State *of the*
Derwent Estuary
2009

A review of pollution sources, loads and environmental quality data from 2003 to 2009

CARING
FOR
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COUNTRY

Derwent Estuary
Program

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The Derwent Estuary Program
EPA Division
Department of Primary Industries, Parks,
Water and Environment
GPO Box 1751
Hobart 7001
Tasmania

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The Derwent Estuary Program (DEP) is a regional partnership between local governments, the Tasmanian Government, commercial and industrial enterprises, and community-based groups to restore and promote our estuary. The DEP was established in 1999 and has been nationally recognised for excellence in reducing water pollution, conserving habitats and species, monitoring river health and promoting greater use and enjoyment of the foreshore. Our major sponsors include: Brighton, Clarence, Derwent Valley, Glenorchy, Hobart and Kingborough councils, the Tasmanian State Government, Southern Water, Tasmanian Ports Corporation, Norske Skog Boyer, Nyrstar Hobart and Hydro Tasmania. This project is partially funded through the Derwent Estuary Program and the Australian Government's *Caring for Our Country*.

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EXECUTIVE SUMMARY

The Derwent Estuary Program (DEP) was established in 1999 as a partnership between state and local governments, industries, scientists and the community to restore and promote the Derwent estuary. A key role of the DEP is to coordinate and support monitoring activities and scientific investigations, and to compile and distribute the resulting information in regular reports. This report updates the previous *State of the Derwent Estuary* report published in 2003. The report reviews environmental quality data for the Derwent estuary to give a representation of current estuary health, highlights environmental trends and provides an overview of recent management actions that have been undertaken to improve environmental conditions.

The Derwent estuary is the largest estuary in south eastern Tasmania, covering an area of nearly 200 square kilometres. The estuary extends from New Norfolk (maximum extent of salt water) to the mouth, which lies between Tinderbox and the Iron Pot light. The Derwent is relatively deep, and is highly stratified in its narrow upper reaches, and well-mixed in its broad, lower reaches. Tides are generally small, with an average tidal range of one metre. The average flushing period of the estuary is estimated to be about 12 days.

The Derwent estuary lies at the heart of the Hobart metropolitan area and is an integral part of Tasmania's natural, cultural and economic heritage. The estuary is an important and productive ecosystem, supporting large areas of wetlands, seagrasses, tidal flats and rocky reefs. A number of protected species, including the endangered spotted handfish, inhabit the Derwent estuary. Approximately 40% of Tasmania's population – 202,000 people – live around the estuary's margins and the Derwent is widely used for recreation, boating, fishing and marine transportation. The estuary supports several large industries, including paper production, zinc smelting and boat building, and is Tasmania's fourth busiest port.

A number of environmental issues affect the Derwent estuary, in particular:

- heavy metal contamination of water, sediments and biota by mercury, zinc, cadmium, lead and copper;
- linfestation by introduced marine pests, including the northern Pacific seastar;
- loss and degradation of estuarine habitat and species;
- altered environmental flows and physical barriers to fish migration;
- intermittent faecal contamination of recreational waters;
- organically-enriched sediments and locally depressed oxygen levels; and
- elevated nutrient concentrations and localised algal growth.

Contaminants enter the Derwent estuary from a variety of sources. Point sources include ten wastewater treatment plants (WWTPs) and two large industries (the Norske Skog paper mill and Nyrstar Hobart zinc smelter). Non-point or diffuse sources include urban runoff, rubbish tips and contaminated sites, catchment inputs carried by the Derwent and Jordan Rivers, marine and aquaculture inputs, atmospheric fall-out, and wastes associated with shipping operations, port facilities and marinas. Additionally, under certain conditions, pollutants may be remobilised from contaminated sediments within the estuary. Contaminants associated with these various sources include pathogens, nutrients, organic matter, wood extractives such as resin acids, silt, litter and gross solids, and a range of toxicants including heavy metals and hydrocarbons.

Pollutant loads

From 2003 through 2008 there have been several significant reductions in pollutant loads to the Derwent estuary, particularly with respect to organic matter discharged by the Norske Skog paper mill (>80% reduction) and nutrients discharged by WWTPs (approximately 30% reduction). These reductions were in large part due to improved wastewater treatment at Norske Skog and reuse of treated sewage effluent, particularly from the Rosny WWTP. Nearly 20% of the sewage from the Hobart metropolitan area is now reused to support agriculture and other beneficial uses.

During the period from 2003 to 2008, cumulative loads of dissolved inorganic nitrogen decreased by 25%, total phosphorus loads decreased by 30% and biological oxygen demand (BOD) loads decreased by 85%. Total nitrogen and total suspended solids loads are dominated by riverine inputs and vary from year to year in response to regional rainfall/run-off patterns. Inputs of these parameters both declined by about 30% between 2003 and 2008, probably due in large part to low river flows during 2006, 2007 and 2008. Zinc inputs to the estuary are difficult to quantify, as the primary sources are non-point emissions of groundwater, however it appears that discharges have been relatively constant during the reporting period. Cumulative inputs of faecal bacteria and litter are also difficult to quantify, but evidence suggests that urban stormwater still contributes the majority of these pollutants to the Derwent.

At present:

- the majority of nutrients entering the Derwent estuary are derived from marine and catchment sources, followed by WWTPs;
- the Nyrstar Hobart zinc smelter discharges the majority of heavy metals, however a recent extension of the groundwater recovery systems should soon reduce this;
- the Norske Skog paper mill discharges the majority of anthropogenic organic matter, albeit greatly reduced since 2007; and
- stormwater accounts for the majority of faecal bacteria and litter.

Water quality

Water quality in the Derwent estuary has been assessed based on results from the recreational water quality monitoring program which monitors faecal bacterial indicators weekly at over 30 beaches, bays and other sites during summer months and the ambient monitoring program which measures other water quality indicators monthly at over 20 sites between New Norfolk and the Iron Pot.

Nearly all of the Derwent's main swimming beaches have received good or fair water quality ratings over the past few summer seasons, with the cleanest water found at Opossum Bay, Hinsby and Taroona beaches, Blackmans Bay and Little Sandy Bay. Water quality at swimming beaches has shown a clear improvement over the past six years (due in part to dry weather during the past few summers), and classifications for a number of beaches have been upgraded. However localised contamination does occur, particularly near stormwater and rivulet outfalls, and swimming is not recommended in the Derwent for several days following heavy rain. Recreational water quality of the Derwent's bays, coves and environmental sites is variable. Several sites (e.g. Sullivans Cove and Kangaroo Bay) typically have excellent water quality, while at other sites (e.g. Cornelian Bay, Marieville Esplanade, Watermans Dock) water quality has been poor. The DEP has developed new information products to better inform the community about recreational water quality in the Derwent, including weekly water quality snapshots in The Mercury newspaper and on the DEP website, as well as signage at beaches and other key sites.

A number of water quality indicators – including salinity, dissolved oxygen, organic carbon and total suspended solids – are strongly influenced by River Derwent flow, which has been well below average in recent years. Dissolved oxygen (DO) levels in the upper estuary are depressed at depth during low-flow, summer conditions, and increasingly hypoxic conditions have been observed in this area over the past few summers. The low summer DO levels have been influenced both by natural organic inputs from the catchment as well as organic loads from the newsprint mill. Total suspended solid levels in the Derwent estuary are generally low, except after heavy rains and floods.

Nutrient levels in waters off south east Tasmania show strong seasonal variations, with highest values measured in winter months. In the Derwent estuary, nutrient concentrations are typically highest at mid-estuary sites, in embayments and at depth, reflecting inputs from WWTPs and possibly sediments, particularly in the upper estuary. There have also been indications of increasing nutrient levels in the lower estuary, possibly associated with aquaculture expansion in the d'Entrecasteaux Channel. Chlorophyll *a* levels are typically higher in the middle estuary and embayments, occasionally reaching 'bloom' conditions. Apparent trends over the past five years include an increase in dissolved nutrient levels at depth in the upper and lower estuary and in Prince of Wales Bay.

Long-term data sets for heavy metals suggest significant decreases in water column concentrations of zinc, cadmium and other metals over the past thirty years. However, levels of zinc are still in excess of recommended national guidelines. Zinc concentrations are highest at mid-estuary sites, in embayments and at depth, reflecting inputs from contaminated groundwater at the Nyrstar Hobart zinc smelter site.

Sediment quality

The majority of the Derwent's sediments do not meet national sediment quality guidelines for heavy metals, particularly for mercury, lead, zinc and cadmium. The middle reaches of the estuary are particularly contaminated and heavy metals in this area can be ten or more times the recommended levels, particularly for mercury and zinc. Derwent estuary sediments are also organically-enriched, particularly in the middle and upper estuary. There have been some reductions in heavy metal levels in surface sediments since the 1970s – particularly at mid-estuary sites – and short cores suggest that maximum heavy metal levels are now found at depths of 10 to 20 cm, below the surface. Recent studies indicate that the majority of heavy metals in Derwent estuary sediments are strongly bound and do not tend to be released to the water column under normal conditions. However, during low oxygen events, heavy metals may disassociate from sediments, becoming more bioavailable.

Seafood safety

Concentrations of heavy metals in mussels and oysters appear to have declined since 2003 in some regions of the estuary (i.e. above the Tasman Bridge and in Ralphs Bay). However, levels remain well in excess of national food standards and shellfish should not be harvested or consumed from any areas of the Derwent. Mercury levels in Derwent-caught flathead are also somewhat in excess of recommended guidelines, and a 2008 pilot survey of mercury levels in other recreationally-targeted fish indicated that levels in black bream were well above guidelines, while levels in estuary trout were somewhat above and mullet were well below. Precautionary health advice was subsequently issued by the Director of Public Health recommending against the consumption of black bream and limiting consumption of other Derwent-caught fish, particularly by pregnant women and children.

Habitat and species

Recent surveys of estuarine and foreshore habitats indicate that unvegetated, soft-bottom habitats are by far the most abundant habitats in the estuary (86%), followed by seagrass and macrophytes (7%, primarily in the upper estuary), tidal sandflats (6%, primarily in Ralphs Bay) and rocky reefs (1%, primarily in the lower estuary). The Derwent foreshore retains 49% of its native vegetation, including 12 threatened vegetation communities. Previous studies and anecdotal information suggest that Derwent estuary wetlands, seagrass beds and some rocky reef communities (e.g. giant kelp) were far more abundant in the past and that estuarine sediments were considerably sandier.

The Derwent estuary supports a wide range of fauna, both permanent and migratory, due to its diverse aquatic and foreshore habitats. For example, over 120 species of birds and over 150 species of fish have been documented in the Derwent. Soft-bottom macroinvertebrate communities are also surprisingly abundant and diverse throughout the estuary. There is little comparable quantitative data on which to ascertain long-term trends in Derwent estuary fauna, hence, population and species diversity trends for most species of birds, fish and macroinvertebrates are not well known. Monitoring of fauna at selected sites indicates positive trends for some species (e.g. little penguins, spotted handfish) and negative trends for others (e.g. migratory shorebirds, seahorses).

A number of threatened species have been recorded in or around the Derwent estuary, including over 130 threatened plants and 16 threatened animals. Threatened animals that inhabit or visit the Derwent include the humpback and southern right whales (both endangered), fairy tern (rare) and New Zealand fur seal (rare). The spotted handfish (endangered) is endemic to the Derwent estuary and, despite low current numbers, is showing some signs of recovery following habitat restoration efforts in recent years.

Introduced marine species

The Derwent estuary has been extensively colonised by introduced marine species. At least 79 species have been recorded, including four high priority species for which National Control Plans have been developed: the northern Pacific seastar *(Asterias amurensis)*, European green crab *(Carcinus maenas)*, Japanese seaweed *(Undaria pinnatifida)*, and European clam *(Varicorbula gibba)*. A number of other introduced species (e.g. New Zealand half crab, New Zealand seastar, and New Zealand screw shell) also pose a significant threat to the ecology of the estuary. Rice grass – an invasive intertidal weed – has been successfully managed in the Derwent through annual surveys and control actions, and the area of infestation has been reduced from two hectares in 1995 to about four square metres in 2009.

Climate change

Regional risks associated with climate change have been investigated through several recent studies, and include inundation and erosion of low-lying coastal communities and associated infrastructure, as well as the loss of critical estuarine ecosystems. Areas of particular vulnerability in the Derwent area include low-lying communities such as Lauderdale and Kingston Beach, coastal roads, sewerage and stormwater systems and low-lying rubbish tips and landfills. A number of key estuarine habitats are also at risk from sea level rise, particularly tidal wetlands, saltmarshes and tidal flats, along with the birds, fish and other fauna that depend on these habitats.

Derwent estuary foreshore

The Derwent foreshore extends for a distance of 233 km and is remarkable for its scenery, diversity and ease of public access. Approximately half of the foreshore is publicly owned and managed by state and local governments, largely as parks and reserve areas. These areas provide good opportunities for enhanced public use and recreation, with associated economic and tourism benefits. A number of key foreshore priorities have been identified by the DEP, including development of a regional foreshore tracks network, interpretation, improved management of foreshore vegetation and management guidelines to address foreshore reclamation and dredging activities.

Recent and ongoing management

A number of major initiatives have been implemented by industries and councils to further improve water quality in the Derwent since the last State of the Derwent report was published in 2003. These include:

- Continuing site works at the Nyrstar Hobart zinc smelter to reduce heavy metal discharges, including construction of a 15 ML stormwater biofiltration system, extension of the subsurface groundwater collection system, reprocessing of historic contaminated stockpiles and rehabilitation of foreshore areas.
- Expansion of the wastewater treatment plant at Norske Skog paper mill to incorporate secondary treatment, resulting in a >80% reduction in BOD, representing a major step-change in organic carbon loading to the estuary.
- Implementation of a major effluent reuse scheme on the eastern shore (Rosny WWTP), continued full reuse at Brighton and Bridgewater, and partial reuse at several Hobart and Glenorchy WWTPs such that nearly 20% of sewage effluent from the Hobart metropolitan area is now reused.
- Implementation of numerous stormwater management projects by councils, including several large-scale water sensitive urban design projects, litter and gross pollutant traps, education programs, and catchment management projects.

Major DEP initiatives since 2003 have included the revision and endorsement of the *Derwent Estuary Environmental Management Plan* (2009) and preparation of two Australian Government-supported Water Quality Improvement Plans to better inform management of heavy metals and nutrients. Other key projects have included:

- Initiatives to improve regional stormwater management (e.g. water sensitive urban design manual; guidelines for sediment and erosion control on building sites).
- Improved monitoring and reporting on recreational water quality and seafood safety.
- Development of estuarine models and decision support tools.
- Management of Derwent habitat and species (e.g. rice grass eradication, little penguin conservation, Derwent habitat atlas).
- Foreshore projects (e.g. inventory of foreshore tracks and Derwent interpretation plan).

Many of these projects were implemented with support from Australian Government and NRM South grants. The DEP has also developed a range of communication tools, including a comprehensive website (www.derwentestuary.org,au), regular newsletters and Derwent estuary report cards.

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This report was produced with financial and technical support from the Derwent Estuary Program's major partners – as listed below – and with financial support from the Australian Government's *Caring for Our Country* program.

- Tasmanian State Government (including the Department of Primary Industries, Parks, Water, and Environment and the Department of Health and Human Services)
- Brighton Council
- Clarence City Council
- Derwent Valley Council
- Glenorchy City Council
- Hobart City Council
- Kingborough Council
- Nyrstar Hobart
- Norske Skog Boyer
- Southern Water
- Tasmanian Ports Corporation
- Hydro Tasmania

In addition to the partners listed above, many people provided information, editorial review and other input to this document. Specific references are provided in the text of the report, so rather than listing individuals here, we wish to acknowledge their respective organisations, which include the following:

- University of Tasmania, including the Tasmanian Aquaculture and Fisheries Institute
- CSIRO Marine and Atmospheric Research
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- Southern Tasmanian Councils
- Tasmanian Conservation Trust
- Birds Tasmania
- Understorey Network
- Aquenal
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ABBREVIATIONS

ACE CRC	Antarctic Climate and Ecosystem Cooperative Research Centre
ANOVA	Analysis of Variance
ANZECC	Australian New Zealand Environment and Conservation Council
AOX	Adsorbable Organically Bound Halogens
ARC	Australian Research Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AST	Analytical Services Tasmania
ASTs	Above-Ground Storage Tanks
AWQ	Ambient Water Quality
B&W	Box and Whisker (plots)
BOAT	Bird Observers' Association of Tasmania
BOD	Biochemical Oxygen Demand
CBD	Central Business District
CDOM	Coloured Dissolved Organic Matter
CES	Combined Effluent Stream
Chl-a	Chlorophyll-a
COD	Chemical Oxygen Demand
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFF	Department of Agriculture, Fisheries and Forestry (Australian Government)
DEP	Derwent Estuary Program
DEPA	Derwent Estuary – Pittwater Area
DGT	Diffusive Gradient Thin-Film
DHHS	Department of Health and Human Services
DIC	Dissolved Inorganic Carbon
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorous
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
DPIPWE	Department of Primary Industries, Parks, Water and Environment (Tasmanian Government)
DPIW	Department of Primary Industries and Water (Tasmanian Government)
DPIWE	Department of Primary Industries, Water and Environment (Tasmanian Government)
EAAF	East Asian-Australasian Flyway
EAC	East Australian Current
EMPCA	Environmental Management and Pollution Control Act 1994
EPA	Environment Protection Agency
ERA	Ecological Risk Assessment
ERA	Environmental Risk Assessment
ERLUR	Environmentally Relevant Land Use Register
ETP	Effluent Treatment Plant
EZ	Electrolytic Zinc
FRP	Filtered reactive phosphate
FAO	Food and Agriculture Organisation
FSANZ	Food Standards Australia New Zealand
GIS	Geographical Information Systems
GPTs	Gross Pollutant Traps
HLP1	Hobart Leach Product #1
IPCC	Intergovernmental Panel on Climate Change
ISQG	Interim Sediment Quality Guidelines
LGAT	Local Government Association of Tasmania
LIDAR	'Light Detecting and Ranging' technique
LIST	Land Information Services Tasmania
MAST	Marine and Safety Tasmania
MHWM	Mean High Water Mark
MLE	Multiple Lines of Evidence
NCP	National Control Plan
NELMS	New Environmental Licensing and Monitoring System
NH	Nyrstar Hobart
NIMPCG	National Introduced Marine Pest Coordinating Group
NOx	Nitrate and nitrite
NRM	Natural Resource Management
NTU	Nephelometric Turbidity Units
NWQMS	National Water Quality Management Strategy
PAH	Polycyclic Aromatic Hydrocarbon
PAR	Photosynthetically Active Radiation
PCB	Polychlorinated Biphenyls
ppt	parts per thousand
PSP	Paralytic shellfish poisoning
PWS	Parks and Wildlife Service (Tasmanian Government)
QLD	Queensland
RDC	Refractory Detrital Carbon
RDN	Refractory Detrital Nitrogen
RDP	Refractory Detrital Phosphorus
RPDC	Resource Planning and Development Commission
SD	Secchi (Disk) Depth
SETP	Secondary Effluent Treatment Plant
SSP	Single Super Phosphate
STP	Sewage Treatment Plants
TAFI	Tasmanian Aquaculture and Fisheries Institute
TASMARC	TAsmanian Shoreline Monitoring and ARChiving
TasPorts	Tasmanian Ports Corporation
TASVEG	Tasmanian vegetation map (Tasmanian Vegetation Monitoring and Mapping Program, DPIPWE)
TIDB	Tasmanian Irrigation Development Board
TOC	Total Organic Carbon
TN	Total Nitrogen
TP	Total Phosphorus
TPAC	Tasmanian Partnership for Advanced Computing
TSS	Total Suspended Solids
USTs	Underground Storage Tanks
UTAS	University of Tasmania
WHO	World Health Organisation
WIMS	Water Information Management System
WoNS	Weeds of National Significance
WQIP	Water Quality Improvement Plan
WSUD	Water Sensitive Urban Design
WWTP	Waste Water Treatment Plant

1.0 INTRODUCTION

The Derwent estuary lies at the heart of the Hobart metropolitan area and is an asset of great natural beauty and diversity (**Figure 1.1**). It is an integral part of Tasmania's cultural, economic and natural heritage. The estuary is an important and productive ecosystem and was once a major breeding ground for the southern right whale. Areas of wetlands, underwater grasses, tidal flats and rocky reefs support a wide range of species, including black swans, wading birds, penguins, dolphins, platypus and seadragons, as well as the endangered spotted handfish.

