condition.	Minor erosion of right bank downstream of Old Coast Road. Significant area of ground disturbance upstream of Stanwell Tops, which is a potential sediment source.
Stanwell Creek	Faecal contamination, particularly during wet weather periods. Faecal coliforms levels generally exceed the secondary recreational contact guidelines.	Decline and/or weed invasion of Coastal Saltmarsh (EEC) and Swamp Oak Floodplain (EEC). Presence of noxious weeds. Cleared riparian vegetation and replacement with Kikuyu grass.	Loss/damage to potential habitat for threatened amphibians (Green and Golden Bell Frog and Red-crowned Toadlet), threatened birds (Sooty Oystercatcher and foraging habitat for owls) through urban development and human disturbance. Swamp Oak Forest provides potential foraging habitat for a variety of birds and mammals. Loss of fauna and riparian habitat through clearing, weed invasion and urban development.	AWT (1999) macroinvertebrate study should be repeated to monitor current condition.	The right bank and both banks immediately upstream are generally stable. Areas of highly active erosion present downstream of the causeway.

Estuary	Water Quality (WCC 2007 and AWT 1999)	Flora	Fauna	Aquatic Ecology	Bank Erosion / Hydrology
Stoney Creek	Faecal contamination, particularly during wet weather periods. Faecal coliforms levels generally exceed the secondary recreational contact guidelines. Potential impacts from the impoundment of the tributaries on the escarpment. Discharges from the Illawarra Coke Colliery Pty Ltd.	Decline and/or weed invasion of riparian vegetation.	Disturbance of fauna and riparian habitat through weed invasion.	AWT (1999) macroinvertebrate study should be repeated to monitor current condition. Potential impacts from the impoundment of the tributaries on the escarpment. Discharges from the Illawarra Coke Colliery Pty Ltd.	The estuary is almost entirely bounded by bedrock and does not exhibit erosion issues.
Flanagans Creek	Elevated nutrient, total nitrogen, ammonia and nitrate levels Faecal coliforms levels generally exceed the primary recreational contact guidelines.	Decline and/or weed invasion of riparian vegetation.	Loss of fauna and riparian habitat through clearing, weed invasion and urban development.	Low macroinvertebrate diversity indicative of the urbanised catchment, water quality problems and/or loss of riparian habitat.	Short reach subject to recent riparian vegetation removal and minor erosion. Impacts on hydrology due to straightening of the creek at the beach.
Slacky Creek	Low dissolved oxygen and elevated total nitrogen, ammonia and nitrate levels. Manganese is also of concern for recreational purposes.	Decline and/or weed invasion of riparian vegetation.	Loss of fauna and riparian habitat through clearing, weed invasion and urban development.	Low macroinvertebrate diversity indicative of the urbanised catchment, water quality problems and/or loss of riparian habitat.	Minor left bank erosion and in-channel sedimentation. Approximately 100 m of minimally active, localized erosion of both banks. Some in channel deposition of tailing-like sediments. May indicate erosion of upstream fill deposits.

Estuary	Water Quality (WCC 2007 and AWT 1999)	Flora	Fauna	Aquatic Ecology	Bank Erosion / Hydrology
Whartons Creek	Low dissolved oxygen and elevated total nitrogen, nitrate and phosphorus levels. Elevated copper and zinc levels. Faecal coliforms levels generally exceed the primary recreational contact guidelines.	Decline and/or weed invasion of riparian vegetation. Cleared riparian vegetation and replacement with Kikuyu grass.	Loss of fauna and riparian habitat through clearing, weed invasion and urban development.	Low macroinvertebrate diversity indicative of the urbanised catchment, water quality problems and/or loss of riparian habitat.	Erosion head with moderately active erosion downstream. Potential erosion in reach highly constrained by development. Reported large erosion site along tributary of Whartons Creek adjacent to Corrie Road.
Collins Creek	Elevated total nitrogen, nitrate and phosphorus levels in some reaches. Elevated ccopper and zinc levels Faecal coliforms levels generally exceed the primary recreational contact guidelines.	Decline and/or weed invasion of Coastal Saltmarsh (EEC). Decline and/or weed invasion of riparian vegetation. Cleared riparian vegetation and replacement with Kikuyu grass (revegetation in progress).	Dense riparian vegetation for foraging habitat for a range of species. Loss of fauna and riparian habitat through clearing and urban development.	Low macroinvertebrate diversity indicative of the urbanised catchment, water quality problems and/or loss of riparian habitat.	Potential erosion, especially on outside of bends, throughout reach downstream of railway crossing to a private access road bridge. Potential erosion on outside of bend. Potential erosion for approximately 100 m downstream of Thirroul Street. Potential left bank instabilities over a 100 m reach downstream of footbridge at Woonoona High.

Estuary	Water Quality (WCC 2007 and AWT 1999)	Flora	Fauna	Aquatic Ecology	Bank Erosion / Hydrology
Bellambi Gully	Elevated pH, suspended solids, nutrients, copper and zinc. Elevated conductivity, BOD, COD and ammonia reported for both dry and wet weather in 1994. Elevated *E. coli* bacteria levels also detected, during wet weather, indicative of sewage effluent contamination. Faecal coliforms levels generally exceed the primary recreational contact guidelines. Runoff and discharges from Bellambi Coal Company, Russel Vale waste disposal area, urban development, including housing development and recreational areas.	Decline and/or weed invasion of Coastal Saltmarsh (EEC). Conservation of mangroves. Decline and/or weed invasion of riparian vegetation. Cleared riparian vegetation and replacement with Kikuyu grass.	Potential habitat for threatened amphibians (Green and Golden Bell Frog and Red-crowned Toadlet), threatened birds (Australasian Bittern, Black Bittern and foraging habitat for owls). Dense riparian vegetation for foraging habitat for a range of species. Loss of fauna and riparian habitat through clearing and urban development.	Low macroinvertebrate diversity indicative of the urbanised catchment, water quality problems and/or loss of riparian habitat.	Potential localised bed and bank erosion. Potential bank instabilities upstream of rail crossing for 20 metres. Potential bank erosion 50 metres upstream and downstream of footbridge. Waterway extremely constrained by development and is potentially eroding over a 200 m section downstream of Princes Highway. Potential moderate to highly active erosion of both banks upstream of Gladstone Street. Potential moderate left bank erosion for 100 m upstream of Brompton Road. Minor bank erosion downstream of culverts under Northern Distributor.