Approximately 200,000 people – 40% of Tasmania's population – live around the estuary's margins. The Derwent is widely used for recreation, boating, fishing and marine transportation, and is internationally known as the finish-line for the Sydney Hobart Yacht Race. The Derwent supports several large industries, including paper and zinc production, boat-building and chocolate manufacturing. Upstream, the Derwent supplies most of Hobart's drinking water and is an important source of hydro-electric power.

A number of environmental issues affect the Derwent estuary:

- heavy metal contamination of water, sediments and seafood;
- loss of estuarine habitat and species;
- introduced marine pests and weeds;
- altered river flow regimes and blocked fish migration routes;
- elevated levels of nutrients and organic matter, and low dissolved oxygen levels.

Sources of contaminants to the Derwent include sewage, stormwater and industrial wastes, as well as agricultural, forestry and aquaculture inputs from the adjacent Derwent and Jordan River catchments and D'Entrecasteaux Channel. Although there have been major improvements in recent years, the Derwent remains a significantly modified estuary. A strategic and coordinated management approach across all levels of government, industry and the community remains our best prospect for a cleaner and healthier estuary in the future.

The Derwent Estuary Program (DEP) is a regional partnership between the Tasmanian Government, local governments, industry, scientists and the community to restore and promote our estuary. The DEP was established in 1999 and has been nationally recognised for excellence in reducing water pollution, conserving habitats and species, monitoring river health and promoting greater use and enjoyment of the foreshore.

The DEP's partners and supporters include:

- Tasmanian State Government
- Brighton Council
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- Glenorchy City Council
- Hobart City Council
- Kingborough Council
- Southern Water
- Norske Skog Boyer
- Nyrstar Hobart
- Tasmanian Ports Corporation
- Hydro Tasmania
- Australian Government
- Tasmanian Aquaculture and Fisheries Institute/ University of Tasmania
- CSIRO Marine Research
- NRM South
- Tasmanian Conservation Trust

Despite the pressures it faces on a daily basis, the Derwent is showing promising signs of recovery in response to management actions undertaken by councils and industries. As the condition of the estuary improves, there is growing interest in conserving and enjoying the Derwent's natural features.

The DEP is underpinned by a comprehensive integrated monitoring program that documents environmental conditions and trends, and also supports scientific research into key issues such as heavy metals and nutrient processes. Cooperative monitoring arrangements between the State Government, industries, local governments and the scientific community have generated a wealth of new information on water and sediment quality, seafood safety and estuarine habitats and species, which have been analysed and interpreted in this new report.

Several large integrated projects have also been completed during the past five years, in particular *Water Quality Improvement Plans* for heavy metals and nutrients, supported by the Australian Government. These projects included the development of estuarine hydrodynamic, sediment transport, toxicant and nutrient response models which have both improved our understanding of estuarine processes and provide a good basis for predictive modelling of different management scenarios.

The new *State of the Derwent Estuary* report reviews environmental quality data collected since 2003 to give a representation of current estuary health and to highlight environmental trends. **Sections 2 and 3** review Derwent estuary values and uses and provide an overview of the estuary's physical setting. **Section 4** reviews pollutants associated with point and diffuse sources and documents trends over the past six years. **Section 5** provides an overview of several integrated studies, carried out in recent years. **Sections 6 through 8** give more detailed information about water quality, sediment quality, and seafood safety. **Section 9** reviews the latest information on Derwent habitat and species. **Section 10** reviews several key foreshore issues and opportunities, **Section 11** provides an update on introduced species and **Section 12** reviews recent initiatives related to climate change. Finally, **Section 13** contains a summary and recommendations.

Figure 1.1: Derwent estuary

2.0 DERWENT ESTUARY VALUES AND USES

Values of the Derwent estuary include intrinsic natural values associated with land, water and biota, cultural and historical values, and socio-economic values reflected in our current uses. The Derwent estuary is widely used for a diverse range of commercial, industrial, social and recreational purposes. An important regional management goal is to maximise these benefits, while minimising potential environmental damage and conflicts between users.

2.1 Derwent estuary values

2.1.1 Natural Values

Estuaries are partially enclosed bodies of water formed where freshwater from rivers and streams flows into the ocean, mixing with seawater. These transitional areas between land and sea are typically protected from the full force of ocean waves, winds and storms by the promontories, islands, reefs and sandy spits that mark an estuary's seaward boundary. The sheltered, tidal waters of estuaries support unique communities of plants and animals, specially adapted for life at the margin of the sea. Estuarine environments are among the most productive on earth, producing more organic matter per year than equivalent areas of forest, grassland or agricultural land. The wetlands that fringe many estuaries also provide a number of valuable services. Water draining from the catchment to the estuary carries sediments, nutrients and other pollutants. As this water flows through marshes and other wetlands, pollutants are filtered out creating cleaner and clearer water – a benefit to both people and marine life. Wetlands also act as natural buffers between the land and the sea, absorbing flood waters and dissipating storm surges.

A wide range of habitat types is found in and around estuaries. In the Derwent, these include beaches and dunes, rocky foreshores, salt marshes and other wetlands, mud and sand flats, seagrass meadows, kelp forests and rocky reefs. Details about these habitat types are given in **Section 9.**

Innumerable birds, mammals, fish, invertebrates and other animals depend on the estuarine habitats of the Derwent as places to live, feed and reproduce. The Derwent is particularly important for migratory birds which rely on the estuary as a resting and feeding ground during their long journeys. More information about the fauna of the Derwent estuary is provided in **Sections 9.4 and 9.5.**

Table 2.1: Conservation areas around the Derwent estuary

Name	Municipality	Area (ha)	Date Effective	Comments
Derwent Cliffs State Reserve	Derwent Valley	5	9/1/52	scenic
Derwent River Conservation Area	Derwent Valley	1,568	27/2/41	river, marsh; includes private lands; boundaries ill-defined
Goulds Lagoon Wildlife Sanctuary	Glenorchy	8	20/5/38	waterfowl; private land
Green Point Nature Reserve	Brighton	22	3/5/78	research station – old proposal
Mount Direction Conservation Area	Brighton/Clarence	1,130	24/7/96	dry schlerophyll forest
Cape Direction Wildlife Sanctuary	Clarence	5	2/9/48	muttonbird rookery
East Risdon Nature Reserve	Clarence	88	17/3/71	rare eucalypts
Gordons Hill Nature Recreation Area	Clarence	34	30/7/79	open eucalypt woodland
Meehan Range (Mt. Direction) Nature Recreation Area	Clarence	430	12/3/81	dry sclerophyll forest
Murphys Flat Conservation Area	Derwent Valley	66	1/5/01	wetland
Knopwood Hill Nature Recreation area	Clarence	39	27/5/83	dry sclerophyll forest
Rosny Hill Nature Recreation Area	Clarence	21	26/8/81	scenic
Ralphs Bay Conservation Area	Clarence	7.3	30/4/99	coastal
South Arm Conservation Area	Clarence	784	29/5/91	wetland migratory waders
South Arm Nature Recreation Area	Clarence	68	6/11/80	coastal recreation, beaches and dunes
Truganini Conservation Area	Hobart	43	18/8/76	representative forest
Kingston Golf Course Wildlife Sanctuary	Kingborough	61	26/11/42	dry schlerophyll forest
Tinderbox Marine Reserve	Kingborough	53	18/9/91	rocky reef habitat
Tinderbox Nature Reserve	Kingborough	73	27/12/00	representative forest

(Source – Parks and Wildlife Tasmania; Date accessed: August 2009; Last updated: August 2009; www.parks.tas.gov.au)

The estuary's natural values are closely integrated with the social fabric of the region. People are attracted to the region for many of the opportunities that the estuary offers, including aesthetics, recreational pursuits such as water sports, yachting, fishing and bird watching, and simply being able to connect with the natural environment.

2.1.2 Conservation areas

There are 19 gazetted conservation areas in the catchment of the Derwent estuary as listed in **Table 1**. Fifteen of these are land-based while the other five, Derwent River Conservation Area, Muphys Flat, Ralphs Bay, Tinderbox Marine Reserve and South Arm Conservation Area, are predominantly intertidal or subtidal. The Derwent River Conservation area is the largest reserve on the estuary (1,568 hectares) and occupies most of the wetlands and mudflats below the high water mark between New Norfolk and Dogshear Point (see **Section 9.1.1** for more information).

2.1.3 Heritage

The first human occupation of the Derwent area is unknown, but Aborigines are thought to have arrived in Tasmania over 35,000 years ago. During the Ice Age, the river valley is likely to have been a major communication route between the coast and the hinterland. In recent times, two Aboriginal tribes inhabited the region surrounding the Derwent estuary: the Oyster Bay Tribe on the eastern shore; and the South East Tribe on the western shore. Both tribes were hunter-gatherers and used the Derwent as a source of food, with shellfish, particularly oysters and mussels, as a major element of their diet (Ryan, 1996). The Derwent estuary shoreline contains a very high density of Aboriginal sites, predominantly shell middens and quarries, many of which have been or are being destroyed by modern development. The Derwent was known to Aborigines by the following names: TEETOOMELE MENENNYE, RAY. GHE.PY.ER.REN.NE and NIB.BER.LIN (Plomley, 1990).

In 1793, Captain Willaumez of the d'Entrecasteaux/Kermadec expedition entered and surveyed the river, naming it 'Riviere du Nord'. One year later, Commodore Sir John Hayes of the East India Company explored the river further and renamed it Derwent, after the Derwent River in Cumberland, England (Nomenclature Board Hobart). 'Derwent' is thought to be derived from the Celtic word for 'clear water'. Risdon Cove was selected as Tasmania's first European settlement in 1803, however, due to unfavourable conditions, the settlement was moved to Sullivans Cove in 1804, where it prospered and grew into the City of Hobart. Sites with important European heritage values include Risdon Cove, Sullivans Cove/Battery Point, Queens Domain, Royal Botanical Gardens, Government House, Mount Nelson signal station, Mulgrave and Alexandra batteries, Kangaroo Bluff Historic Site and the Iron Pot Light.

2.2 Derwent estuary uses

The Derwent estuary is surrounded by Tasmania's largest population centre, and the estuary is widely used for recreation both on and off the water. The estuary is also very much a 'working waterfront'. The Derwent is Tasmania's third largest port and is an important regional centre for shipping of goods. Antarctic support vessels, commercial fishing vessels and, increasingly, cruise ships and visiting military vessels use the Derwent. There are several major water-dependent industries situated on the foreshore, including the Norske Skog paper mill, the Nyrstar Hobart zinc smelter, Impact Fertilisers, and Incat Catamarans, as well as a host of smaller commercial enterprises. The Derwent estuary is an important tourism resource for Hobart, which is the most visited place in Tasmania. These various uses are indicated in **Figure 2.1** and described in greater detail in the sections below.

2.2.1 Population centre

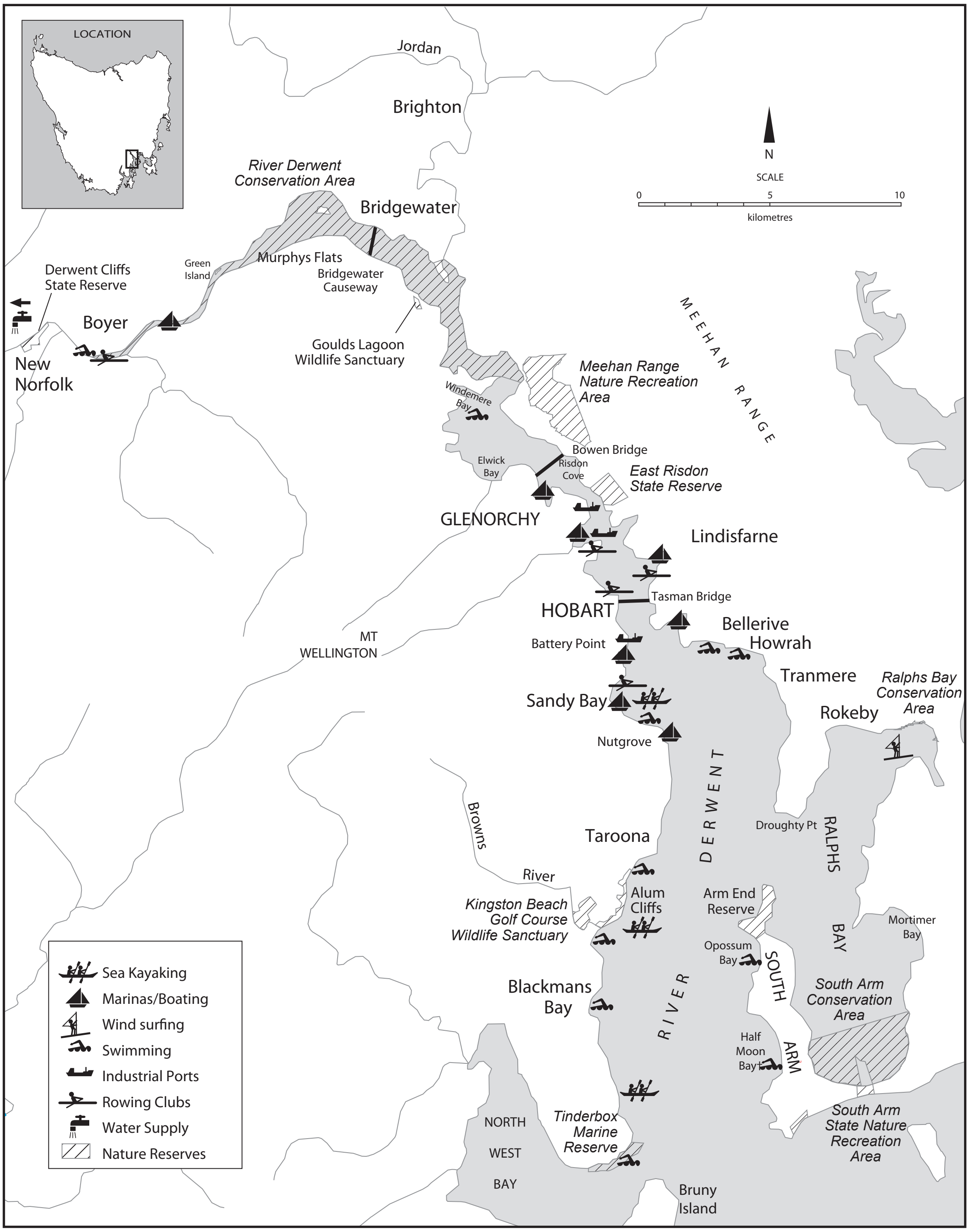
Approximately 202,000 people live in the Derwent estuary region within six different local government areas, as indicated in **Table 2.2.** The majority live along the eastern and western shores of the middle estuary in the metropolitan areas of Hobart, Glenorchy and Clarence, with smaller population centres at Kingston/Blackmans Bay, Bridgewater/Brighton and New Norfolk.

Table 2.2: Population by local goverment area

Local Government Area	**2003**	**2005**	**2007**	**Annual Population Change (2003-2007)**
Clarence	50,257	51,072	51,173	0.7%
Hobart	48,533	48,808	49,720	0.6%
Glenorchy	44,925	44,900	44,250	-0.4%
Kingborough	30,961	32,057	32,228	1.0%
Brighton	13,436	14,027	14,791	2.3%
Derwent Valley	9,372	9,688	9,770	1.0%
Total Greater Hobart Area	**197,484**	**200,552**	**201,932**	**0.6%**
Tasmania	482,128	488,948	493,341	0.6%

(Source: Australian Bureau of Statistics website; Date accessed: April 2009; Last updated: August 2009; www.abs.gov.au)

Figure 2.1: Uses of the Derwent estuary



During the period from 2001 to 2007, the Greater Hobart region had an annual population increase of 0.6%.

2.2.2 Foreshore land use

The estuary's foreshore has historically been a focal point for development, although the uses have shifted over time in response to changing economic and social demands. In recent years there have been numerous developments and projects along the foreshore associated with residential, tourism, recreational, and industrial or commercial developments.

In some areas, the foreshore has changed dramatically since the early 1800s due to infilling, together with reclamation of tidal flats and wetlands. Large areas of Sullivans Cove, Hunter Street and Macquarie Point, for example, were previously intertidal or subtidal wetlands. Similarly, many low-lying areas and wetlands at the heads of bays were filled (often used as tips), including Wentworth Park, Eastlands, Cornelian Bay, Selfs Point, Wilkinsons Point, and the Boyer paper mill.

Land tenure along the foreshore (100 m landward of mean high water) was mapped in 2003 and analysed through the DEP, with assistance from Department of Primary Industries, Water and Environment. About 50% of the foreshore is privately owned, 30% is state owned, 10% is council owned and the remaining 10% is occupied by roads and associated corridors. Planning and development controls of foreshore lands are heavily influenced by land tenure, however, all subtidal areas fall within the jurisdiction of Crown Land.

The Derwent foreshore is well-endowed with numerous parks, reserves and conservation areas owned and managed by state and local governments. These include formal gardens, sport and recreation grounds, playgrounds and picnic areas, and a large number of foreshore reserves and conservation areas. There are also numerous tracks and trails that run along the foreshore, ranging from informal rough footpaths to well-developed shared cycling/walking tracks, such as the inter-city cycleway.

2.2.3 Industry and commerce

Commercial and industrial access to the estuary and river were critical to the early economic development of the region for local transportation, shipping, water supply and wastewater discharge. This dependence has declined over the past 50 years as other forms of transport have predominated. However, a number of water-dependent commercial activities are still situated along the foreshore. These include:

- Prince of Wales Bay maritime industries including Incat which relies on the estuary for construction and maintenance of vessels.
- Nyrstar Hobart zinc smelter which relies on the estuary for shipping, water supply, wastewater discharge.
- Norske Skog paper mill which relies on the estuary for water supply and wastewater discharge.
- Selfs Point fuel storage facilities which relies on the estuary for shipping, refuelling of vessels.
- Impact Fertilisers relies on the estuary for shipping
- Domain slipway and other slipway facilities (boat maintenance, some construction).
- Hobart docks / TasPorts Corporation (commercial, tourism and research shipping).
- Sullivans Cove (commercial fishing and tourism).