Estuary	Water Quality (WCC 2007 and AWT 1999)	Flora	Fauna	Aquatic Ecology	Bank Erosion / Hydrology
Bellambi Lagoon	Poorer water quality at the northern end of the lagoon than at its mouth. Elevated total nitrogen, ammonia, phosphorus, copper and zinc. Faecal coliform levels generally exceed the primary recreational contact guidelines in the northern part of the lagoon. Heavily urbanised catchment.	Decline and/or weed invasion of EECs, Coastal Saltmarsh, Swamp Oak Floodplain and Bangalay Sand Forest. Conservation of mangroves. Water quality and macroalgae impacts on seagrasses. Main management issues include weed invasion, tracks made through bushland by motorbikes, fires and lack of barrier fences and gates. Decline and/or weed invasion of riparian vegetation. Cleared riparian vegetation and replacement with Kikuyu grass.	Potential habitat for threatened amphibians (Green and Golden Bell Frog), threatened birds (Australasian Bittern, Black Bittern and foraging habitat for owls). Swamp Oak Forest provides hollow bearing trees and potential foraging habitat for a variety of birds and mammals. Bangalay Sand Forest provides hollows, as well as flowering eucalypts for foraging habitat. Dense riparian vegetation for foraging habitat for a range of species. Loss of fauna and riparian habitat through clearing and urban development. Inappropriate levels of impacts from recreational use. Introduced fauna preying on native fauna.	Low macroinvertebrate diversity indicative of the urbanised catchment, water quality problems and/or loss of riparian habitat. Artificial opening may lead to a loss of riparian vegetation and wetland habitat. Conservation of seagrass beds important for fish nursery habitat.	Creek is highly constrained by development between Princes Highway and Northern Distributor. Likely to be experiencing moderate to high degrees of channel instability. Potential moderate right bank erosion over approximately 30 metres. Moderate erosion of left bank extending for approximately 100 m upstream of footbridge at end of Louks Street.

Estuary	Water Quality (WCC 2007 and AWT 1999)	Flora	Fauna	Aquatic Ecology	Bank Erosion / Hydrology
Tom Thumb Lagoon	Elevated suspended solids, but likely to be a natural consequence of tidal movement. Elevated nitrate levels, possibly leachate from the decommissioned landfill site at Greenhouse Park. All heavy metals except arsenic exceed the guideline on a number of occasions. Faecal coliforms appear not to be a major issue, although it is subject to overflows during wet weather. .	Decline and/or weed invasion of EECs, Coastal Saltmarsh and Swamp Oak Floodplain. Conservation of mangroves and competition with saltmarsh Decline and/or weed invasion of riparian vegetation. Cleared riparian vegetation and replacement with Kikuyu grass (J.J. Kelly Park).	Potential habitat for threatened amphibians (Green and Golden Bell Frog). Swamp Oak Forest provides potential foraging habitat for a variety of birds and mammals. Dense riparian vegetation for foraging habitat for a range of species. Damage to wetland habitat through industrial and/or contaminated runoff. Introduced fauna preying on native fauna.	Low macroinvertebrate diversity indicative of the urbanised catchment, water quality problems and/or loss of riparian habitat. Mangroves provide nursery habitat for fish.	No moderate to highly active bank erosion, however scour and channelisation is evident across the floor of the saltmarsh flat in the western arm.

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Appendix A

Flora Species List

Family	Scientific Name	Common Name	Introduced Species	Tom Thumb Lagoon	Bellambi Lagoon	Bellambi Gully	Bellambi Gully	Whartons Creek	Collins Creek	Slacky Creek	Slacky Creek	Flanagans Creek	Stoney Creek	Stanwell Creek	Hargraves Creek
Acanthaceae	*Avicennia marina*	Grey Mangrove		x	x	x	x								
Aizoaceae	*Carpobrotus glaucescens*	Pigface			x										
Aizoaceae	*Tetragonia tetragonioides*	New Zealand Spinach		x	x	x	x	x	x				x	x	x
Amaranthaceae	*Alternanthera denticulata*	Lesser Joyweed		x											x
Apiaceae	*Apium prostratum*	Sea Celery		x	x	x	x		x	x	x		x	x	x
Apiaceae	*Centella asiatica*	Pennywort													
Apiaceae	*Foeniculum vulgare*	Fennel	*	x		x	x					x			
Apiaceae	*Hydrocotyle bonariensis*	Beach Pennywort	*	x	x			x	x	x	x	x	x	x	x
Apocynaceae	*Nerium oleander*	Oleander	*			x	x						x	x	
Apocynaceae	*Parsonsia straminea*	Common Silkpod			x										
Araceae	*Colocasia esculenta*	Taro													x
Araceae	*Zantedeschia aethiopica*	Arum Lily	*		x										
Arecaceae	*Livistona australis*	Cabbage Palm											x		x
Asclepiadaceae	*Araujia sericifera*	Moth Plant	*	x	x										
Asparagaceae	*Asparagus aethiopicus*	Asparagus 'Fern'	*		x				x	x	x		x	x	x
Aspleniaceae	*Asplenium flabellifolium*	Necklace Fern													x
Asteraceae	*Actites megalocarpa*	Dune Thistle			x										
Asteraceae	*Ageratina adenophora*	Crofton Weed	*	x	x	x	x						x		x
Asteraceae	*Arctotheca populifolia*	Beach Daisy	*	x	x	x	x	x	x	x	x	x	x	x	x
Asteraceae	*Baccharis halimifolia*	Groundsel Bush	*	x				x	x	x	x	x			