In addition to these major industries, there are numerous commercial facilities that support recreational and tourism needs, such as;

- marinas and yacht clubs,
- restaurants and cafes, and
- ferry cruises, cycle and boat rentals.

2.2.4 Transportation

Marine transportation and shipping

The Derwent has been described as one of world's best harbours: it is easily navigated with few rocks, reefs or other hazards, has a stable and well-defined channel, a small tidal range and minor to moderate tidal currents. Furthermore, the Derwent has few sedimentation problems that impede navigation, rarely requires dredging, and has many good anchorages with shelter from prevailing winds.

Shipping and other marine transportation operations in the Derwent are jointly managed by the Tasmanian Ports Corporation and the Marine and Safety Authority of Tasmania (MAST). The Port of Hobart is the fourth busiest port in Tasmania (after Burnie, Launceston and Devonport) and handled 2.06 million tonnes of freight in 200708. Imports accounted for about 1,140,000 tonnes – mostly zinc concentrates, petroleum products, phosphate rock, liquid petroleum gas and caustic soda. Exports accounted for the remaining 923,000 tonnes – mostly sulphuric acid, zinc and zinc alloys and fertilisers. (G. Denney, 2009, Tasmanian Ports Corporation, *pers. comm.*).

During 2007-08 Hobart was visited by 241 vessels (>35 m). Most of these were associated with industrial and commercial activities, however, an increasing number of cruise ships and military vessels are visiting the Derwent – providing an important boost to tourism and the local economy. In addition, a number of research and Antarctic re-supply vessels are either based in Hobart or visit regularly (G. Denney, 2009, Tasmanian Ports Corporation, *pers. comm.*).

Land-based transportation

Nearly 10% of the Derwent foreshore is occupied by roadways and associated corridors. These include major state-managed roads (e.g. Midlands, Lyell and Brooker Highways), as well as local roads managed by individual councils. There are four major crossings across the estuary – the Tasman, Bowen and New Norfolk Bridges and the Bridgewater Causeway. Railways are also an important feature of the foreshore, although they now play a reduced role in the transportation of goods and passengers.

2.2.5 Recreation

The Derwent is widely used for recreation both on and off the water. Primary contact (full immersion) sports include swimming, water-skiing, windsurfing, scuba-diving and snorkelling. Secondary contact sports include large and small boat sailing, motor-boating, sea-kayaking and rowing. The Derwent is also an important focus for foreshore recreation, with numerous parks, picnic areas and sports grounds.

Water sports

Most sandy beaches, suitable for swimming, are situated south of the Tasman Bridge. Swimming from docks and rafts is also popular in the river at New Norfolk. The Derwent's main beaches are indicated in **Figure 2.1**. Of these, Kingston, Blackmans Bay, Nutgrove, and Little Sandy Bay beaches are the most intensively used western shore beaches, while Bellerive and Howrah beaches are the most frequently used on the eastern shore. Windsurfing is popular in Ralphs Bay and scuba-diving is practiced at a number of sites including the Tinderbox Marine Reserve.

Recreational boating is very popular in the Derwent. Large and small boat sailing takes place in the middle and lower reaches of the estuary. Of the 26,072 registered pleasure boats in the state (MAST statistics 2008), 21% regularly use the Derwent estuary and channel (*2007 Recreational Boater Survey*, MAST). Ten yacht clubs, six private marinas and numerous small craft anchorages provide slips, mooring and other facilities at sheltered sites throughout the middle and lower reaches of the estuary. MAST manages three jetties in the Derwent, two boat ramps and around 1,400 moorings. There are numerous other council and privately owned jetties, docks and boat ramps along the foreshore as well. Motorboat racing is practised in some parts of the Derwent estuary, particularly in its upper reaches, just downstream of New Norfolk. Water and jet-skiing are also popular in this area and at some sites further south as well.

Larger boating events include the internationally renowned annual Sydney Hobart Yacht Race during which approximately 100 yachts and 10,000 people visit the Hobart waterfront over the three main days of the Sydney Hobart race season. Club races for boats of all classes are held on most weekends, and several regattas (Hobart, Sandy Bay and Bellerive) are held on long weekends in the summer. There are nine rowing clubs distributed throughout the Derwent at the sites indicated in **Figure 2.1.** Four of these are based at New Town Bay. Sea-kayaking is also becoming increasingly common at sites throughout the estuary.

Foreshore recreation

Foreshore recreation occurs at numerous sites around the Derwent including; parks, picnic areas, playgrounds, playing fields, golf courses and other sporting grounds, walking and bicycle tracks. Some of the more notable sites on the western shore include the Kingston Beach golf course, Alum Cliffs track, Nutgrove recreation area, Cenotaph, Queens Domain and Royal Tasmanian Botanical Gardens, Hobart-Glenorchy cycle-way, Claremont golf course, Elwick race course and Montrose and Austins Ferry foreshore parks. On the eastern shore, popular recreation sites include Bedlam Walls, Geilston and Lindisfarne Bay parks, the Rosny foreshore and State Recreation Area, Bellerive and Wentworth parks and South Arm.

An increasing number of walking and cycling tracks are being used and developed around the Derwent foreshore. There are approximately 111 km of tracks along the Derwent estuary foreshore including tracks on both the eastern and western shores of the Derwent (DEP Tracks Survey 2007). These include the Inner City Cycleway between Hobart and Glenorchy, the multiple-use foreshore tracks along the Bellerive-Howrah foreshore, the Alum Cliffs track and many smaller trails and footpaths.

2.2.6 Fishing

The Derwent estuary supports an extensive recreational fishing industry throughout its length. In the 12 months prior to May 2000 an estimated 124,590 Tasmanian residents aged five years or older fished at least once, representing a 29% participation rate in recreational fishing. The majority of recreational fishing occurs in the south and east of the state with the Derwent accounting for 7% of the total effort. The species and number caught by recreational fishers in the Derwent in 2000-01 included flathead (36,017), bream (9,215), trout (5,582), Australian salmon (4,846) and cod (236) (Lyle 2005).

The Derwent is an important regional fishing port. Fifty commercial fishing vessels were home-ported in Hobart in 2008-09 and an additional 30 fishing vessels visited and used the port facilities (G. Denney, 2009, Tasmanian Ports Corporation, *pers. comm.*). Commercial fishing operations in the Derwent estuary have historically been quite significant, however, at present only the lower reaches of the estuary are open to commercial fishing. Commercial catches in the lower estuary amounted to 29.7 tonnes between 2002-03 and 2007-08. Whiting accounted for 90% of the catch (P. Ziegler, 2009, Tasmanian Aquaculture and Fisheries, *pers. comm.*).

There are presently no shellfish or finfish farming operations in the Derwent, nor should shellfish collected from any part of the Derwent (including Ralphs Bay) be consumed because of high concentrations of zinc, cadmium and other heavy metals (see **Section 8** – seafood safety).

2.2.7 Tourism

The Hobart area is the most visited place in Tasmania. According to the *Tourism Tasmania Tourism Visitor Survey 2007-08*, approximately 897,100 adult visitors came to Tasmania in 2008, of which 573,800 (67%) visited and stayed overnight in the Hobart area (Tourism Tasmania 2009). The greater Hobart area combines a rich history, galleries, markets, restaurants and waterside pubs with a working port. This provides a diverse experience for visitors and locals alike. Many sites along the Derwent foreshore and surrounds represent some of the most popular tourist attractions in Tasmania, including Sullivans Cove and Salamanca Place, Royal Tasmanian Botanical Gardens, and Mount Wellington. Other popular sites near the estuary include the Taroona Shot-tower, Cadbury factory, Tasmanian Museum and Art Gallery, the Maritime Museum, Moorilla Estate Winery and Bellerive Boardwalk.

The Derwent estuary is an attraction itself, drawing many visitors and locals to participate in tourism and recreational activities on or near the water. Several ferry operators run cruises from the Hobart wharf area to attractions such as Cadburys, Moorilla, Wrest Point, Bellerive and further afield to Bruny Island, Peppermint Bay and Port Arthur. A commuter service conveys city workers from the Eastern Shore to the City. Other operators provide an experience under sail aboard replica sailing vessels and modern cruising yachts.

World-class sporting and cultural events on or around the Derwent estuary are a major draw-card for Hobart and Tasmania, attracting local, national and international interest. The Sydney to Hobart, Melbourne to Hobart and Three Peaks yacht races, the Taste of Tasmania and Hobart Summer Festival, the Australian Wooden Boat Festival and Ten Days on the Island are some of the water and land-based events that utilise the Derwent and its foreshore. There are also many smaller local festivals, including local regattas, music festivals, sporting events and races.

Cruise ships and visiting naval vessels are also important contributors to the local economy and tourism industry. During 2007-08 Hobart received 21 cruise ships over 66 visits bringing approximately 105,400 passengers and crew which is a 27% increase from 2007-08. The passengers and crew from these vessels radiate out from the port of Hobart, visiting all regions of southern Tasmania (Tourism Tasmania Cruise Ship Results 2008 – 2009).

Convention-based tourism is another increasingly important contributor to the local tourism industry and economy. Approximately 23,800 delegates attended conferences/conventions in Tasmania during 2008, many of which would have experienced the Derwent first-hand via ferry cruises, foreshore walks or other events.

2.2.8 Research, education and Antarctic gateway

Hobart is an important centre for research and education, particularly for marine and Antarctic studies. The following research and education centres are located in the area:

- CSIRO Division of Marine Research (Hobart).
- Tasmanian Aquaculture and Fisheries Institute – Univeristy of Tasmania (Taroona).
- University of Tasmania, including the Antarctic Cooperative Research Centre (Sandy Bay).
- Australian Antarctic Division (Kingston).

Several Antarctic icebreakers and other large research vessels are based in Hobart, including the *Aurora Australis, Astrolabe* and *Southern Surveyor,* and a number of other research vessels visit Hobart on a regular basis.

Antarctic tourism is a rapidly growing area. During the southern hemisphere summer, a number of ships depart Hobart for Macquarie Island and the Antarctic continent, carrying scientists and tourists to visit and explore this relatively untouched wilderness. Operators to Antarctica see Hobart as a very important and attractive port, being close to the city and having well-developed infrastructure and suppliers.

3.0 PHYSICAL SETTING

Information on the physical setting of the Derwent estuary (geology, climate, river flows and estuarine circulation) is provided in the following section, as is an overview of broader catchment characteristics. Further discussion of estuarine water quality, sediments, habitat and biota are provided in **Sections 6, 7, 9** and **11**. Potential changes to the physical environment of the estuary due to climate change, are discussed in **Section 12**.

3.1 Estuary morphology, bathymetry and geology

The Derwent estuary extends for a distance of 52 km from New Norfolk to the Iron Pot and covers an area of 198 km^2. The morphology of the estuary is that of a drowned river valley, which was formed between 6,500 and 13,000 years ago, when sea level rose around 60 m to near its current level.

South of the Tasman Bridge, the lower reaches of the Derwent estuary are 4-6 km wide, characterised by a relatively straight western shoreline and a single large (>50 km^2) embayment – Ralphs Bay – on the eastern shoreline. The middle part of the estuary – between the Bridgewater Causeway and Bowen Bridge – is 1 to 2 km wide, with a more convoluted shoreline and numerous small embayments. Average water depths in the lower and middle estuary are in the order of 10 to 20 m, with a maximum depth of 44 m observed immediately south of the Tasman Bridge. North of the Bowen Bridge, the estuary is characterised by a well-defined channel (3 to 10 m deep) bordered by extensive shallow flats and wetlands. Several deep holes (8 to 17 m) are found in the vicinity of Boyer and just to the east of New Norfolk. Bathymetric data has recently been compiled by CSIRO (Herzfeld *et al*. 2005) to support hydrodynamic modeling, as discussed in **Section 5** (see **Figure 5.3**).

The regional geology of the Derwent estuary is complex, dominated by Jurassic dolerites and Cambrian basalts, with smaller areas of Triassic and Recent sedimentary deposits (Department of Mines 1976). High-resolution geophysical and bathymetric surveys were conducted across the lower Derwent estuary in 2000 and 2001 to investigate the distribution of Cainozoic sediments and Tertiary volcanic rocks. Magnetic data indicated the location of several previously unknown Tertiary volcanic centres. Seismic reflection profiles recorded a complex sedimentary history aged from late Tertiary to Holocene (Roach and Gibbons 2001).

Coastal landforms along the Derwent foreshore are highly varied and include sandy or muddy intertidal flats, sand and pebble beaches, dunes, rocky shorelines and platforms, steep bluffs and sea cliffs. These landforms have predominantly been shaped by erosional processes as sea level continues to rise. Mapping of the foreshore has been conducted as part of an assessment of coastal vulnerability to erosion from changes in sea level (Sharples 2006) as discussed in **Section 12**.

3.2 Estuarine circulation and coastal oceanography

The circulation of the Derwent estuary has been investigated by a number of scientists, (e.g., Thomson and Godfrey 1985; Davies and Kalish 1989, 1994; Hunter and Andrewartha 1992; CSIRO Division of Marine Research 1999, 2001; Herzfeld *et al.* 2005). Most investigators describe the middle to lower reaches of the estuary as being partially to well-mixed (dominated by wind-driven and tidal mixing), with relatively large vertical mass movements within the water column. In contrast, the middle-to-upper reaches of the estuary are highly stratified. The upper estuary has a distinct salt wedge, the toe of which is normally situated in the vicinity of New Norfolk except during high river flows (greater than 150 cubic metres per second) when the salt wedge migrates downstream as far as Bridgewater.

The average tidal range of the Derwent is slightly greater than one metre, ranging from a minimum of 0.3 m to a maximum of 1.6 m. Tides in the Derwent tend to be asymmetric, in that the diurnal (daily) tide has a slightly greater range than the semidiurnal (twice daily) tide. Hence, Hobart occasionally has only daily tides and usually has large variations in the heights of successive tides. Tidal currents are relatively weak, typically in the order of 0.1 to 0.2 m/sec (Thomson and Godfrey 1985; Davies and Kalish 1994). Investigations and modelling conducted by CSIRO indicate that, on average, surface currents flow to the south at velocities of 0.1 to 0.2 m/sec, while bottom currents flow northwards at velocities of 0.02 – 0.05 m/sec. More detailed circulation modelling has been done in specific areas of the estuary, such as the area downstream from Norske Skog Boyer's outfall (Parslow *et al*. 2001) and around existing or proposed sewage treatment plant outfalls. In 2005, a detailed hydrodynamic model was developed for the Derwent estuary by CSIRO scientists to support the *Derwent Water Quality Improvement Plan* (Herzfeld *et al*. 2005). See **Section 5** for details. Similar models have been developed for the D'Entrecasteaux Channel (Herzfeld 2008) and are being developed for the wider region by CSIRO Marine Research.

In the lower Derwent estuary, a combination of wind effects and the Coriolis force deflect the main flow of River Derwent water along the estuary's eastern

Figure 3.1: The Derwent estuary catchment

shoreline, such that low salinity surface water extends further along the eastern shore than along the western shore. The average flushing period for the estuary is estimated to be about 12 days (M. Herzfeld, 2009, CSIRO, *pers. comm.*), although the relatively isolated deep waters of the upper estuary may be retained for a much longer period (20 to 35 days) during low flows (Davies and Kalish 1994). Flushing times may vary considerably in time and space, depending on river flow, wind stress and other variables, as discussed in Herzfeld *et al*. (2005).

The marine waters off south eastern Tasmania are known to be an area of convergence between subtropical and sub-Antarctic water masses, the location of which varies seasonally and from year to year. During the warmest months (February-March), nutrient-poor, subtropical waters may be carried along the east coast of Tasmania, occasionally extending as far south as Storm Bay and into the mouth of the Derwent estuary. During the cooler months (August-September), nutrient-rich sub-Antarctic waters enter Storm Bay and the Derwent estuary (Harris *et al*.1987). The seasonal interplay between these water masses strongly influences the nutrient and algal dynamics of south east Tasmanian coastal waters.

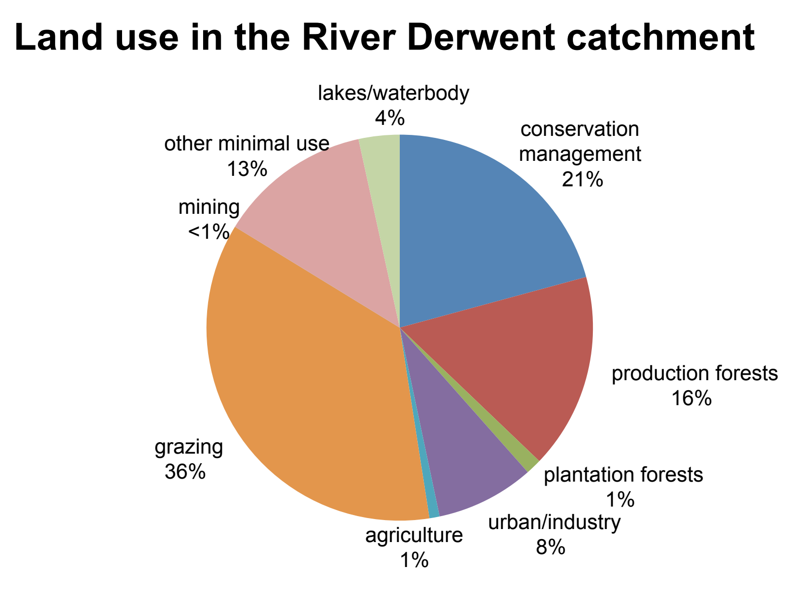
3.3 The Derwent catchment

The Derwent estuary's catchment covers an area of approximately 8,900 km^2 in central and south eastern Tasmania (approximately one-fifth of Tasmania's land mass) and comprises the River Derwent catchment (7,764 km^2), the Jordan River catchment (742 km^2) and other areas immediately adjacent to the estuary (375 km^2), as indicated in **Figure 3.1.** Diversions in the upper Ouse catchment (Great Lake) have effectively reduced the natural catchment area. The region has varied relief, ranging from the gently undulating agricultural lands of the Southern Midlands to the high altitude plateaus and peaks of the Central Plateau, Mt. Field and Mt. Wellington. These topographic features are a reflection of the underlying geology, which can be broadly described as post-Carboniferous sediments intruded by igneous dolerite and basalt. Precipitation within the catchment is variable, ranging from 600 mm/yr in the vicinity of the estuary, to about 800 mm/yr in the Central Highlands, to 2,000 mm/yr in more mountainous areas to the north and west.

Vegetation mapped across the catchment indicates the natural open grassy woodlands in the south east of the catchment have largely been cleared for agriculture, with remnant pockets remaining in some areas. The middle and upper sections of the catchment support relatively intact native vegetation. The broad vegetation classes include: alpine vegetation, rainforest, dry and wet eucalypt forests, eucalypt woodlands, heath, scrub, button grass plains and moorlands (Andrew 2002; DPIWE 2003a).