Family	Scientific Name	Common Name	Introduced Species	Tom Thumb Lagoon	Bellambi Lagoon	Bellambi Gully	Bellambi Gully	Whartons Creek	Collins Creek	Slacky Creek	Slacky Creek	Flanagans Creek	Stoney Creek	Stanwell Creek	Hargraves Creek
Asteraceae	*Bidens pilosa*	Cobbler's Pegs	*	x		*	*						x	x	x
Asteraceae	*Chrysanthemoides monilifera* subsp. *rotundata*	Bitou Bush	*	x	x	x	x		x						
Asteraceae	*Conyza albida*	Tall Fleabane	*		x										
Asteraceae	*Conyza bonariensis*	Flaxleaf Fleabane	*	x					x						
Asteraceae	*Delairea odorata*	Cape Ivy	*	x	x										
Asteraceae	*Hypochaeris radicata*	Catsear	*		x										
Asteraceae	*Olearia viscidula*	Wallaby Weed													
Asteraceae	*Senecio linearifolius*				x										
Asteraceae	*Sonchus oleraceus*	Common Sowthistle	*		x										
Asteraceae	*Taraxacum officinale*	Dandelion	*			x	x								
Basellaceae	*Anredera cordifolia*	Madeira Vine	*	x	x	x	x		x	x	x	x			
Brassicaceae	*Cakile maritima*	Sea Rocket				x	x	x	x			x	x	x	x
Cactaceae	*Opuntia stricta*	Prickly Pear	*					x							
Caprifoliaceae	*Lonicera japonica*	Japanese Honeysuckle	*		x										
Casuarinaceae	*Allocasuarina littoralis*	Black Sheoak													x
Casuarinaceae	*Casuarina cunninghamiana*	River Oak		x											
Casuarinaceae	*Casuarina glauca*	Swamp Oak		x	x	x	x	x	x	x	x		x	x	x
Celastraceae	*Elaeodendron australe*												x		x
Chenopodiaceae	*Atriplex prostrata*		*		x			x	x	x	x		x		x
Chenopodiaceae	*Sarcocornia quinqueflora*			x	x										
Chenopodiaceae	*Suaeda australis*			x	x										

Family	Scientific Name	Common Name	Introduced Species	Tom Thumb Lagoon	Bellambi Lagoon	Bellambi Gully	Bellambi Gully	Whartons Creek	Collins Creek	Slacky Creek	Slacky Creek	Flanagans Creek	Stoney Creek	Stanwell Creek	Hargraves Creek
Commelinaceae	*Commelina cyanea*	Native Wandering Jew		x	x	x	x						x	x	x
Convolvulaceae	*Calystegia marginata*				x										
Convolvulaceae	*Calystegia sepium*				x										
Convolvulaceae	*Calystegia soldanella*			x											
Convolvulaceae	*Dichondra repens*	Kidney Weed						x	x	x	x			x	x
Convolvulaceae	*Ipomoea cairica*		*			x	x	x	x	x	x	x	x	x	x
Convolvulaceae	*Ipomoea indica*	Morning Glory	*	x	x			x							
Cyperaceae	*Bolboschoenus fluviatilis*	Marsh Club-rush		x	x	x	x								
Cyperaceae	*Cyperus eragrostis*	Umbrella Sedge	*			x	x								
Cyperaceae	*Cyperus laevigatus*														x
Cyperaceae	*Gahnia sieberiana*	Red-fruit Saw-sedge			x	x	x								
Cyperaceae	*Ficinia nodosa*	Knobby Club-rush		x	x	x	x	x	x	x	x	x	x	x	x
Cyperaceae	*Lepidosperma filiforme*				x										
Dennstaedtiaceae	*Hypolepis muelleri*	Harsh Ground Fern			x										
Dennstaedtiaceae	*Pteridium esculentum*	Bracken			x	x	x								
Dilleniaceae	*Hibbertia scandens*	Climbing Guinea Flower			x										
Elaeocarpaceae	*Elaeocarpus reticulatus*	Blueberry Ash			x										
Epacridaceae	*Monotoca elliptica*	Tree Broom-heath			x										
Euphorbiaceae	*Breynia oblongifolia*	Coffee Bush			x	x	x								

Family	Scientific Name	Common Name	Introduced Species	Tom Thumb Lagoon	Bellambi Lagoon	Bellambi Gully	Bellambi Gully	Whartons Creek	Collins Creek	Slacky Creek	Slacky Creek	Flanagans Creek	Stoney Creek	Stanwell Creek	Hargraves Creek
Euphorbiaceae	*Glochidion ferdinandi*	Cheese Tree												x	
Euphorbiaceae	*Ricinus communis*	Castor Oil Plant	*	x	x	x	x		x	x	x				
Fabaceae (Caesalpinioideae)	*Senna pendula*		*	x	x	x	x		x			x	x	x	x
Fabaceae (Faboideae)	*Canavalia rosea*	Coastal Jack Bean			x										
Fabaceae (Faboideae)	*Erythrina sykesii*	Coral Tree		x		x	x	x	x						
Fabaceae (Faboideae)	*Glycine clandestina*				x	x	x								
Fabaceae (Faboideae)	*Kennedia rubicunda*	Dusty Coral Pea			x	x	x								
Fabaceae (Mimosoideae)	*Acacia longifolia* subsp. *longifolia*	Sydney Golden Wattle			x			x	x	x	x	x		x	x
Fabaceae (Mimosoideae)	*Acacia longifolia* subsp. *sophorae*	Coastal Wattle		x	x	x	x		x				x	x	x
Fabaceae (Mimosoideae)	*Acacia maidenii*	Maiden's Wattle			x	x	x							x	x
Fabaceae (Mimosoideae)	*Acacia mearnsii*	Black Wattle		x											
Fabaceae (Mimosoideae)	*Acacia saligna*	Golden Wreath Wattle		x	x	x	x								
Geraniaceae	*Geranium solanderi* var. *solanderi*	Native Geranium			x										
Geraniaceae	*Pelargonium austral*	Native Storksbill			x										
Goodeniaceae	*Selliera radicans*	Swamp Weed				x	x								
Juncaceae	*Juncus kraussii*	Sea Rush		x	x	x	x	x	x	x	x		x	x	x
Juncaginaceae	*Triglochin striatum*	Streaked Arrowgrass		x											
Lamiaceae	*Westringia fruticosa*	Coastal Rosemary			x			x					x		x

Family	Scientific Name	Common Name	Introduced Species	Tom Thumb Lagoon	Bellambi Lagoon	Bellambi Gully	Bellambi Gully	Whartons Creek	Collins Creek	Slacky Creek	Slacky Creek	Flanagans Creek	Stoney Creek	Stanwell Creek	Hargraves Creek
Lauraceae	*Cassytha pubescens*				x										
Lomandraceae	*Lomandra longifolia*	Spiny-headed Mat-rush			x	x	x		x				x		x
Luzuriagaceae	*Geitonoplesium cymosum*	Scrambling Lily			x	x	x						x		x
Malvaceae	*Lagunaria patersonia* subsp. *bracteatus*	Norfolk Island Hibiscus	*	x	x	x	x								
Malvaceae	*Sida rhombifolia*	Paddy's Lucerne	*	x	x								x	x	x
Menispermaceae	*Sarcopetalum harveyanum*	Pearl Vine			x										
Menispermaceae	*Stephania japonica* var. *discolor*	Snake Vine			x	x	x						x	x	x
Moraceae	*Ficus coronata*	Creek Sandpaper Fig													
Moraceae	*Ficus macrophylla* subsp. *macrophylla*												x		
Moraceae	*Ficus obliqua* var. *obliqua*														
Moraceae	*Ficus rubiginosa*	Port Jackson Fig, Rusty Fig													x
Myoporaceae	*Myoporum acuminatum*			x		x	x					x			
Myrsinaceae	*Myrsine variabilis*	Muttonwood													x
Myrtaceae	*Acmena smithii*	Lilly Pilly											x	x	x
Myrtaceae	*Callistemon citrinus*	Crimson Bottlebrush				x	x								
Myrtaceae	*Eucalyptus botryoides*	Bangalay			x										
Myrtaceae	*Eucalyptus longifolia*	Woollybutt			x										

Family	Scientific Name	Common Name	Introduced Species	Tom Thumb Lagoon	Bellambi Lagoon	Bellambi Gully	Bellambi Gully	Whartons Creek	Collins Creek	Slacky Creek	Slacky Creek	Flanagans Creek	Stoney Creek	Stanwell Creek	Hargraves Creek
Myrtaceae	*Eucalyptus robusta*	Swamp Mahogany			x	x	x								
Myrtaceae	*Eucalyptus sieberi*	Silvertop Ash													
Myrtaceae	*Leptospermum laevigatum*	Coast Teatree			x	x	x	x	x	x	x			x	x
Myrtaceae	*Melaleuca ericifolia*	Swamp Paperbark			x										
Myrtaceae	*Melaleuca linariifolia*	Flax-leaved Paperbark			x										
Myrtaceae	*Melaleuca quinquenervia*	Broad-leaved Paperbark		x											
Myrtaceae	*Melaleuca styphelioides*	Prickly-leaved Tea Tree		x											
Ochnaceae	*Ochna serrulata*	Mickey Mouse Plant	*		x										
Oleaceae	*Ligustrum sinense*	Small-leaved Privet	*	x											
Oxalidaceae	*Oxalis perennans*				x			x	x	x	x			x	
Pittosporaceae	*Pittosporum revolutum*	Rough Fruit Pittosporum			x										
Pittosporaceae	*Pittosporum undulatum*	Sweet Pittosporum		x	x					x	x				x
Plantaginaceae	*Plantago lanceolata*	Lamb's Tongues	*	x	x	x	x			x	x		x	x	x
Poaceae	*Arundo donax*	Giant Reed	*	x						x	x				
Poaceae	*Chloris gayana*	Rhodes Grass	*		x										
Poaceae	*Cortaderia selloana*	Pampas Grass	*		x	x	x								
Poaceae	*Cynodon dactylon*	Common Couch		x	x	x	x	x	x	x	x	x	x	x	x
Poaceae	*Ehrharta erecta*	Panic Veldtgrass	*		x								x	x	x