Land use across the Derwent catchment consists predominantly of grazing (36%), followed by conservation management (21%), production forests (16%), 'other minimal use' (12.8%), urban/industry

Figure 3.2: Land use in the River Derwent catchment



Source: Hydro Tasmania Consulting 2008; DPIWE 2003b.

(8%), lakes/waterbodies (3%), plantation forests (1%), agriculture (1%) and mining (<1%) (Hydro Tasmania Consulting 2008; DPIWE 2003b) as shown in **Figure 3.2**. These values are based on 2001-02 mapping and may not reflect more recent changes.

Agricultural land in the Derwent catchment covers an area of approximately 3,300 km^2, and is predominantly located in the catchments of the Jordan, Clyde and Ouse Rivers and along the River Derwent Valley between Ouse and New Norfolk. Sheep and cattle grazing is the main agricultural activity, with smaller areas cultivated for crops such as vegetables, hops, poppies, stone-fruit, vines and oil crops. Several large salmon and trout hatcheries are situated in the catchment at Wayatinah and along the Tyenna River.

Major conservation areas in the Derwent catchment include portions of the Cradle Mountain-Lake St Clair National Park at the River Derwent's headwaters, Mt Field National Park and portions of the Tasmanian Wilderness World Heritage Area.

Forestry is a significant land use in the western and northern areas of the catchment. The forests are dominated by *Eucalyptus delegatensis* (gum-top stringybark) and *Eucalyptus regnans* (swamp gum). *E. regnans* is the tallest growing flowering tree in the world and has strongholds in old growth forests of the Styx Valley sub-catchment and along the River Derwent near Wayatinah. Native forest harvesting in the catchment is undertaken primarily by clearfelling followed by regeneration to plantation forest and native forest. Plantations, consisting mainly of *Pinus radiata* (radiata pine), have been established in the foothills of the River Derwent valley.

An environmental review of the Derwent catchment provides further information on the geographical, biological and hydrological characteristics of the catchment, including the hydro-electric generation system and known environmental issues in the catchment (Hydro Tasmania Consulting 2001).

3.4 River inputs to the estuary

Various rivers and streams flow into the Derwent estuary influencing estuarine dynamics including flows and water quality. The River Derwent and its tributaries contribute the vast majority of flows into the estuary. Other tributaries of the Derwent estuary include the Jordan River which contributes small and often intermittent flows to the estuary, with a mean discharge of less than 1 cubic metres per sec (cumec). Several major streams flow year round from the well-watered mountainous slopes on the western shore of the estuary, whilst smaller perennial streams flow to the estuary from the drier eastern shore.

The River Derwent also contributes organic, sediment and nutrient inputs to the estuary and with changes in the flow regime, the levels of these entering the estuary may have been altered (**see Section 6**). Further information on nutrient sources and concentrations in the River Derwent catchment and fluxes to the Derwent estuary can be found in the report by Coughanowr (2001). A review of surface water quality monitoring in the NRM South region of Tasmania, including the Derwent catchment and other rivers and streams entering the estuary, has also been completed by Hydro Tasmanian Consulting (2008).

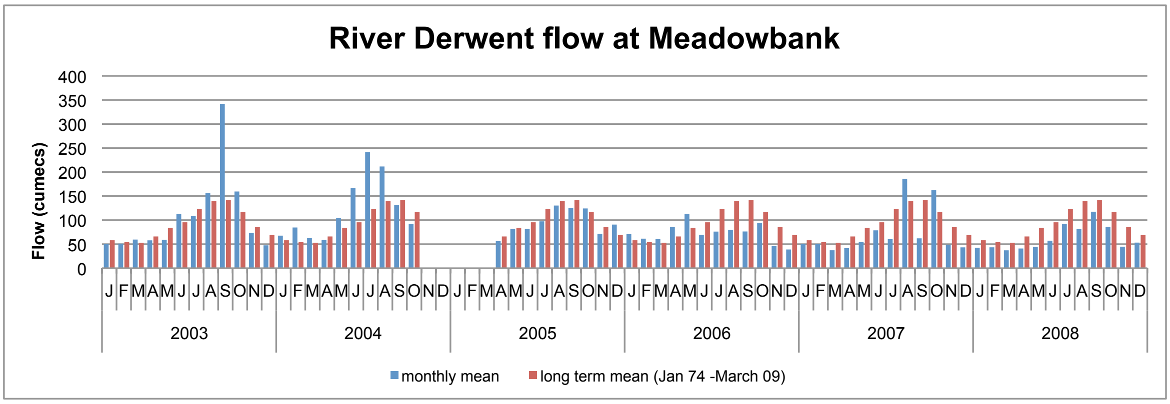
3.4.1 River Derwent

The River Derwent originates at Lake St Clair and flows south over a distance of 187 km to New Norfolk at the head of the Derwent estuary. The River Derwent is one of the largest rivers in Tasmania, both in terms of catchment area and flow. The long term mean annual flow (1974-2009) in the Derwent is 90.6 cumec. However, there is a defined seasonal trend with the highest average flow and greatest flood frequency occurring in the second half of the year. Over the past five years, the mean monthly flow has decreased from 106.5 cumec in 2003 down to 61.8 cumec in 2008. Average monthly flow in the Derwent from 2003 through 2008 is given in **Figure 3.3**.

The Derwent catchment is characterized by a modified flow regime with the generation of hydro-electric power, controlled release and extraction for irrigation, land use change and the supply of water for municipal, industrial and fish farm purposes playing important roles. Over the past 90 years, the volume and seasonality of flows in the Derwent has been strongly affected by changes in catchment land use, diversion, impoundment and diversion of water from the catchment, as well as by a climatic dry period.

The cumulative effect of the aforementioned impacts has resulted in an estimated 32% reduction in River Derwent flows from an annual average of 130 cumecs in the 1920s (1922-1929) to approximately 88 cumecs annual average (2003-2008). The 1920's flow was measured on the River Derwent at Bushy Park (including the Tyenna and Plenty River tributaries), while the more recent flow was measured downstream from Meadowbank Dam (W.Soutter, 2009, Hydro Tasmania, *pers. comm.*). The different sampling locations may account for some difference in flow, but the greatest impact was caused by the diversion of Great Lake outflow (inclusive of the diversion flow from Lake Augusta to Great Lake via the Liawenee Canal). The Great Lake outflow is no longer part of the Derwent catchment. The Great Lake now flows to the north to the South Esk catchment via the Poatina Power Station. (W. Souter, 2009, Hydro Tasmania, *pers. comm.*).

Figure 3.3: Comparison of monthly mean and long-term monthly mean flow in the River Derwent



Source: data provided by Hydro Tasmania.

It is likely that flow modifications in the River Derwent have affected dynamics in the estuary including water circulation patterns, dilution and flushing of wastewater discharges, oxygen replenishment, displacement of saline water, delivery of silt, impacts on primary production, and the seasonal cycles of migratory fish. In 2001 an initial assessment of the environmental flow requirements of the lower River Derwent and upper Derwent estuary was conducted and an initial minimum flow regime was defined that recommended no further water abstractions from the system in summer (Davies *et al*. 2002). Further review and recommendations were carried out by Davies (2005), as discussed in the *Derwent Estuary Water Quality Improvement Plan for Heavy Metals* (DEP 2007). There have been no further studies to update this initial recommendation and there are currently no environmental flows defined for the River Derwent. While surface water modeling has been conducted for the Derwent, the lack of defined environmental flows meant interim environmental flows were applied (Hydro Tasmania Consulting 2007). Further work is required in this area.

3.4.2 Water supply

The River Derwent and its tributaries are an important source of municipal and industrial water supplies. The majority of Hobart's municipal water supply is taken from the River Derwent just above New Norfolk and purified at the Bryn Estyn water treatment plant prior to distribution. Water from the River Derwent is used to supply councils within the greater Hobart area via 400 km of bulk main pipes service areas as far as Snug, Kempton, Sorell and throughout the Derwent Valley. Water for irrigation is also supplied (off-peak) through Bryn Estyn to the Jordan and Pittwater-Coal water management areas, and the South East Irrigation Scheme.

Bryn Estyn treats and distributes up to 170 ML/day from the Derwent (average around 25,000 ML/year), which is approximately 60 to 65% of the total annual average demand (Hobart Water 2006). In summer, when demand may rise to 240 ML/day, storage dams (Lake Fenton, Mt. Wellington) supply the remainder. Water taken from the Derwent to the treatment plant fluctuates depending on the level of demand and the water availability in other catchments for supply. **Table 3.1** indicates the variation in River Derwent water supply treated at Bryn Estyn between 2002-03 and 2008-09. The general increase in the off-peak supply of Derwent water (primarily for irrigation) is associated with business growth as farmers increase the number of connections to the South East Irrigation Scheme or have constructed dams with greater capacity (Southern Water, 2009, *pers. comm.*).

To help ensure long term sustainable high-quality drinking water supply to Hobart and surrounds, the water supplier Hobart Water (now operated as Southern Water) developed a *Derwent Drinking Water Catchment Plan* (2007) that identifies hazards to water quality and management actions to reduce risks.

The Norske Skog paper mill at Boyer also draws water from the River Derwent at Lawitta and at the mill site. The water is used for pulp and paper production and discharged back into the river downstream of the mill. Between 2003 and 2008, the annual quantity of water drawn from and discharged to the river has ranged from 19,395 ML in 2003, down to 17,190 ML in 2007, and up to 21,515 ML in 2008. Higher levels in 2008 are related to the amount of cooling water needed at the newly constructed effluent treatment plant at the mill (P. Kearney, 2009, Norske Skog., *pers. comm.*).

Table 3.1: Water supply from the River Derwent, Bryn Estyn Treatment Plant

Bryn Estyn Treatment Plant	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**	**2008/09**
Average winter extraction (ML/day)	n/a	n/a	n/a	n/a	55	60	61
Average summer extraction (ML/day)[1]	n/a	n/a	n/a	n/a	112	130	108
Average daily summer demand (ML)[2]	171	147	148	134	145	159	n/a
Off-peak supply (ML/year)[3]	1,743	1,608	1,839	1,889	2,684	3,136	2,400
Annual Derwent source of supply (ML/year)	23,699	21,378	22,839	24,157	30,725	33,183	n/a

1. Total water extracted, with about 2.5% discharged back into the Derwent
2. Water demand supported by Derwent River and other storages (Lake Fenton and Mt Wellington)
3. Majority of off-peak supply from the Derwent goes to the South East Irrigation Scheme.

n/a = not available

Source: Southern Water, 2009, pers. comm.; Hobart Water 2003, 2006, 2008.

3.4.3 Hydro-electric power generation

The Derwent and three of its nine tributaries have been dammed or diverted to over 20 storages for hydro-electricity generation. These include both run-of-the-river storages at low altitude and large storages at higher altitude for manipulating winter runoff. Ten hydro-electric power plants are situated on the Derwent or its tributaries and the majority of the catchment's flows are diverted through these power plants, which in 2008 had a combined average power generation of 227.5 megawatts (W. Soutter, 2009, Hydro Tasmania, *pers. comm.*). Water storage construction commenced in the 1800s with the creation of Lake Crescent dam for irrigation. The impoundment of Great Lake followed in 1916, with a 10% reduction in yield due to diversion to the South Esk catchment in 1964 (Davies and Kalish 1994). Construction of additional dams for hydro-electricity continued until 1968, e.g. Lakes Repulse, Cluny and Meadowbank.

3.4.4 Irrigation

Throughout the Derwent catchment 434 (current) entitlements for water extraction and irrigation are registered on the State Government's Water Information Management System (WIMS – December 2006). These equate to a dam extraction volume of 15,828 ML. The majority of entitlements occur in the lower sub-areas and relate to agriculture, except for the largest extraction entitlement for the Hobart water supply that was for 45,000 ML in 2006 (Hydro Tasmania Consulting 2007). The upper Derwent catchment has few or no registered WIMS entitlements as this area is unpopulated and utilised either for electricity generation or contained within protected areas.

Not all dams are required to be registered under the current Tasmanian law. A permit is not required if the dam is not on a watercourse and holds less than 1 ML of water storage and is only used for stock and domestic purposes. It is also recognised that there are a number of illegal unlicensed dams up to 20 ML in size across the catchment (Hydro Tasmania Consulting 2007). The estimated total volume of unlicensed dams is 712.6 ML (Hydro Tasmania Consulting 2007).

An integrated series of projects is being developed by the Tasmanian Irrigation Development Board (TIDB) and Hydro Tasmania to address water management and supply issues with a focus on the Ouse, Shannon and Clyde sub-catchments. Together, these initiatives form the *Ouse, Shannon and Clyde Rivers Project*. While the components of this project are closely linked, the drivers underlying each are distinct. For example, there are two main components related to irrigation water supply. The TIDB's *Shannon Clyde Irrigation Scheme Project* addresses irrigation water supply and reliability issues in the Clyde district. Another part of the project, being managed by Hydro Tasmania, aims to cap currently undefined water entitlements in the Ouse Irrigation District (C. Cleary, 2009, TIDB, *pers. comm.*). Other aspects of the broader *Ouse, Shannon and Clyde Rivers Project* aim to address water management and environmental issues in the Ouse and Shannon districts, including:

- Unquantified and uncapped water entitlements in the Ouse Irrigation District.
- Reduced renewable energy generation due to water releases from Great Lake to meet water supply commitments to irrigators on the Shannon and Ouse Rivers.
- Poor river health and water quality for the Ouse River.
- Absence of an environmental flow for the Ouse River.
- Poor environmental conditions and water quality in Lagoon of Islands.
- Water management and availability issues in the Clyde Irrigation District.
- Reliability of town stock and domestic water supply in the Clyde region.

Once Hydro Tasmania has established an agreement with irrigators to resolve un-capped water rights in the Ouse Irrigation District, they propose to transfer water from the Cluny Lagoon on the River Derwent via pipeline to irrigators in the Ouse Irrigation District. They also aim to build a water regulation storage at Stone Hut Hill on the Ouse River between Liawenee Canal and Monpeelyata Canal to supply environmental flows to the Ouse River (C. Cleary, 2009, TIDB, *pers. comm.*).

The Clyde Irrigation District is currently serviced by the River Clyde Irrigation Scheme. However, reliability of the existing Scheme is highly variable. During the 2007-08 and 2008-09 irrigation season the Clyde catchment experienced significant water shortages resulting from a long period of sustained drought and below-average rainfall and increasing demand by irrigators for water. As a consequence of the prolonged drought combined with Commonwealth requirements, no irrigation water was released from Lakes Crescent and Sorrell during the last two seasons (2007-08 and 2008-09), impacting significantly on town stock and domestic water supplies and the income of agricultural businesses (C. Cleary, 2009, TIDB, *pers. comm.*).

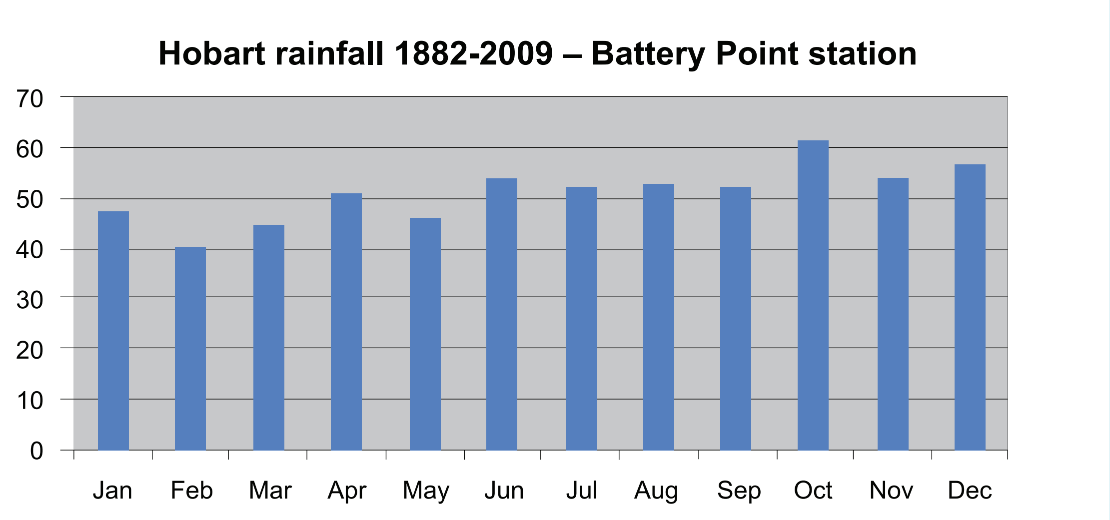
The TIDB is developing a pipeline to transfer water from the Shannon into the Clyde catchment. The proposed Shannon Clyde Irrigation Scheme will harvest available natural yields from the Shannon and Clyde River systems with supplementation of supply from Great Lake when required, delivering up to 8,700 ML at high reliability to the Clyde Valley. This includes 1,700 ML to be supplied by pipeline to non-riparian properties in the Hollow Tree region, between Bothwell and Hamilton (C. Cleary, 2009, TIDB, *pers. comm.*).

The TIDB are also investigating an option to supply irrigation water at the top end of the Jordan catchment via an extension of the Arthurs pipeline. Irrigation water to the lower end of the Jordan catchment is also being considered via pipeline from the River Derwent (S. Meyer, 2009, TIBD, *pers. comm.*).

3.5 Climate

The Derwent estuary region experiences a cool temperate climate, with a mean maximum temperature of 22°C in February and 12°C in July. In general, due to topographic influences and the north west/south east orientation of the River Derwent valley, katabatic (down-slope) winds prevail, blowing from the north west. However, during the summer months, southerly sea breezes tend to dominate in the afternoon.

Figure 3.4: Mean annual rainfall in the Hobart area



Source: Bureau of Meteorology; accessed July 2009; http://www.bom.gov.au

Precipitation is monitored by the Bureau of Meteorology at a number of sites in the vicinity of the Derwent estuary, including Blackmans Bay, Bellerive, Glenorchy, Hobart (Ellerslie Road and Botanical Gardens), Kingston, Lindisfarne, Rokeby and Taroona. The mean annual rainfall over the Derwent estuary is about 600 mm, with slightly higher rainfall on the western side of the estuary than on the eastern side. Rainfall is usually distributed relatively evenly throughout the year, with a mean minimum of 40 mm in February and a mean maximum of 63 mm in October (**Figure 3.4**).

Environmental conditions in the Derwent estuary in any given year are strongly affected by climate. Warm, dry years are often marked by poor estuarine mixing, resulting in low dissolved oxygen in the upper estuary, while wet weather brings high surface runoff containing litter, silt, faecal bacteria and other pollutants to the estuary.

4.0 POLLUTION SOURCES AND ESTIMATED LOADS

Contaminants enter the Derwent estuary from a variety of sources. Point sources include ten sewage treatment plants, or wastewater treatment plants (WWTPs), and two large industries (the Norske Skog paper mill and Nyrstar Hobart zinc smelter) as shown in **Figure 4.1.** Non-point or diffuse sources include urban runoff, tips and contaminated sites, catchment inputs carried by the Derwent and Jordan Rivers, aquaculture operations in the d'Entrecasteaux Channel, atmospheric contributions and wastes associated with shipping operations, port facilities and marinas. Some pollutants are also derived from contaminated sediments within the estuary itself. Contaminants associated with these various sources include pathogens, nutrients, organic matter, silt and gross solids, wood extractives such as resin acids, and a range of toxicants including heavy metals and hydrocarbons.