Family	Scientific Name	Common Name	Introduced Species	Tom Thumb Lagoon	Bellambi Lagoon	Bellambi Gully	Bellambi Gully	Whartons Creek	Collins Creek	Slacky Creek	Slacky Creek	Flanagans Creek	Stoney Creek	Stanwell Creek	Hargraves Creek
Poaceae	*Imperata cylindrica* var. *major*	Blady Grass			x	x	x	x	x	x	x				
Poaceae	*Oplismenus aemulus*				x										x
Poaceae	*Paspalum dilatatum*	Paspalum	*	x		x	x		x				x	x	x
Poaceae	*Pennisetum clandestinum*	Kikuyu Grass	*	x	x	x	x	x	x	x	x	x	x	x	x
Poaceae	*Phragmites australis*	Common Reed		x	x	x	x	x	x			x	x	x	x
Poaceae	*Spinifex sericeus*	Hairy Spinifex		x	x	x	x	x	x	x	x	x	x	x	x
Poaceae	*Sporobolus virginicus*	Sand Couch		x	x	x	x							x	
Poaceae	*Stenotaphrum secundatum*	Buffalo Grass	*	x		x	x						x	x	x
Poaceae	*Zoysia macrantha*	Coast Couch		x											
Polygonaceae	*Acetosa sagittata*	Rambling Dock	*	x									x		x
Polygonaceae	*Polygala myrtifolia*		*										x		
Polygonaceae	*Persicaria decipiens*	Slender Knotweed		x	x										x
Polygonaceae	*Rumex crispus*	Curled Dock	*	x		x	x						x	x	x
Potamogetonaceae	*Ruppia megacarpa*			x											
Primulaceae	*Samolus repens*	Creeping Brookweed		x	x	x	x								x
Proteaceae	*Banksia integrifolia*	Coast Banksia			x	x	x		x	x	x		x	x	x
Proteaceae	*Banksia serrata*	Old-man Banksia			x										
Rosaceae	*Rubus fruticosus*	Blackberry	*		x	x	x						x	x	
Rubiaceae	*Coprosma repens*	Mirror Bush	*					x						x	x
Rutaceae	*Correa alba*	White Correa			x										

Family	Scientific Name	Common Name	Introduced Species	Tom Thumb Lagoon	Bellambi Lagoon	Bellambi Gully	Bellambi Gully	Whartons Creek	Collins Creek	Slacky Creek	Slacky Creek	Flanagans Creek	Stoney Creek	Stanwell Creek	Hargraves Creek
Simaroubaceae	*Ailanthus altissima*	Tree of Heaven								x	x				
Smilacaceae	*Smilax australis*	Sarsaparilla													x
Solanaceae	*Solanum nigrum*	Black-berry Nightshade	*		x								x	x	x
Thymelaeaceae	*Pimelea linifolia*	Slender Rice-flower			x										
Typhaceae	*Typha orientalis*	Broad-leaved Cumbungi		x	x	x	x								x
Verbenaceae	*Lantana camara*	Lantana	*	x	x	x	x	x	x	x	x	x	x	x	x
Verbenaceae	*Verbena bonariensis*	Purpletop	*	x	x	x	x							x	
Violaceae	*Viola hederacea*	Ivy-leaved Violet			x										x
Vitaceae	*Cissus hypoglauca*	Giant Water Vine				x	x								
Zosteraceae	*Zostera capricorni*	Eel Grass		x											

* Denotes introduced species

Appendix B

Fauna Species List

Scientific Name	Common Name	Introduced Species	Tom Thumb Lagoon	Bellambi Lagoon	Bellambi Gully	Collins Creek	Whartons Creek	Slacky Creek	Flanagans Creek	Stoney Creek	Stanwell Creek	Hargraves Creek
AVIFAUNA												
Larus novaehollandiae	Silver Gull			x	x	x	x	x	x		x	x
Acridotheres tristis	Common Myna								x		x	
Gallinula tenebrosa	Dusky Moorhen		x	x	x				x		x	x
Columba livia	Australian Rock Dove	*	x						x			
Anas platyrhynchos	Domestic Duck	*							x			
Chenonetta jubata	Australian Wood Duck			x					x			
Pelecanus conspicillatus	Australian Pelican			x					x			
Rhipidura leucophrys	Willie Wagtail		x	x	x		x		x		x	x
Egretta novaehollandiae	White faced Heron		x							x	x	x
Dacelo novaeguineae	Laughing Kookaburra									x	x	
Grallina cyanoleuca	Magpie-lark									x	x	
Platycercus elegans	Crimson Rosella									x		
Coracina novaehollandiae	Black-faced Cuckoo Shrike									x		
Phalacrocorax varius	Pied Cormorant			x	x					x	x	
Hirundo neoxena	Welcome Swallow		x	x	x		x			x	x	x
Malurus lamberti	Variegated Fairy-wren		x				x				x	

Scientific Name	Common Name	Introduced Species	Tom Thumb Lagoon	Bellambi Lagoon	Bellambi Gully	Collins Creek	Whartons Creek	Slacky Creek	Flanagans Creek	Stoney Creek	Stanwell Creek	Hargraves Creek
Anas superciliosa	Pacific Black Duck		x	x	x	x	x				x	
Psophodes olivaceus	Eastern Whipbird		x	x							x	x
Vanellus miles	Spur-winged Plover		x	x							x	x
Hirundo ariel	Fairy Martin		x				x				x	
Ocyphaps lophotes	Crested Pigeon							x				
Cacatua galerita	Sulphur Crested Cockatoo						x	x				x
Passer domesticus	House Sparrow	*					x					
Haematopus fuliginosus	Sooty Oystercatcher						x					
Sterna bergii	Crested Tern				x		x					
Phalacrocorax varius	Pied Cormorant			x	x		x					
Anas castanea	Chestnut Teal		x	x								
Corvus coronoides	Australian Raven			x	x	x	x	x				
Phylidonyris novaehollandiae	New Holland Honeyeater			x	x							
Phalacrocorax carbo	Great Cormorant			x								
Egretta garzetta	Little Egret		x	x								
Gymnorhina tibicen	Australian Magpie		x									
Cacatua roseicapilla	Galah		x									x
Anas gracilis	Grey Teal		x									
Platalea regia	Royal Spoonbill		x	x								

Scientific Name	Common Name	Introduced Species	Tom Thumb Lagoon	Bellambi Lagoon	Bellambi Gully	Collins Creek	Whartons Creek	Slacky Creek	Flanagans Creek	Stoney Creek	Stanwell Creek	Hargraves Creek
Anhinga melanogaster	Darter				x							
Ardea intermedia	Intermediate Egret		x		x							
Porphyrio porphyrio	Purple Swamphen				x				x			
Pycnonotus jocosus	Red-whiskered Bulbul	*			x							
Trichoglossus haematodus	Rainbow Lorikeet					x				x	x	
Elanus axillaris	Black-shouldered Kite				x	x					x	x
AMPHIBIA												
Litoria fallax	Eastern Dwarf Tree Frog			x								
Limnodynastes peroni	Striped Marsh Frog			x	x						x	x
Crinia signifera	Eastern Common Froglet		x									
MAMMALIA												
Pteropus poliocephalus	Grey-Headed Flying-Fox			x								
*Oryctolagus cuniculus**	European Wild Rabbit		x		x							
REPTILIA												
Physignathus lesueurii lesueurii	Eastern Water Dragon				x							

* Denotes introduced species

Appendix C

Ecology Figures

Appendix D

Macroinvertebrate Habitat Data

Macroinvertebrate Habitat Assessment

Location	Site	Riparian Vegetation				Instream Vegetation		Aquatic Vegetation				Natural Substrate
		Trees %	Shrub %	Groundcover %	Exotic Species %	Bank Overhang %	Trailing Bank %	Algae %	Moss %	Macrophytes %	Detritus %	
FL	**1**	10	20	70	30	70	50	0	10	30	40	Gravel
FL	**2**	30	30	10	40	60	30	10	20	0	10	Gravel/ Pebble
SL	**1**	30	50	20	40	10	5	0	0	15	0	Gravel/ Pebble
SL	**2**	10	75	15	50	70	50	0	5	0	5	Gravel/ Pebble
WH	**1**	10	80	10	40	80	60	50	40	0	0	Gravel/ Pebble
WH	**2**	10	30	60	50	70	50	10	70	0	20	Cobble/ Pebble
CL	**1**	10	30	50	70	10	10	10	0	20	70	Silt/ Clay
CL	**2**	30	10	60	40	5	5	40	30	20	10	Cobble/ Pebble
BG	**1**	10	0	5	95	10	10	0	0	5	10	Gravel/ Pebble
BG	**2**	10	30	60	80	60	50	0	0	0	30	Gravel/ Pebble
BL	**1**	0	5	95	30	0	0	0	0	0	50	Silt
BL	**2**	0	0	100	40	0	90	0	0	0	20	Silt
TTL	**1**	5	15	80	60	20	60	0	10	0	20	Silt/ Sand
TTL	**2**	0	40	60	70	0	0	10	0	0	90	Silt/ Sand

Macroinvertebrate Site Water Quality

Location	Site	Water Quality				
		Temperature ^{o}C	Conductivity *u*S/cm	Turbidity NTU	DO mg/L	pH
Flanagans Creek	1	17.5	444	122	9.69	6.71
Flanagans Creek	2	17.9	440	59	9.94	6.8
Slacky Creek	1	19.4	554	84	8.9	7.2
Slacky Creek	2	19.3	557	75	7.92	7.4
Whartons Creek	1	19.4	345	79	4.07	7.92
Whartons Creek	2	19.2	578	79	6.18	7.6
Collins Creek	1	17.4	494	69	2.03	6.13
Collins Creek	2	17.6	574	117	4.99	6.75
Bellambi Gully	1	14.8	1430	154	6.05	8
Bellambi Gully	2	15.6	1492	167	6.97	7.56
Bellambi Lagoon	1	24	8000	147	1.4	8.92
Bellambi Lagoon	2	24.8	3000	88	1.3	8.69
Tom Thumb Lagoon	1	22.3	2520	185	5	7.23
Tom Thumb Lagoon	2	19.5	1233	131	1.5	7.53

ANZECC (2000) Default Trigger Values for Slightly Disturbed Ecosystems in Southeast Australia

Parameter	Trigger Value
Conductivity *u*S/cm	125-2200
Turbidity NTU	0.5-10
DO mg/L	< 6 mg/L
pH	6.5-8.5