4.1 Wastewater treatment plant discharges

In many urban areas, sewage is a major source of nutrients to aquatic systems, and may also contribute pathogens (as indicated by faecal indicator bacteria) and toxicants. Nutrient enrichment may trigger algal blooms, seagrass die-off and other ecosystem changes, while pathogens represent a risk to human health. Toxicants in sewage are typically related to trade wastes and household chemical wastes. In Tasmania, WWTPs exceeding 100 kL/day design capacity are regulated by the Environment Protection Agency (EPA), under the provisions of the *Environmental Management and Pollution Control Act 1994*. The *State Policy on Water Quality Management 1997* also includes a number of relevant provisions, including the implementation of the waste hierarchy through avoidance of discharges and prioritization of effluent reuse wherever feasible; setting of discharge limits in line with published Emission Limit Guidelines for sewage treatment plants or based on site-specific considerations and the setting of mixing zones where required.

Prior to July 2009 in Tasmania, the provision of water and sewerage services was mainly the responsibility of individual local councils. Following the establishment of three regional water corporations under the *Water and Sewerage Corporation Act 2008* by the State Government, Southern Water became the water and wastewater service provider for southern Tasmania. Southern Water is owned by the southern Tasmanian local councils and began operations on 1st July, 2009.

There are currently ten WWTPs that discharge treated effluent directly to the Derwent estuary at the locations shown in **Figure 4.1**. Treated effluent from the two plants in Brighton has been reused (for irrigation) since 1999 and is no longer normally discharged to the estuary. In October 2006 the Rosny plant commenced effluent reuse as part of the Coal River Recycled Water Scheme and is largely used for irrigation.

There are two WWTPs with dedicated trade waste receival stations in the greater Hobart area, of which one (Prince of Wales Bay WWTP) receives the majority of tankered trade waste. The remaining plants receive a combination of domestic and commercial wastewater generated within their respective catchments. Regional areas generally receive a smaller proportion of commercial wastewater than urban areas.

Several small communities adjacent to the Derwent estuary are not served by sewers and rely on septic tank systems or alternative water treatment and disposal systems. These include areas around Tinderbox, South Arm, Granton and Boyer Road. Wastewater inputs to the estuary from these areas are difficult to quantify and are probably relatively small, but nonetheless may have local effects on water quality. Sewage and wastewater may also be discharged directly to the Derwent from recreational and small commercial vessels, many of which lack holding tanks.

Accidental spillage of raw sewage from WWTPs, pump stations and other infrastructure malfunctions occurs from time to time and is usually related to sewerage surcharge during wet weather or blockages due to tree-root intrusions during dry weather. Localised impacts from these sources can be significant; for more information, see **Section 4.4**. Other key issues include management of trade wastes, design and management of septic systems and greater consistency in monitoring.

4.1.1 Current WWTP effluent quantity and quality

The type and degree of wastewater treatment and thus effluent quality varies from plant to plant. Eight of the Derwent plants operate at secondary treatment level (removal of solids and organic matter) and two – Selfs Point and Rokeby – operate at tertiary level (removal of solids, organic matter and nutrients). All effluent is disinfected prior to discharge.

Effluent is monitored at all WWTPs on at least a monthly basis for total suspended solids (TSS), biochemical oxygen demand (BOD), faecal bacteria and volume. Most plants also monitor nutrients (dissolved and total phosphorus, ammonia, nitrate + nitrite, total nitrogen). This data gives an indication of typical effluent quality and is reported to the EPA as a regulatory requirement.

The combined total average daily flow from all WWTPs discharging to the Derwent in 2008, after reuse, was approximately 43,500 kL/day (**Table 4.1**). A summary of monitoring results from all Derwent estuary WWTPs in 2008 is also presented in **Table 4.1**, with relative contributions from each plant shown in **Figure 4.2**. The three largest WWTPs in terms of flows are at Macquarie Point, Selfs Point and Prince of Wales Bay – these contributed 67% of treated effluent to the estuary in 2008. Macquarie Point alone contributed nearly half the sewage-derived BOD and TSS loads to the estuary, and four plants contributed about 80% of sewage-derived nutrients (Macquarie Point, Prince of Wales Bay, Cameron Bay and Blackmans Bay). Due to difficulties in calculating mass emissions of thermotolerant coliforms, relative loads could not be calculated. Instead, the geomean values for each plant are provided.

4.1.2 Recent trends in WWTP effluent quality

Since 2003, there have been significant reductions in the cumulative loads of sewage-derived contaminants discharged to the Derwent estuary. Total suspended solids have fallen by 49%, total phosphorus by 34% and BOD by 27% (**Table 4.1; Figure 4.3**). During this same time period, cumulative flows decreased by 27%. Estimated thermotolerant coliform loads have varied considerably from year to year, and it is difficult to identify long-term trends. Inter-annual variability is caused by factors such as plant capacity and performance, rainfall conditions and infrastructure-related issues.

4.1.3 Recent management actions and new initiatives

Since 2003, a number of upgrades and new initiatives have been implemented by local councils, including the following:

Brighton

- Ten year sewage plan completed (2006);
- Improved sludge dewatering system installed at Green Point;
- Full effluent reuse achieved in 2006 and 2007;
- Reviewing feasibility and options to decommission Brighton lagoons and transfer/treat sewage at the Bridgewater plant.

Clarence

- Major works carried out in 2005 and 2006 to reduce saltwater influx to Rosny sewerage system, including repairs/replacement of mains under Lindisfarne Bay and along the shoreline;
- Rosny effluent reuse scheme commenced October 2006;
- Helminth filtration system commission to treat effluent from Rosny WWTP (2007);
- Lauderdale sewerage feasibility study completed and construction commenced.

Derwent Valley

- Management of Turiff Lodge WWTP was subcontracted to Hobart Water, now Southern Water since July 2005;
- Process audit carried out (2007).

Glenorchy

- Improvements of sludge treatment (step screens) at Cameron Bay and Prince of Wales Bay WWTPs;
- Collinsvale reuse scheme commenced in late 2006; sewage from approximately 50 homes near Sorell Creek (previously on septic systems) is now collected in a lagoon system and fully reused;
- Some effluent from Cameron Bay reused on nearby golf course starting mid 2005.

Hobart

- Three year project to improve management of trade wastes commenced in 2006; discharge limits set and compliance review of about 1000 premises undertaken;
- New project to reduce phosphorus levels at Selfs Point WWTP (2007);
- Continued reuse of some effluent from Selfs Point at Cornelian Bay sports ground, Regatta Grounds and New Town Bay wetlands;
- A biological and sediment monitoring report on the Macquarie Point WWTP outfall was completed (Meidecke 2006). This report concluded that 'the outfall is having no identifiable effect on the estuary environment in the vicinity of the outfall'.

Kingborough

- Ongoing improvements to digester operation and the installation of odour beds at Blackmans Bay WWTP have reduced odours;
- The replacement of the foreshore sewage outfall at Blackmans Bay will be completed during 2009;
- The design and approval process for the replacement of the foreshore sewage outfall at Taroona is proceeding.

Southern Water

- Investigation, planning and upgrade of the Salamanca sewerage system;
- Stage 1 works of the Lauderdale sewerage scheme;
- Completion of the Cambridge wastewater plant;
- Upgrade of Rokeby helminth filters, and;
- Replacement of the Blackmans Bay outfall.

Figure 4.1: Wastewater treatment plants and major industries

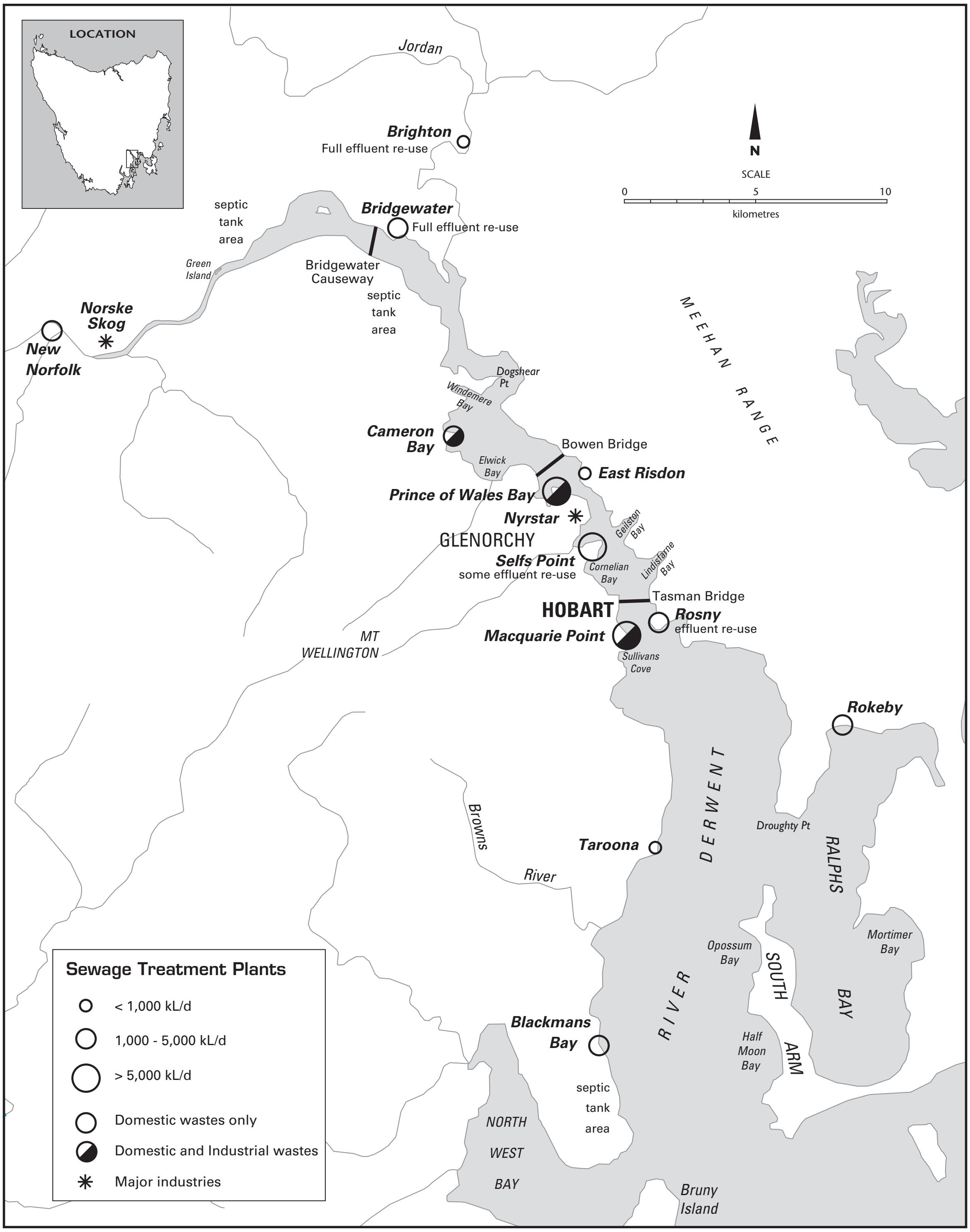


Figure 4.2: Derwent wastewater treatment plants – relative contributions of contaminants in 2008, after reuse

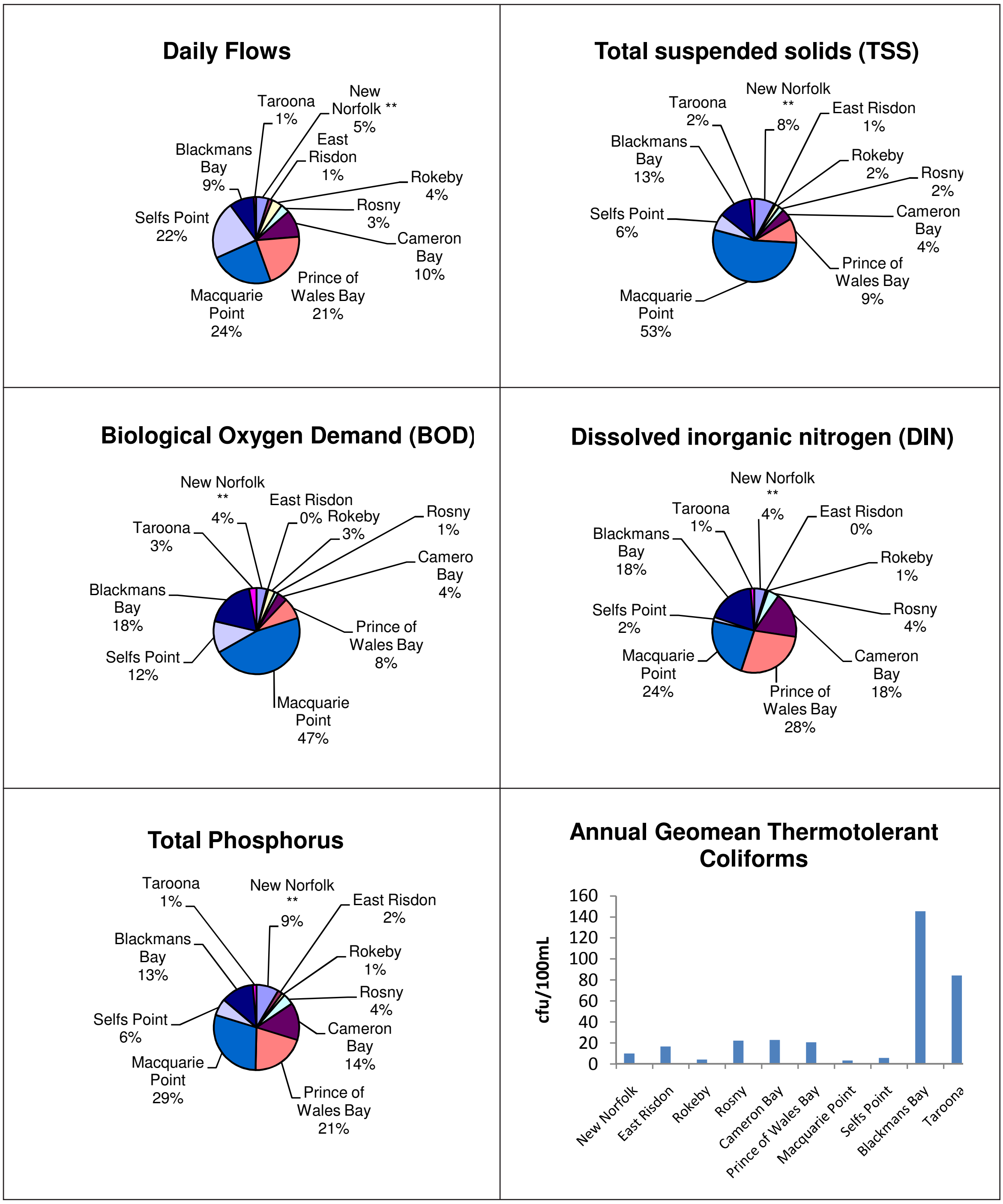


Table 4.1: Derwent wastewater treatment plants – average daily flows, mean concentrations and annual inputs, after reuse

Treatment plant	Discharge	TSS		BOD		Ammonia		NOx		DIN		Total Phosphorous		Total Nitrogen		Dissolved Reactive Phosphorus		Thermotolerant coliforms
	kL/day	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	mg/L	t/yr	cfu/100 mL
New Norfolk **	2033	24.2	18.0	11.9	8.8	16.8	12.5	3.4	2.5	20.2	15.0	11.0	8.2	-	-	-	-	10
East Risdon	663	5.5	1.3	5.0	1.2	0.5	0.1	1.9	0.5	2.4	0.6	6.9	1.7	4.5	1.1	5.4	1.3	16.7
Rokeby	1697	6.1	3.8	9.5	5.9	2.5	1.5	1.7	1.1	4.2	2.6	1.7	1.1	5.4	3.3	1.4	0.9	4.3
Rosny	1457	8.8	4.7	5.8	3.1	21.5	11.4	5.5	2.9	27.0	14.4	7.6	4.0	30.2	16.1	6.2	3.3	22.2
Cameron Bay	4433	6.2	10.0	5.2	8.4	31.1	50.3	5.6	9.1	36.7	59.4	8.4	13.6	39.0	63.1	-	-	22.9
Prince of Wales Bay	8984	6.6	21.6	5.6	18.4	25.6	83.9	2.7	8.9	28.3	92.8	6.0	19.7	30.7	100.7	-	-	20.7
Macquarie Point	10296	32.5	122.1	28.3	106.4	15.0	56.4	6.1	22.9	21.1	79.3	7.5	28.2	26.9	101.1	-	-	3.4
Selfs Point	9364	4.3	14.7	7.9	27.0	1.0	3.4	0.5	1.7	1.5	5.1	1.8	6.2	3.0	10.3	1.6	5.5	5.8
Blackmans Bay	3987	19.8	28.8	29.0	42.2	41.9	61.0	0.5	0.7	42.4	61.7	8.2	11.9	49.3	71.7	-	-	145.4
Taroona	381	31.1	4.3	45.8	6.4	31.2	4.3	2.6	0.4	33.8	4.7	9.6	1.3	39.3	5.5	-	-	84.4
Totals																		
2008	43295	229		228		285		51		336		96		373		X		3.87E+12
2007	48737	251		259		334		56		389		113		443		X		4.36E+13
2006	54625	294		290		373		68		441		140		388		X		3.01E+13
2005	57674	517		367		353		85		438		127		X		X		1.60E+13
2004	56066	416		296		393		90		483		139		X		X		1.26E+13
2003	58956	448		314		369		95		464		146		X		X		1.73E+13
% change 2007-2008	-11%	-9%		-12%		-15%		-9%		-14%		-15%		-16%		X		-91%
% change 2003-2008	-27%	-49%		-27%		-23%		-46%		-28%		-34%		X		X		-78%

1. Rokeby NOx is recorded as nitrate only

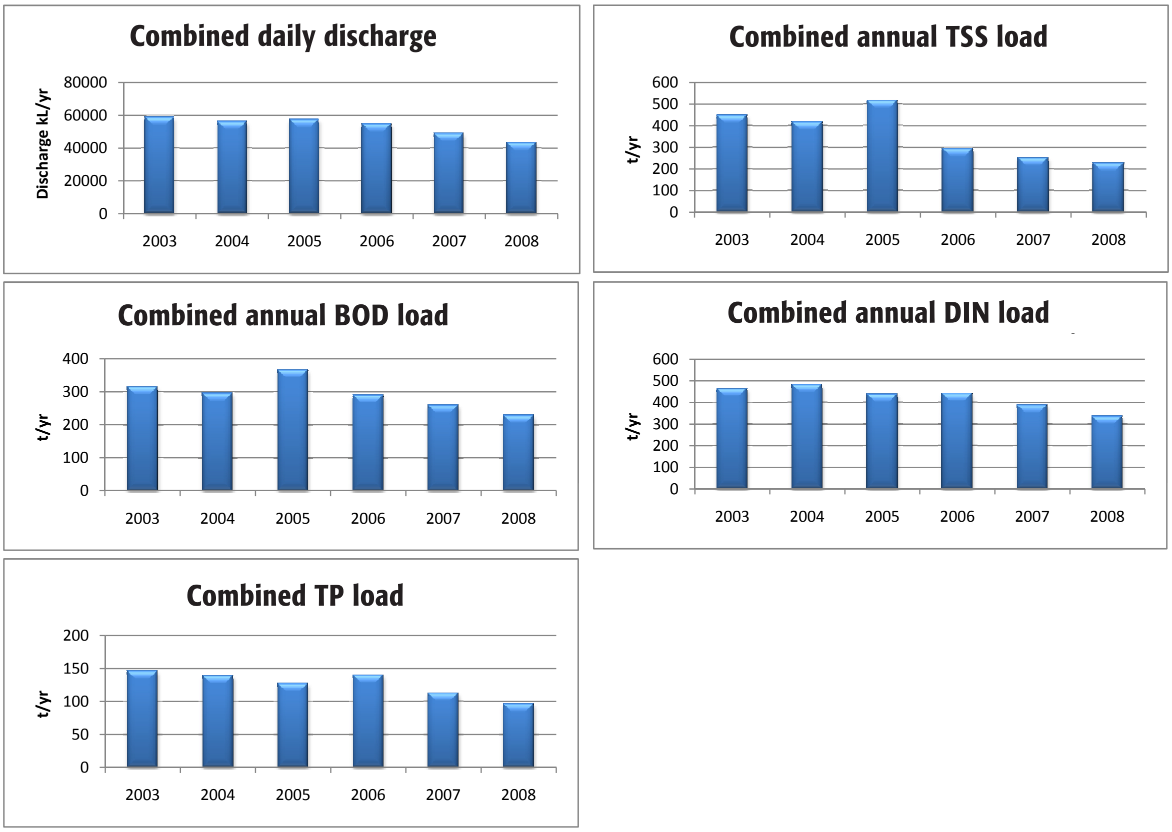
**Thermotolerant coliform concentrations for each WWTP are presented as a geometric mean of the 12 monthly samples*

***Nutrient data for New Norfolk WWTP is based on 2002 data*

Macquarie Point has recorded carbonaceous biochemical oxygen demand

NB: Data presented for most WWTPs is derived from one effluent sample per month, annual loadings should be viewed as "best estimate only".