Appendix E

Macroinvertebrate Family List

Location	Edge Habitat	FL	FL	SL	SL	WH	WH	CL	CL	BG	BG	BL	BL	TTL	TTL
Site		US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US1	US1	US 2
Family	Hydraenidae,	0	0	0	24	0	0	0	0	5	0	0	0	0	0
Family	Corduliidae	0	0	0	1	0	0	5	0	0	0	0	0	0	0
Family	Gerridae	5	2	13	1	9	0	0	0	7	16	0	0	0	0
Family	Hydrometridae	5	1	0	1	3	1	0	0	0	0	0	0	0	0
Family	Veliidae	8	14	13	1	1	3	4	0	0	22	0	0	0	0
Family	Hydrobiidae	69	26	0	140	112	147	0	42	0	1	77	101	31	0
Phylum	Platyhelminthe	0	0	0	1	0	0	0	1	0	0	0	0	0	0
Family	Chironomidae	9	1	0	7	3	0	20	0	43	3	2	0	0	1
Family	Stratiomyidae	2	0	0	3	3	4	0	2	16	5	0	0	0	0
Subclass	Oligochaeta	0	0	0	0	3	0	12	1	0	1	0	0	0	0
Family	Leptoceridae	15	0	0	0	0	0	0	0	1	3	0	0	0	0
Family	Baetidae	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Class	Conchostraca	2	0	0	0	2	0	2	0	0	0	26	1	0	0
Family	Atyidae	13	8	0	0	0	0	0	0	0	0	0	0	0	0
Family	Megapodagrionidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Planorbidae	1	0	0	0	0	0	1	1	0	0	0	0	0	0
Family	Bactidae	1	7	0	0	0	0	0	0	0	0	0	0	0	0
Family	Leptophlebiidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Location	Edge Habitat	FL	FL	SL	SL	WH	WH	CL	CL	BG	BG	BL	BL	TTL	TTL
Site		US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US1	US1	US 2
Order	Collembola	15	1	0	0	124	0	0	0	0	1	0	0	0	0
Family	Ceratopogonidae	2	1	0	0	3	2	0	0	0	0	0	0	0	0
Family	Coenagrionidae	0	1	0	0	0	0	2	0	0	1	0	0	0	0
Family	Dixidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Cyclopoida	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Calamoceratidae	5	2	0	0	0	0	0	0	0	0	0	0	0	0
Family	Protoneuridae	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Family	Sphaeromatidae	0	0	0	0	2	0	1	0	0	0	18	23	32	8
Family	Erycinidae	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Family	Talitridae	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Family	Lymnaeidae	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Family	Culidae	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Family	Hymenosomatidae	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Family	Simuliidae	0	0	0	0	0	0	1	0	19	0	0	0	0	0
Family	Notonectidae	0	0	0	0	0	0	14	0	1	5	0	11	0	0
Family	Glossiphoniidae	0	0	0	0	0	0	26	0	0	0	0	0	0	0
Family	Corixidae	0	0	0	0	0	0	2	0	0	0	0	1	0	0
Family	Chaoboridae	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Family	Cirolanidae	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Location	Edge Habitat	FL	FL	SL	SL	WH	WH	CL	CL	BG	BG	BL	BL	TTL	TTL
Site		US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US1	US1	US 2
Family	Psephenidae	1	1	0	0	0	0	0	1	0	0	0	0	0	0
Family	Trombidiidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Scirtidae	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Dytiscidae	0	1	0	0	0	0	0	0	0	2	0	0	0	0
Family	Gomphidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Family	Isotomidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Family	Hydroptilidae	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Family	Sminthuridae	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Family	Pyralidae	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Family	Arrenuridae	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Family	Neurorthidae	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Total Families		**21**	**14**	**2**	**9**	**15**	**9**	**12**	**7**	**7**	**12**	**4**	**8**	**4**	**3**

Location	Pool Rock Habitat	FL	FL	SL	SL	WH	WH	CL	CL	BG	BG	BL	BL	TTL	TTL
Site		US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US1	US1	US 2
Family	Hydraenidae	0	0	1	0	7	0	0	0	0	0	0	0	0	0
Family	Corduliidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Gerridae	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Family	Hydrometridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Veliidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Hydrobiidae	182	0	89	180	171	136	98	46	0	0	6	22	8	0
Phylum	Platyhelminthe	0	1	0	5	4	15	6	2	0	0	0	0	0	0
Family	Chironomidae	1	0	4	0	3	1	0	0	156	24	4	0	0	3
Family	Stratiomyidae	1	0	0	0	0	0	1	2	0	1	0	0	0	0
Subclass	Oligochaeta	0	3	0	0	0	0	1	0	0	0	0	0	0	0
Family	Leptoceridae	1	7	0	0	0	0	0	0	0	0	0	0	0	0
Family	Baetidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Class	Conchostraca	0	0	0	0	0	0	0	0	0	0	17	1	0	0
Family	Atyidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Megapodagrionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Planorbidae	0	0	0	0	0	1	1	2	0	0	0	0	0	0
Family	Bactidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Leptophlebiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Order	Collembola	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Family	Certapoginidae	0	0	0	0	15	0	4	0	0	0	0	0	0	0
Family	Coenagrionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Dixidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Location	Pool Rock Habitat	FL	FL	SL	SL	WH	WH	CL	CL	BG	BG	BL	BL	TTL	TTL
Site		US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US1	US1	US 2
Family	Cyclopoida	0	0	0	0	0	0	0	0	0	0	3	5	0	0
Family	Calamoceratidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Protoneuridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Sphaeromatidae	0	0	0	0	0	0	0	0	0	0	6	16	2	2
Family	Erycinidae	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Family	Talitridae	0	0	0	0	0	0	0	0	0	0	0	0	41	0
Family	Lymnaeidae	1	0	0	0	0	0	0	0	2	0	0	0	0	0
Family	Culidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Hymenosomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Family	Simuliidae	0	1	1	2	0	4	0	0	23	12	0	0	0	0
Family	Notonectidae	0	0	0	0	0	0	0	0	0	0	0	16	0	0
Family	Glossiphoniidae	0	3	0	0	0	0	17	0	0	0	0	0	0	0
Family	Corixidae	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Family	Chaoboridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Cirolanidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Psephenidae	7	2	0	0	0	0	0	0	0	4	0	0	0	0
Family	Trombidiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Scirtidae	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Family	Dytiscidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Gomphidae	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Family	Isotomidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Hydroptilidae	1	1	0	0	2	0	3	1	0	0	0	0	0	0
Family	Sminthuridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Location	Pool Rock Habitat	FL	FL	SL	SL	WH	WH	CL	CL	BG	BG	BL	BL	TTL	TTL
Site		US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US 2	US1	US1	US1	US 2
Family	Pyralidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Ecnomidae	0	0	2	0	0	0	0	0	0	7	0	0	0	0
Family	Hydropsychidae	1	0	0	0	0	0	0	0	3	0	0	0	0	0
Family	Petaluridae	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Family	Nereididae	0	0	0	0	0	0	0	0	0	0	1	0	13	0
Family	Gyrinidae	1	0	0	0	0	0	1	0	0	0	0	0	0	0
Family	Paramelitidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Family	Oniscidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Family	Helicophidae	1	107	0	0	0	0	0	0	0	0	0	0	0	0
Family	Philopotamidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Family	Tasimiidae	3	0	0	0	0	0	0	0	0	2	0	0	0	0
Family	Giripopterygidae	1	2	0	0	0	0	0	0	0	0	0	0	0	0
Family	Mytilidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Family	Richardsonianidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Family	Elmidae	0	0	0	0	1	0	0	0	0	0	0	0	0	0
TOTAL Families		**15**	**11**	**5**	**4**	**7**	**6**	**11**	**7**	**4**	**6**	**6**	**9**	**5**	**3**

Appendix F

Maps of Estuary Erosion

Appendix G

Wollongong IFD Data

Rainfall Intensity-Frequency-Duration Calculation to AR&R | **Program : IFD.xls**
Version : 3

Data
Location : Wollongong

1 HR DUR 2 ARI	43.2	mm/hr
12 HR DUR 2 ARI	10.5	mm/hr
72 HR DUR 2 ARI	3.5	mm/hr
1 HR DUR 50 ARI	92.9	mm/hr
12 HR DUR 50 ARI	25	mm/hr
72 HR DUR 50 ARI	8.5	mm/hr
G (skewness)	1E-11	mm/hr
F2 Geo factor 2 ARI	4.28	
F50 Geo factor 50 ARI	15.8	

Duration		**Design Rainfalls for Average Recurrance Intervals**								
		1 Year	**2 Years**	**5 Years**	**10 Years**	**20 Years**	**50 Years**	**100 Years**	**200 Years**	**500 Years**
(min)	(hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)
		1 yr ARI	2 yr ARI	5 yr ARI	10 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI	200 yr ARI	500 yr ARI
5	0.0833	105.6	135.1	170.7	190.9	218.0	253.1	279.6	306.3	342.1
6	0.1	99.1	126.9	160.9	180.2	206.0	239.6	264.9	290.5	324.8
7	0.1167	93.6	120.0	152.5	171.1	195.9	228.1	252.4	277.0	310.0
8	0.1333	88.9	114.1	145.4	163.3	187.2	218.2	241.7	265.4	297.3
9	0.15	84.8	108.9	139.2	156.5	179.5	209.5	232.2	255.2	286.1
10	0.1667	81.2	104.4	133.7	150.5	172.8	201.9	223.9	246.2	276.2
11	0.1833	78.0	100.4	128.7	145.1	166.7	195.0	216.4	238.1	267.3
12	0.2	75.2	96.7	124.3	140.2	161.3	188.8	209.6	230.8	259.2
13	0.2167	72.6	93.5	120.3	135.8	156.3	183.1	203.5	224.1	251.9
14	0.2333	70.2	90.5	116.6	131.8	151.8	177.9	197.8	218.0	245.2
15	0.25	68.0	87.7	113.3	128.1	147.6	173.2	192.6	212.4	239.0
16	0.2667	66.0	85.2	110.1	124.7	143.8	168.8	187.8	207.2	233.2
17	0.2833	64.2	82.8	107.3	121.5	140.2	164.7	183.3	202.3	227.9
18	0.3	62.5	80.7	104.6	118.5	136.8	160.9	179.2	197.8	222.9
20	0.3333	59.4	76.7	99.7	113.2	130.8	154.0	171.6	189.6	213.8
25	0.4167	53.1	68.8	89.9	102.3	118.5	139.9	156.2	172.8	195.3
30	0.5	48.4	62.7	82.4	94.0	109.1	129.0	144.2	159.8	180.9
35	0.5833	44.6	57.9	76.3	87.2	101.4	120.2	134.6	149.3	169.2
40	0.6667	41.5	53.9	71.3	81.7	95.1	112.9	126.6	140.6	159.6
45	0.75	38.9	50.6	67.2	77.1	89.8	106.8	119.8	133.2	151.4
50	0.8333	36.7	47.8	63.6	73.1	85.3	101.5	114.0	126.9	144.3
55	0.9167	34.7	45.3	60.5	69.6	81.3	97.0	109.0	121.3	138.1
60	1	33.1	43.2	57.8	66.5	77.8	92.9	104.5	116.4	132.7
75	1.25	29.2	38.2	51.3	59.2	69.3	82.9	93.3	104.1	118.8
90	1.5	26.3	34.5	46.4	53.7	63.0	75.4	85.0	94.9	108.4
91	1.5167	26.2	34.3	46.2	53.4	62.6	75.0	84.5	94.4	107.8
120	2	22.4	29.3	39.7	46.0	54.0	64.8	73.2	81.8	93.6
180	3	17.7	23.2	31.7	36.8	43.4	52.3	59.2	66.3	76.0
240	4	15.0	19.7	27.0	31.4	37.2	44.8	50.8	57.0	65.5
360	6	11.8	15.6	21.5	25.2	29.8	36.1	41.0	46.1	53.1
480	8	10.0	13.2	18.3	21.5	25.5	31.0	35.3	39.7	45.8
540	9	9.3	12.4	17.2	20.2	24.0	29.1	33.1	37.3	43.1
600	10	8.8	11.7	16.2	19.0	22.6	27.5	31.4	35.3	40.8
720	12	7.9	10.5	14.6	17.2	20.5	25.0	28.5	32.2	37.2
810	13.5	7.4	9.8	13.7	16.1	19.2	23.4	26.7	30.1	34.8
900	15	7.0	9.2	12.9	15.2	18.1	22.0	25.1	28.4	32.8
1080	18	6.3	8.3	11.6	13.7	16.3	19.9	22.7	25.6	29.6
1440	24	5.3	7.0	9.8	11.6	13.8	16.9	19.2	21.7	25.1
2160	36	4.1	5.5	7.7	9.1	10.9	13.3	15.2	17.1	19.8
2880	48	3.5	4.6	6.5	7.6	9.1	11.1	12.7	14.3	16.6
4320	72	2.6	3.5	4.9	5.8	7.0	8.5	9.7	11.0	12.7

Note: Values for 200 and 500 yearARI are approximate only and does not conform to Book 6 of AR&R (1999)

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