Figure 4.3: Summary of combined annual loads from wastewater treatment plants 2003-2008



Extensions of the South East Tasmanian Recycled Water Scheme (supported by the Federal Government) are also continuing, as is a program to replace water and wastewater infrastructure across the region. Environmental assessments will also be carried out for discharges into the Derwent to assess future upgrade requirements.

4.1.4 WWTP effluent reuse

The volume of WWTP effluent reused in the Derwent region continues to increase, with two major schemes now completed and a range of smaller initiatives also operational as indicated in **Table 4.2**. The total amount of effluent reused in 2008 was close to 3000 megalitres (ML). This represents about 18% of the sewage generated in the Hobart metropolitan area.

The largest and most recent initiative reuses effluent from the Rosny WWTP for irrigation in the Coal River valley. The project is a joint $16 million initiative between the Commonwealth Government, Clarence City Council and landowners in the Coal River valley. Under the project 7 km of rising main, 4.6 km of delivery main and 22 km of reticulation mains have been constructed to deliver the treated effluent (up to 2,500 ML annually) directly to farm properties in the valley and golf courses at Seven Mile Beach. The scheme commenced in October 2006, and is now being expanded to include effluent from Cambridge and links to Seven Mile Beach, as well as the construction of a 1,000 ML storage dam.

4.2 Industrial discharges

Pollutants from industries may enter the Derwent via a number of pathways. These include air emissions, discharges of treated effluent, stormwater run-off, ground-water seepage and spills.

At present, there are approximately 30 State-regulated (Level 2) industrial premises and hundreds of local council-regulated (Level 1) premises situated within the estuary's immediate catchment (i.e. excluding the greater River Derwent above New Norfolk and Jordon River catchments beyond Brighton). The majority of these are connected to sewer, however, two major industries discharge treated wastewater directly to the estuary: the Nyrstar Hobart zinc smelter at Lutana, and the Norske Skog paper mill at Boyer (locations shown in **Figure 4.1**).

Table 4.2: Estimated volume of effluent reused from WWTPs in the Derwent estuary region

Reuse initiative	STP	Date commissioned	Reuse in 2004	Reuse in 2005	Reuse in 2006	Reuse in 2007	Reuse in 2008
Brighton Reuse Scheme	Brighton sewage lagoons Bridgewater STP	1996			154 ML 746 ML	100% 100%	165 ML 807 ML
Clarence Reuse Scheme	Rosny STP	2 October, 2006	–	–	210 ML	^813 ML	1717 ML
Cornelian Bay sports ground Regatta grounds	Selfs Point STP	February 2002 February 2004			9 ML*	^15 ML	85 ML
Collinsvale Reuse Scheme***	Collinsvale sewage lagoon	Late 2006	–	–		4.0 ML	4.0 ML
Claremont Golf Club	Cameron Bay STP	Mid 2005	–		**	85.3 ML	85.3 ML

* 2005/2006 data, HCC *pers. com.*
** Data provided by EPA
^ Estimated value
*** Southern Water, *pers. com.*

4.2.1 Nyrstar Hobart Smelter

The Nyrstar Hobart smelter is an electrolytic zinc smelter situated in the suburb of Lutana, in Hobart, on the western shore of the middle reaches of the Derwent estuary and is a Level 2 industrial premise, operating under an Environmental Protection Notice regulated by the EPA. The smelter was commissioned in 1917 and commercial production of zinc began at the smelter in 1921. The smelter has changed hands and names several times since then (over recent years the smelter operated as the Electrolytic Zinc [EZ] Company, the Pasminco Hobart Smelter, the Zinifex Hobart Smelter, and since 2007 as Nyrstar Hobart [NH]). NH produces in excess of 250,000 tonnes of zinc and zinc alloys per year. Other products produced at the site include sulphuric acid (400,000 tonnes/year), lead-silver product, cadmium metal, and copper sulphate. Much of the information in this section was derived from the most recent *Environmental Management Plan* for the site (Nyrstar Hobart 2009).

Contaminants associated with NH include heavy metals, arsenic, fluoride, particulates, sulphur oxides/sulphate and nutrients. These contaminants enter the Derwent via the foreshore outfall/diffuser, groundwater, some stormwater run-off and air/dust emissions. In recent years, as the smelter has made significant improvements to controlling and reducing point source emissions, and heavy metals entering the Derwent estuary from the site are now more associated with non-point rather than point sources. Therefore, annual loads are difficult to estimate with accuracy. At present, groundwater makes the largest contribution to the NH heavy metal load entering the Derwent, followed by air emissions, the effluent treatment plant and intermittent stormwater run-off. Emission sources from the Nyrstar site are monitored on a regular basis. In addition, ambient water quality monitoring is carried out in the Derwent estuary, as is water and sediment quality monitoring in New Town Bay. A long-term fish and shellfish monitoring program is also conducted throughout the estuary (see **Section 8.0** for details).

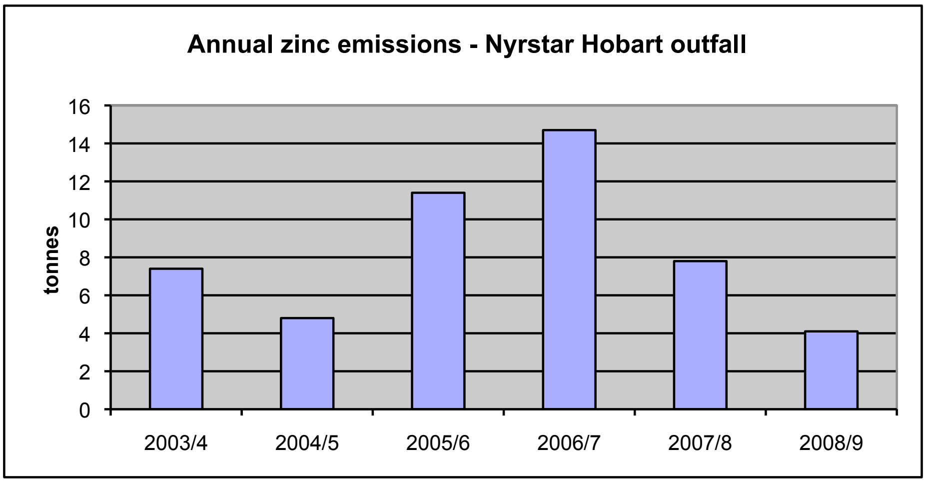
Liquid processing wastes

Nyrstar discharges aqueous effluent at a monitored outfall point. This consists predominantly of around 80,000 to 100,000kL/day of salt water which is pumped from the Derwent and passed through the scrubber system to remove trace sulphur dioxide from tail gas exiting the acid plants. Treated wastewater from the Effluent Treatment Plant (ETP – 3.3 kL/day) is added to the tail gas scrubbing system and forms part of the effluent stream.

The combined effluent streams are monitored at the foreshore outfall on a daily basis for pH, iron, sulphate, copper, cadmium, mercury, lead and zinc. Each year a minimum of two of the 24-hour composite samples are analysed to provide an extended suite of analytes, including arsenic, fluoride, iron and manganese, TSS, ammonia, oil and grease. The analyte suite is further extended to include beryllium, cobalt and nickel for annual *National Pollutant Inventory* reporting.

It is difficult to calculate accurate heavy metal loads associated with the foreshore outfall, as – with the exception of zinc and mercury – most of the heavy metals are usually below detection limits. Due to the large volumes of water discharged, load calculations based on detection limits are likely to be greatly exaggerated. Furthermore, analyses of mercury prior to 2008 were overestimated, due to analytical methods that have since been updated. **Figure 4.4** presents estimated annual mass emissions of zinc, which have ranged from 4 to 14.7 tonnes/year. Estimated mass emissions of mercury in 2008-09 were 31 kg.

Figure 4.4: Annual estimated zinc emissions from Nyrstar outfall (2003-04 – 2008-09)



Stormwater

The *Nyrstar Stormwater Management Strategy* aims to capture and treat all stormwater generated on site, and this is a requirement of their permit for all storms up to the magnitude that would occur at a five year average recurrence interval. The strategy divides the site into catchments with stormwater to be captured in a series of detention basins with a total capacity of >45,000 m^3. Other initiatives/opportunities include segregation of flows, modification of catchment characteristics and improvements in water conservation and reuse.

All of the site's stormwater above the wharf is diverted to the contaminated water ponds and Loogana ponds and treated at the effluent treatment plant prior to discharge via the diffuser. The contaminated water pond has the capacity to store about 6,000 m^3 of stormwater, the Loogana ponds can store about 3,000 m^3, and a holding pond has also been constructed at the southern wharf (590 m^3). During 2007, a large stormwater detention pond was constructed in the Western Hills area (adjacent to the golf course) with the capacity to store 15,000 m^3. The water is passively treated via a series of bio-filters followed by polishing in the Loogana wetland. Some treated water is returned to tanks installed to hold the treated stormwater and from which water may be extracted for dust suppression, cleaning etc.

For larger stormwater events, Nyrstar seeks to minimise discharges and to divert and treat the most highly contaminated flows. At present, there are six emergency overflow points to the Derwent. Any stormwater flows discharged via these points are monitored and reported to the EPA. Between 2003 and 2008, there have been zero to three recorded overflow events/year. Annual zinc loads associated with stormwater are typically below one tonne.

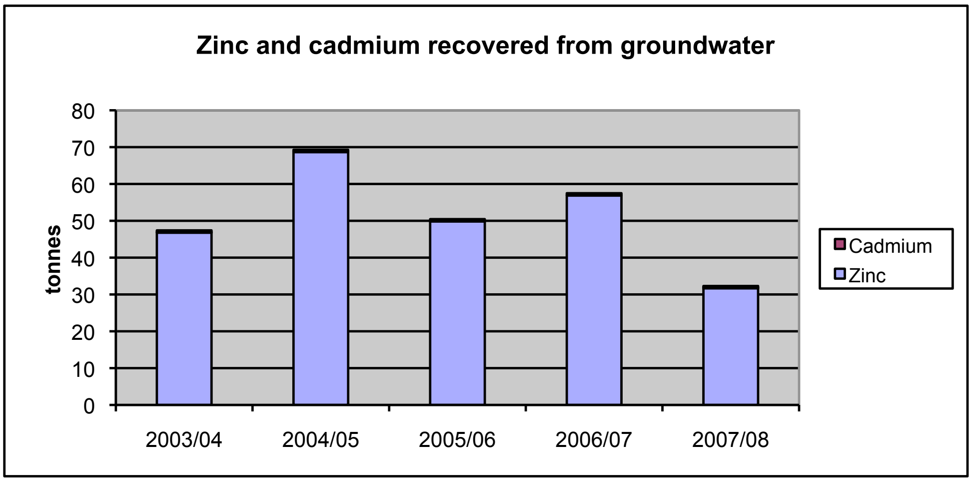
Groundwater

Groundwater beneath the Nyrstar site is severely contaminated with heavy metals, particularly zinc, cadmium and copper. In general, the aquifer is thought to be relatively shallow, with a steep hydraulic gradient (i.e. groundwater travel times appear to be relatively rapid, with box modeling in one area showing a transport rate in the order of 30 to 150 m/year). A major geological contact/fault zone passes through the site and may be a zone of preferential groundwater transport (GHD 2006).

Recent investigations have identified a number of contamination hotspots associated with existing and former production areas and stockpiles. Starting in 1998, a variety of groundwater recovery and treatment operations have been installed at key locations around the site, specifically, a 80 m foreshore interception trench, a vertical extraction well, a sump at Risdon Road, a 140 m horizontal extraction well beneath the leach plant, an interception system at Loogana/Inshallah, and a series of 13 horizontal 'finger' bores recovering groundwater from approximately 4 ha of the primary process area.

It is difficult to quantify the proportion of contaminated groundwater being intercepted by these sites, as the bedrock is fractured, and groundwater movement is difficult to model. The interception sites target the worst known zinc sources, and it is estimated that in the order of 50 to 75% of the groundwater zinc may be captured by these sites. It is also unknown how much zinc is transported to the Derwent by tidal flushing, as all of these interception bores are above the salt water intrusion area.

Figure 4.5: Zinc and cadmium recovered from groundwater at Nyrstar



Note: does not include groundwater extracted/treated from the Loogana/Inshallah secure landfill

Since 2003, over 250 tonnes of zinc and two tonnes of cadmium have been recovered from the groundwater captured through various extraction systems, as illustrated in **Figure 4.5**. Over 80% of these metals have been recovered from the horizontal well. Lead, copper and mercury capture have not been routinely monitored.

In 2006, Nyrstar commissioned a review and further development of the site *Groundwater Management Plan* (GHD 2006), resulting in the following key findings and recommendations:

- The key objective of the strategy is to extend the current recovery program to all known contamination hot-spots;
- The primary remaining source of heavy metal contamination in groundwater is the Electrolysis Department area, followed by the former manganese stockpile and Nyrstar quarry. Remedial actions will therefore be targeted at these areas and prioritised accordingly;
- Interception technology is specific to very localised hydrogeological conditions associated with the contaminant plume. Prior to the design of future recovery points, further information is required about the specific geology and fracture patterns, vertical extent of the aquifer, permeability and contamination, and the physico-chemical behavior of contaminants.

Nyrstar has secured capital allocations to further implement the *Groundwater Management Plan*, namely:

- Installation of horizontal groundwater interception bores at the Electrolysis Department, which was completed in 2009. This system consists of a network of near-horizontal directionally-drilled bores located underneath and down-gradient of the facility. The horizontal bores constitute a large zone of influence and cross the geological fault line in three areas.
- A project to address on-going groundwater contamination associated with the unsealed Electrolysis Department basement
- Investigations as required to design and implement additional groundwater recovery systems;
- On-going monitoring of groundwater quality and recovery infrastructure.

Atmospheric emission, including dust

Airborne materials and gasses arising from materials storage, handling and processing activities involved in the zinc production activities are contained and captured with various gas-cleaning technologies to ensure the health of employees, and to minimise adverse environmental impacts. The clean gas technologies used at NH include wet scrubbing operations, dry filtration operations, chemical conversion and absorption operations and electrostatic collection operations. These operations capture both gaseous and particulate airborne contaminants from process and hygiene ventilation systems prior to the release of carrier gasses to the environment from over 15 stacks. Some stacks are monitored continuously by online monitoring equipment, while others are sampled and analysed at prescribed intervals by professional testers to meet operating permit conditions, *National Pollutant Inventory* and *Greenhouse Challenge Plus Program* reporting requirements. Monitored parameters include gaseous SO_2, SO_3, NOx, and airborne particulates, heavy metals and other contaminants.

Nyrstar stack emissions account for a relatively small proportion of heavy metal loads from the site, but contribute significant amounts of SO_2 (190 tonnes/year), NOx (140 tonnes/year) and particulate matter (49 tonnes/year PM10) to the local airshed. The proportion of fall-out from stack emissions that ultimately enters the estuary is unknown.

An issue of particular concern has been the presence of a highly visible emission from the foreshore stack. This opaque and persistent plume became noticeable in 2006, when the refinery started using significant quantities of zinc concentrate from the Century Mine (QLD), resulting in higher sulphate particulate emissions. A $12 million project to install an electrostatic precipitator to remove the contaminant has recently been completed and successfully remedied this issue.

Dust management remains an important issue for the site. Dust emissions are of concern, particularly during the loading and unloading ships with bulk concentrates and residues, from open areas during high winds, and from vehicle movements on roadways. Estimation of loads falling into the Derwent estuary are not known. Nyrstar has developed a comprehensive *Dust Management Plan* for the site to address material spillage and fugitive dust sources. Key elements include the shed sealing, roadway dust management (road sweeper, water cart, wheel washes, improved road sprays and run off control), covering/management of stockpiles and removal of accumulated dust sources by 'top down' cleans. Dust emissions during out-loading of superphosphate have been particularly difficult to manage. In 2008, NH and neighboring Impact Fertilisers cooperated to successfully commission an innovative ship loading chute system that has sharply reduced dust emissions during loading.

Land and buffer zone management

A number of activities fall under this heading, including management and removal of legacy stockpiles, rehabilitation and revegetation of land (including contaminated areas) and assessment of off-site soil contamination.

There are a number of historic residue stockpiles on the site, including Hobart Leach Product 1 (HLP1), jarosite, manganese oxide and mercury filter cake. These stockpiles have been covered and stabilised and good progress has been made on their removal. In particular, over 90% of the HLP1 stockpile and all of the manganese oxide stockpiles have been removed or reprocessed, and a successful treatment method for the mercury filter cake has been developed, allowing for offsite disposal (secure landfill in Queensland). Removal of the former HLP1 stockpile is nearing completion and the area will be rehabilitated in future years.

Significant progress has also been made on the revegetation of degraded land areas, particularly along the foreshore and main car park area, involving the establishment of 32,000 native plants over a 24,000 m^2 area.

A major soil contamination study has also been recently completed focussing on communities in the vicinity of the smelter site. These areas were historically affected by wind-blown dust associated with past activities at the smelter site. This study analysed heavy metal levels in soils collected at approximately 400 locations and was designed as a follow-up to a previous study carried out in the 1990s. The study confirmed that elevated levels of zinc, lead and cadmium are present in surface soils in parts of Lutana, Geilston Bay and Lindisfarne as shown in **Figure 4.6**, and provided a more precise boundary of the affected area, as compared to the earlier study. Independent health investigations in 1991 and 1997 showed that residents in these affected areas have not taken these contaminants into their bodies (Meidecke *et al* 1992, Menzies Centre 1997), and risks of health effects from existing contamination are considered to be low. Nonetheless, the Director of Public Health continues to recommend precautionary measures to further reduce potential risks from the metals, as outlined in a recent brochure published by the EPA (EPA 2009). Further information is available on the Environment Division website at www.environment.tas.gov.au.

Summary of management actions: 2003 to 2009

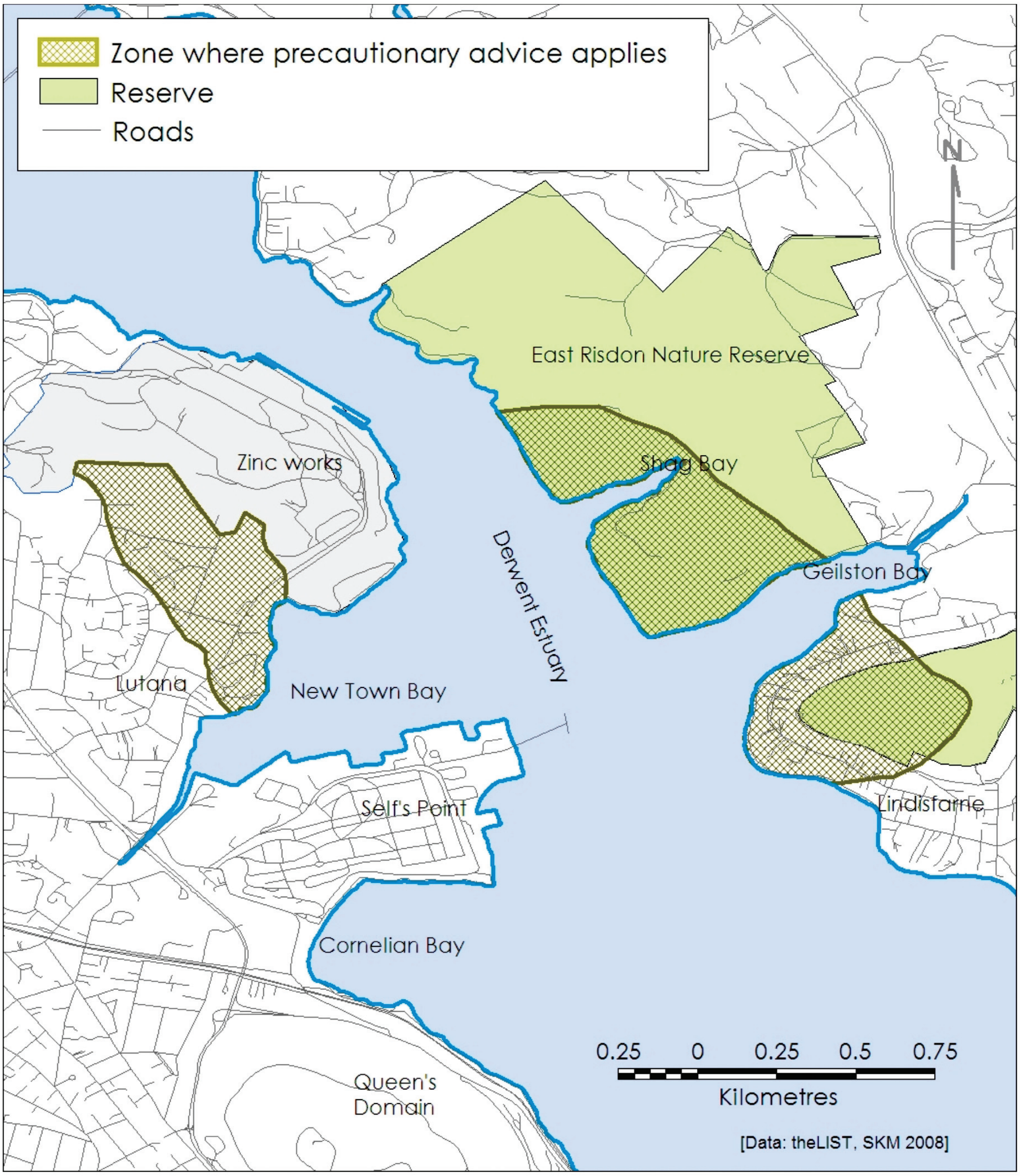
Since publication of the *2003 State of the Derwent Estuary Report*, the following key actions have been taken to further improve site practices and reduce pollution loads:

- Investigations and reports on site contamination, dust management, stormwater management and groundwater management;
- Continuing management and reduction of historic residue stockpiles;
- Rehabilitation of 24,000 m^2 of foreshore land, including revegetation with 32,000 plants;
- Construction of a 15,000 m^3 stormwater detention pond and associated biofiltration system;
- Installation of a groundwater extraction system (horizontal bores) beneath and down-gradient of the Electrolysis Department;
- Community soil contamination study;
- Mitigation of foreshore stack emission.

Focus areas for further improvements over the next few years include:

- Elimination of stockpiles of process and non-process wastes and rehabilitation of cleared land;

Figure 4.6: Soil contamination in Lutana, East Risdon and Lindisfarne



Source: EPA 2009.

- Extension of groundwater recovery systems and mitigation of the unsealed Electrolysis basement;
- Extension of the stormwater containment and treatment infrastructure, with a particular focus on water reuse opportunities;
- Closure and rehabilitation of the former quarry;
- Further reduction of fugitive dust emissions.

4.2.2 Norske Skog Paper

The Norske Skog paper mill is located at Boyer on the northern bank of the upper Derwent estuary, approximately 4 km downstream from New Norfolk. The mill has been operating since 1941 and is Australia's largest manufacturer of newsprint and specialty newsprint papers, producing about 290,000 air-dried tonnes per year. In 2008, Norske Skog Boyer manufactured paper using thermo-mechanical pulp (55%) from plantation pine, cold caustic soda pulp (25%) from eucalypt regrowth, recycled fibre (15%) and kraft pulp and fillers (5%). The main brightening agents used are hydrogen peroxide and sodium hydrosulfite. The mill also operates an on-site water treatment plant that processed approximately 11,700 ML of River Derwent water in 2008 (17,000 ML/yr in previous years) via a water intake at Lawitta. Solid wastes consist primarily of wood wastes, water and wastewater treatment plant sludge and ash from the coal-fired boiler. The majority of solid waste is disposed of to an onsite landfill, although pilot trials of agricultural land-spreading of wastewater treatment plant sludge are underway. Much of the information in this section was derived from the most recent *Environmental Management Plan* for the site (Norske Skog 2009). Contaminants associated with the paper mill include organic matter, suspended solids, wood extractives (such as resin acids), hydrocarbons, nutrients, aluminium, sulphur, faecal bacteria, and air emissions associated with the coal-fired boilers. The majority of these contaminants enter the Derwent estuary via a combined effluent stream (CES), but other sources include the water treatment plant settling ponds, sewage treatment plant effluent, stormwater runoff, groundwater and air/dust emissions.

Emission sources from the site are monitored on a regular basis. In addition, ambient water quality monitoring in the estuary is carried out at monthly intervals for in-situ physical parameters, TSS, colour, total organic carbon (TOC), nutrients, chlorophyll *a* and zinc (see **Section 6.0**). Extensive surveys, investigations and modeling were carried out as part of an Ecological Risk Assessment (ERA) (Boyer Mill ERA 2001) and a follow-up macroinvertebrate survey was carried out in 2003 (Aquenal 2003). Starting in 2007, a project has been underway to examine the source and fate of carbon in the Derwent estuary, supported by the Australian Research Council (ARC) Linkage funding scheme, Norske Skog and the Derwent Estuary Program (DEP). One task in this project has been to investigate estuarine responses associated with the introduction of secondary treatment at the Norske Skog mill (**see Section 5.5** for details).

Liquid emissions – Combined Effluent Stream

Liquid emissions from the site consist predominantly of pulp and paper processing effluent (average of 25 ML/day in 2008) together with cooling water used in the process (average of 33 ML/day), discharged via the CES. During the period 1989 to 2007, this effluent was treated to primary level (i.e. removal of solids and resin acids) at the mill's effluent treatment plant. Starting in October 2007, this treatment plant was upgraded to provide secondary treatment (i.e. removal of dissolved organic matter). The new treatment system now consists of a primary clarifier, an integrated biofilm activated sludge plant and a secondary clarifier.

The CES contributes the majority of pollutant loads to the Derwent from the site. This treated process effluent is warm (average 31°C) and highly coloured due to eucalypt wood extractives. The effluent contains organic matter (measured as BOD), TSS and resin acids (toxic to fish at elevated concentrations). Nutrient concentrations are generally moderate. The CES is currently monitored on a daily to weekly basis for pH, temperature, TSS, BOD, TOC, resin acids, nutrients (TN, TP, NOx, NH_4 and FRP [defined in **Section 6.0**]) and oil and grease. Estimated loads from the CES for 2003-2008 are provided in **Figure 4.7**.

The new secondary effluent treatment plant (SETP) has been very successful in reducing BOD loads (>80% reduction) and has also reduced resin acids by nearly 50%. The secondary-treated effluent also has lower temperatures and more stable pH. There has been a moderate increase in nutrient levels as the secondary treatment process requires addition of some nutrients in order to sustain the biological secondary treatment process. Since secondary effluent treatment commenced the resulting effluent has been tested quarterly for whole effluent toxicity (Microtox), and no significant toxicity has been recorded. Starting in November 2009, the Boyer paper mill implemented another major change in pulp processing, whereby only pine is pulped via thermo-mechanical processing. This will result in further changes to effluent quality, in particular a reduction in colour and a further reduction in BOD.

Liquid emissions – water treatment plant and sewage treatment plant

Liquid emissions from the water treatment plant (for process water) include TSS, aluminium and sulphur (as sulphate), associated with the use of aluminium sulphate as a coagulant in the water treatment process. In the past, this alum sludge was partially treated using a system of alternate settling ponds, situated in a low-lying area to the west of the plant (Western Wetlands). During heavy rainfall, however, these occasionally overflowed to the Derwent. In 2008 several Geobags (geotextile filtration systems) were installed to capture the alum sludge before it discharged into the settling ponds. These have significantly enhanced sludge retention and dewatering. Quarterly monitoring is carried out for TSS, aluminium, sulphur and a range of other parameters. Water quality discharged from this area has improved, but still exhibits elevated levels of aluminium and suphur, and occasionally elevated TSS.

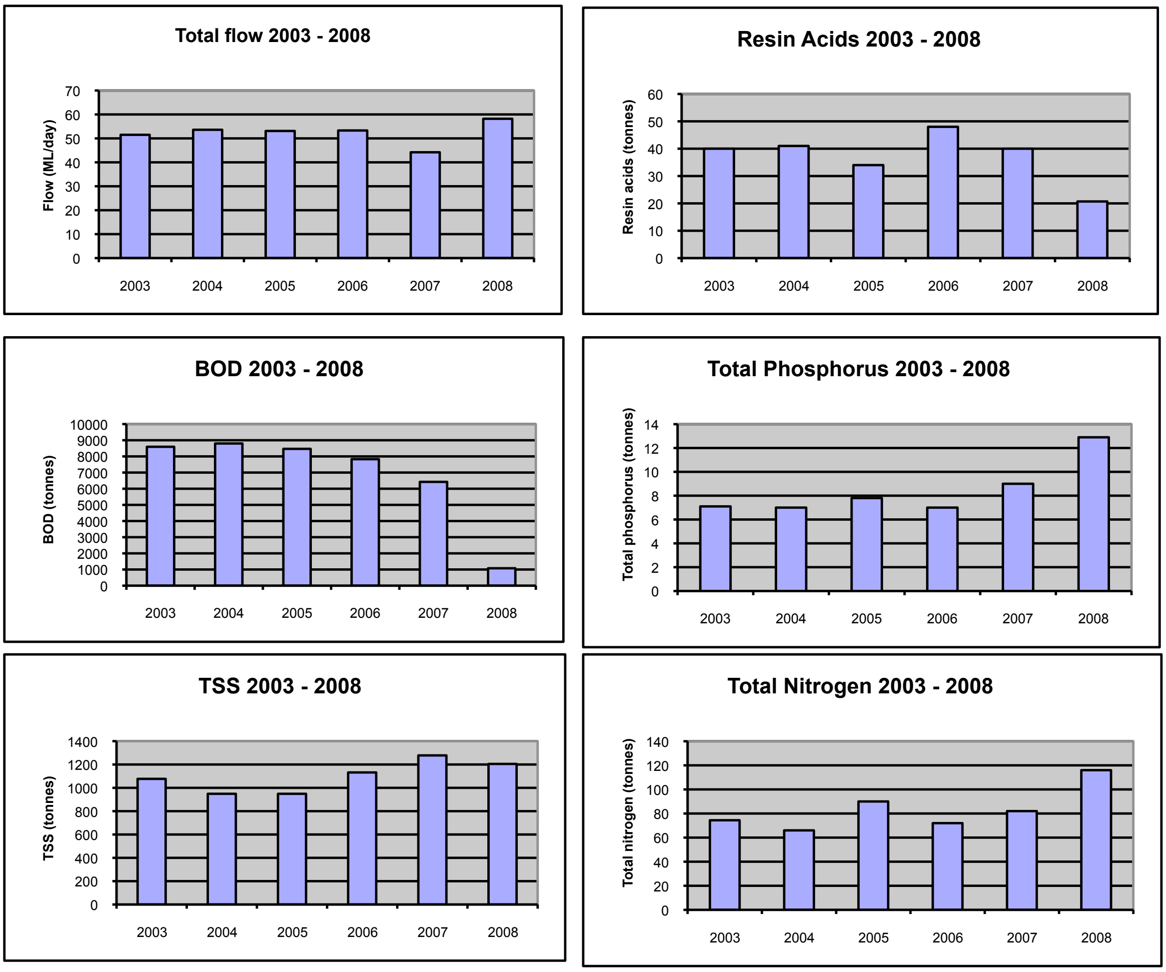
The on-site sewage treatment plant has an estimated flow of 80 kL/day and is monitored monthly for faecal coliforms. All samples have been below 100 colony forming units (cfu)/100 ml during the past four years.

Liquid emissions – stormwater, groundwater and tip leachate

Other diffuse emissions from the mill site include stormwater runoff, groundwater discharges and leachate from the landfill and ash dump:

- Stormwater is monitored twice yearly at nine sites for a wide range of parameters, following a storm event that causes watercourses to flow. Stormwater quality is variable, with occasionally elevated levels of TSS, total petroleum hydrocarbons, copper, zinc and aluminium at some sites.
- Groundwater investigations carried out in the 1990s identified some localised areas of contamination (e.g. barium, copper, mercury, zinc and sulfide), but

Figure 4.7: Norske Skog Boyer Combined Effluent Stream – annual discharges to the Derwent 2003-2008



*Sources: Combined Effluent Stream (CES) monitoring reports (EPA) & *National Pollutant Inventory (nutrients prior to 2008). Note: starting in 2007, when the SETP was commissioned daily flows have included both treated effluent as well as cooling water.*

suggested that there was little off-site migration to the estuary. Thirteen bores are currently monitored six-monthly for a wide range of parameters. The groundwater monitoring program has recently been reviewed and modifications are proposed;
- Leachate from the landfill and ash dump is also monitored twice yearly. Analyses indicate elevated levels of barium, adsorbable organically bound halogens (AOX) and sulphur. Since 2001, leachate from the landfill has been collected and treated at the effluent treatment plant.

Air emissions

Air emissions are predominantly associated with the main coal-fired boiler (No. 5), which is the largest in southern Tasmania, burning over 100,000 tonnes of coal/year. This boiler is fitted with an electrostatic precipitator to control particulate emissions and is monitored twice yearly for a range of parameters, including particulates, sulphur dioxide (SO_2), nitrate + nitrite (NOx), heavy metals and fluoride. Mass emissions are reported as part of the *National Pollution Inventory*. Until 2006 the mill occasionally operated two standby boilers (No.'s 3 and 4) if the No. 5 boiler shut for maintenance or in emergency situations. However, the standby boilers had very high particulate emissions and their use has now been discontinued. Instead the mill is now shut down during maintenance operations or emergencies.

Summary of management actions: 2003 to 2008

Since publication of the 2003 State of the *Derwent Estuary Report*, the following key actions have been taken to further improve site practices and reduce pollution loads:
- 2003: CES relocated through a lined channel to reduce odours;
- 2006: Stand-by boilers no longer used;
- 2007: Upgrade of the bleach plant resulting in lower flows and reduction in chemical use;
- 2007: Secondary treatment plant commissioned;
- 2008: Geobags installed in Western Wetlands to capture alum sludge from the water treatment plant.

Focus areas for further improvements during the period 2009 through 2012 include:
- Late 2009, softwood conversion (elimination of eucalypt pulp stream) – expected to further reduce effluent organic load and chemical usage;
- Achievement of European Commission Best Available Technologies emission targets.

4.2.3 Impact Fertilisers

Impact Fertilisers is situated immediately to the north west of the Nyrstar Hobart smelter at Lutana, and is operated as a Level 2 industrial premise regulated by the EPA. The plant has been operating since 1924 and currently produces between 150,000 and 210,000 tonnes/year of superphosphate fertilisers through a process that combines phosphate rock with sulphuric acid (produced by Nyrstar). Contaminants associated with the fertiliser plant include nutrients (particularly phosphorus), particulates, fluoride and heavy metals. These contaminants enter the Derwent via airborne dust emissions, stormwater run-off, and groundwater. Much of the information in this section was derived from the most recent *Environmental Management Plan* and *Annual Report* for the site (Impact Fertilisers 2004, Impact Fertilisers 2008).

Liquid processing wastes generated at the plant are re-used within the production process. A stormwater retention pond, with 1.7 ML capacity, was constructed on the site in 2004 to capture run-off from the majority of the site. Water from this pond is reused as part of the production process during normal operating conditions; however, during heavy rainfall events and/or during plant closures this pond overflows to the Derwent estuary, resulting in occasional emissions of phosphorus. Volumes and concentrations discharged are monitored and reported to the EPA, and estimated annual stormwater loads are provided in **Table 4.3**.

Groundwater contamination may be associated with historical or current stockpiles and storage dams. However, there is limited information on groundwater quality or mass emissions associated with groundwater flows. A series of groundwater monitoring bores have recently been installed to further evaluate this situation.

Table 4.3: Stormwater pond discharges and loads at Impact Fertilisers

Year	Number of overflow events	Total volume of stormwater	Phosphorus (kg)	Zinc (kg)	Cadmium (kg)
2004	1	309	192	4	0.04
2005	7	2354	1435	26	0.3
2006	0	0	0	0	0
2007	4	5144	3395	111	0.8
2008	1	972	642	21	0.1

Atmospheric emissions (largely hydrogen fluoride) include particulates and fluoride associated with the manufacturing process. A four-stage scrubbing plant and dust collection baghouse minimise these emissions and are regularly monitored. Dust management and spillage have been important issues for the site, and major improvements have recently been achieved in loading and unloading operations at the Risdon wharf of single super phosphate (SSP) and phosphate rock. Further efforts are being directed at reducing windblown losses from the phosphate rock storage area and spillage during transport, through implementation of a dust management plan, developed in 2006.

Recent management actions to improve environmental performance at the site have included the following:

- Removal/reprocessing of the scrubber liquor evaporation pond (2008);
- Installation of a dust suppression hopper at the Risdon wharf resulting in a major reduction of dust emissions during SSP out-loading (2008);
- Improved dust management of the phosphate rock stockpile, including use of bitumen, dust-binding agents and water sprays (2008);
- Infrastructure improvements to support improved stormwater management including concreting of roads and drains and installation of sediment traps (2008).

Key areas for further work include:

- Further improvements to management of the phosphate rock stockpile;
- Improvements to unloading operations at Risdon wharf (phosphate rock);
- Minimising phosphorous discharges from the stormwater pond.

4.2.4 Selfs Point

The Selfs Point fuel storage area was established in 1951 under the *Self Point Land Act 1951*, which allowed for the reclamation of land in this area to support specific uses. The area was largely constructed on reclaimed land and supports a variety of land uses associated with storage, transfer and/or processing of petroleum products. Most of this development took place in the 1960s and 70s. The following information has been obtained from the *Selfs Point Review of Zoning* (Hobart City Council 2005).

Current uses include:

- Five sites used for oil and gas storage (Shell, Mobil, BP, Caltex, Origin Gas);
- Bitumen plant (BP);
- Waste oil recycling;
- Tanker berth and refuelling wharf (owned and operated by TasPorts).

The majority of this area is owned by Crown Lands and leased out to various operators under 21 or 50 year leases. One site (Australian Petroleum) was sold to that company in 1996. Other nearby land uses includes the Selfs Point WWTP, Cornelian Bay Cemetery, playing fields (Rugby Park), and public housing at Stainforth Court. Although the area is largely owned by Crown Lands, environmental management of the individual premises in this area is largely the responsibility of Hobart City Council (with the exception of BP Bitumen, which is regulated as a level 2 premise by the EPA).

A risk assessment and safety audit of the area was carried out in 1992 on behalf of the Department of Environment and Planning (ICI Australia Engineering 1992) and concluded that the Selfs Point facilities were appropriately located, designed and managed to minimise the potential for adverse effects on the community, and that residential areas were sufficiently distant such that the risk of fatality in the event of an accident was extremely remote. The report also found that the risk of oil pollution from the facilities was low, with the exception of the wharf, where there was the potential for pollution from the transfer pipelines. A number of recommendations were made to reduce this risk. In 2001, the Hobart Ports Corporation (now TasPorts) completed a hazardous operations audit at the Selfs Point tanker berth facility and an action plan was developed to address identified issues (Hobart City Council 2005).

No integrated environmental assessment has been carried out at Selfs Point. However, a brief environmental assessment carried out by Hobart City Council as part of the *Cornelian Bay Planning Study* (Hobart City Council 1998) identified several issues of environmental concern related to use of the area for oil and gas storage, specifically:

- Potential soil and groundwater contamination;
- Stormwater management;
- Odour and noise pollution.

The Hobart City Council *Selfs Point Zoning Review* (Hobart City Council 2005) noted that soils and groundwater in the vicinity of the oil depots may be contaminated with heavy hydrocarbons and lead, and that stormwater interceptors may require repositioning and/or better maintenance to capture hydrocarbons from surface run-off. Investigations in 1998, by the Department of Primary Industries and Water, found substantial levels of contamination at the former Ampol site at Selfs Point. Hydrocarbons were leaching directly into the Derwent and decontamination works were subsequently commissioned.

Table 4.4: Other large industrial and commercial premises in the DEP program area

Name	Level	EMP/EPN	Location	Major Products	Effluent to	Site run-off to
Gunns Veneers	2		New Norfolk	Veneers	Norske Skog CES	Derwent
Gunns Ltd	2		Austins Ferry, Glenorchy	Timber products	Absorption trenches and sewer	Derwent
Cadbury Schweppes	2		Claremont, Glenorchy	Chocolates, confectionary	Cameron Bay WWTP	Derwent
Incat	1	na	Glenorchy	Catamarans	Prince of Wales Bay WWTP	Derwent
National Foods	2	EMP: 2003 EPN: 2004	Lenah Valley, Glenorchy	Dairy products	Selfs Point WWTP	New Town Rivulet
Cuthbertsons Tannery	2		South Hobart, Hobart	Leathergoods	Macquarie Point WWTP	Hobart Rivulet
Cascade Brewery	2	2003	South Hobart, Hobart	Beer, beverages	Macquarie Point WWTP	Hobart Rivulet
Boxall Marine Products	2		Glenorchy	Fish products		
Hobart Fish Port	2		Hobart	Fish products		
Cates Abattoir	2		Glenorchy	Meat	Ponds on site	
BOC Gases	2		Selfs Point, Hobart			Derwent
BP Bitumen	2		Selfs Point, Hobart			Derwent
Byrn Estyn water treatment plant				Water purification		Derwent
Hobart Ports, including Domain Slipway				Marine and port operations		Derwent

4.2.5 Other industries

A number of other industries are located immediately adjacent to the Derwent or near rivulets that discharge into the estuary, as summarised in **Table 4.4**. The majority of these direct their processing wastes to sewer, however, stormwater runoff and spills from many of these sites could potentially enter the estuary. In most cases, stormwater inputs are not monitored and cannot be readily quantified.

Other smaller-scale sites not specifically listed in **Table 4.4** include: quarries, concrete batching plants, brick and paver manufacturers, truck and railway depots, small metal foundries, electro-platers and galvanisers, hospitals, vineyards, nurseries, automotive repair facilities, petrol stations and car washes, boat-yards and marinas. Local councils are responsible for regulating most of these premises (primarily via trade waste agreements), however, no full regional inventory or assessment has been carried out.

4.3 Stormwater

Stormwater runoff is the water from rain that flows across the land, carrying with it litter, vegetative debris, loose soil and a range of pollutants that have been deposited on the land surface, including pathogens, nutrients, hydrocarbons, heavy metals and pesticides. This water eventually enters the Derwent estuary untreated, flowing through a system of kerbs, gutters and pipes. Where stormwater is discharged into urban streams this may also result in downstream flooding and erosion. Stormwater pollutants can significantly degrade water quality and aquatic habitats in the Derwent estuary. Traditional design of buildings and subdivisions has given little consideration to stormwater, except to direct it off developments as quickly as possible via a network of pipes and drains, providing direct delivery of water and pollutants to coastal waters. This creates another stormwater issue of increased flows, which can lead to:

- increased flow volume (carrying higher pollution loads and placing stress on downstream infrastructure);
- increased flow velocity (when discharged into urban streams this can cause stream bank and bed erosion causing siltation in the receiving waters of the estuary); and
- reduced soil-water and groundwater replenishment.

Table 4.5: Some stormwater pollutants, their possible sources and potential impacts

Pollutants	Sources	Impacts
Suspended solids	Erosion Construction sites Road/footpath wear	Smother ecosystems Block sunlight Cause respiratory problems in fish
Metals	Vehicle wear & emissions Atmospheric deposition Illegal/accidental discharges Trade waste discharges	Toxicity to aquatic organisms Bioaccumulation through food chain
Nutrients	Detergents Decaying organic matter Fertilisers Sewage leaks & overflows	Encourage riparian and aquatic weeds Encourage algal growth Increase potential for eutrophication
Pathogens	Sewage overflows Illegal connections Animal faeces	Cause disease in humans and livestock Reduce recreational amenity
Hydrocarbons	Vehicle wear & emissions Spills Illegal discharges	Toxicity to aquatic organisms Loss of aesthetic amenity

The Derwent estuary receives stormwater from 57 urban and suburban catchments by way of 13 major rivulets and over 270 outlet pipes. The quality of stormwater discharged from these points is strongly linked to catchment land uses and the condition of rivulet banks and riparian strips. Construction sites, roads, industrial sites, commercial areas and eroding stream banks are major contributors to stormwater pollution. In addition, there are some occasional cross-connections between the stormwater and sewerage systems that contribute to pollution levels. It is estimated that stormwater runoff delivers approximately 90% of the faecal bacteria load to the Derwent and about half of the suspended sediment load. Stormwater pollution remains one of the greatest risks to the health of the Derwent estuary, exacerbated by population growth and urban sprawl caused by the recent housing boom in southern Tasmania.

Tasmania's *State Policy on Water Quality Management 1997* has identified that stormwater is a significant management issue, which is largely undertaken by local councils. To assist in stormwater management, a *State Stormwater Strategy* is currently being developed by the State Government. Since 2003, a number of stormwater management projects have been undertaken by the DEP, local councils and the State Government, which are described in **Section 4.3.5**. Many of these projects have been supported through Australian Government grants. These projects make use of a range of technologies, including stormwater litter traps, media filtration systems, Water Sensitive Urban Design (WSUD) techniques including biofiltration systems and vegetated swales, stormwater harvesting, education programs and catchment management.

Given the large number of catchments and stormwater outfalls that drain to the Derwent and the high cost of stormwater treatment, it is clearly not possible to treat all stormwater discharges. A regional strategy is needed to minimise stormwater run-off from new developments, using the principles of WSUD. Preventing sediment laden stormwater from leaving building and construction sites is also a high priority.

4.3.1 Rivulet and stormwater monitoring

From July 2002 to June 2005, the DEP coordinated a regional rivulet and stormwater monitoring program in collaboration with six local councils and three Waterwatch groups (DEP 2004). Water samples were collected each month at twelve rivulets (upper and lower catchment sites) and three stormwater dams, and analysed for total suspended solids (TSS), nutrients, heavy metals and faecal bacteria. A total of 34 sites were monitored, as indicated in **Figure 4.8**. To a large degree this monitoring design reflects base-flow water quality, rather than water quality associated with specific storm events which would typically have much higher levels of some contaminants, particularly TSS and faecal bacteria. Nonetheless, the results of the three-year monitoring program demonstrated a clear relationship of decreasing stormwater quality with increasing catchment urbanisation.

In **Table 4.6** and **Figure 4.9** this data is grouped into categories that reflect changing land uses as one travels down the greater Hobart catchments, and is compared to national guidelines. Water quality becomes progressively poorer as the level of human influence intensified down the catchments. Pristine sites representing data collated from three 'upper catchment' sites, where rivulets flowed through undeveloped land in forested catchments, generally had good water quality. In contrast, urban rivulets and stormwater drainage located in the lower, urbanised parts of the catchment (above tidal influence), typically showed poor water quality that often exceeded national water quality guidelines for bacteria, sediments, zinc and nutrients. For further details, see the full monitoring report (DEP 2005).

Table 4.6: Summary of data from DEP Rivulet and Stormwater Monitoring Program (2002-2005)
Values represent median and range

Location → **↓ Parameter**	**Pristine**	**Upland**	**Lowland**	**Drains**	**ANZECC (2000) Guideline (1)**	**Guideline for Urban Streams (2)**
Suspended solids (mg/L)	2 (1 – 95.3)	2 (1 – 401)	4.7 (1 – 2175)	9 (1 – 2205)	**5**	<25
Turbidity (NTU)	1.9 (0.4 – 55)	3.6 (0.4 – 270)	7.25 (0.5 – 906)	26 (1.1 – 2700)	**2-25**	–
Lead (μg/L)	<5 (1 – 5)		<5 (1 – 1420)	<5 (1 – 40)	**3.4**	<25
Zinc (μg/L)	2 (1 – 82)		32 (1 – 5110)	125 (11 – 816)	**8**	<50
Copper (μg/L)	1 (1 – 9)		3 (1 – 370)	8 (1 – 45)	**1.4**	<10
Chromium (μg/L)	<1 (1 – 3)		<1 (1 – 5)	1.5 (1 – 5)	**1**	<10
Faecal coliforms (cfu/100ml)	19.5 (1 – 11800)	36 (1 – 16200)	510 (1 – 41600)	2000 (1 – 1600000)	**150** (a) **1000** (b)	<1000
Enterococci (cfu/100ml)	19 (1 – 5500)	35 (1 – 10000)	300 (2 – 40000)	818 (1 – 98800)	**35** (a) **230** (b)	–
Total phosphorus (mg/L)	0.0065 (0.002 – 0.11)	0.02 (0.002 – 0.66)	0.06 (0.002 – 3.47)	0.19 (0.04 – 2.34)	**0.013**	<0.05
Oxides of nitrogen Nox (mg/L)		0.061 (0.002 – 0.48)	0.1295 (0.002 – 0.756)	0.5875 (0.01 – 2.51)	**0.19**	–
Total nitrogen (mg/L)	0.19 (0.067 – 0.86)	0.3 (0.06 – 1.7)	0.8 (0.1 – 7.98)	2.01 (0.605 – 17.8)	**0.48**	<0.5

(a) Primary contact recreational guiudeline – includes activities involving direct contact, e.g. swimming

(b) Secondary contact recreation guideline – includes activities such as boating or fishing

(1) 'Trigger value' from the Australian and New Zealand Guidelines for Fresh and Marine Water Quality, biota. ANZECC (2000) for upland rivers in Tasmania; note: metals data is for the protection of 95% of freshwater

(2) Australian Runoff Quality (Draft 2003)

Data for individual rivulets throughout greater Hobart is graphed in **Figure 4.10**. These graphs illustrate the difference between water quality from upper and lower catchment rivulet sites. At most rivulet sites, TSS and turbidity levels were relatively low, with elevated concentrations observed in stormwater drains. *Enterococci* levels were relatively high, exceeding human health guidelines at most lower rivulet sites – particularly at Hobart Rivulet and the Kingston Beach stormwater outfall. This suggests on-going sources of faecal contamination, possibly associated with leaking infrastructure. Nutrients were also found to be elevated at most lower rivulet sites.

4.3.2 Modelling stormwater pollutant loads

The annual load of pollutants delivered to the Derwent estuary via stormwater and catchment runoff has been modelled, using *Model for Urban Stormwater Improvement Conceptualization* (MUSIC version 3) software. The loadings were calculated for all the greater Hobart catchments draining directly into the Derwent estuary (excluding the Jordan River – upstream from Brighton, and the River Derwent – upstream from New Norfolk). Pollutant loading rates to the Derwent estuary were based upon 2003 rainfall, provided by the Bureau of Meteorology. The modelled outputs were then calibrated with 2003 urban rivulet monitoring data, in order to calculate the expected annual pollutant loading to the estuary from the greater Hobart catchments (**Table 4.7**).

Table 4.7: Modelled stormwater pollutant loads to the Derwent estuary (tonnes/year)

Total Nitrogen	184
Total Phosphorous	30
Total Suspended Sediments	7996
Litter	852

These modelled loads are substantial. For example, the estimated 852 tonnes of litter discharged to the Derwent via the stormwater system each year would equate to 852 ute loads of rubbish, highlighting that the stormwater

Figure 4.8: Stormwater monitoring sites from DEP Rivulet and Stormwater Monitoring Program (2002-2005)

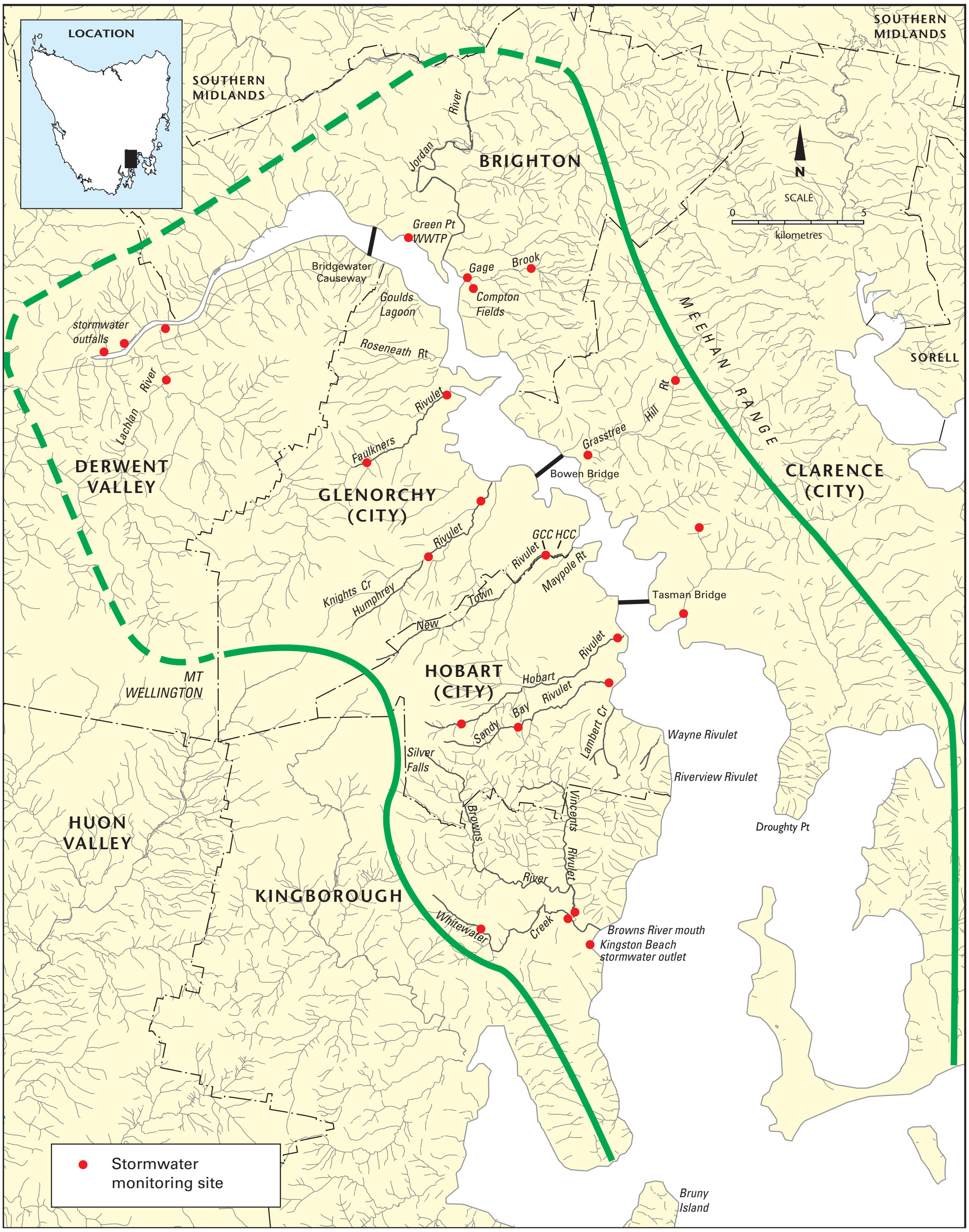
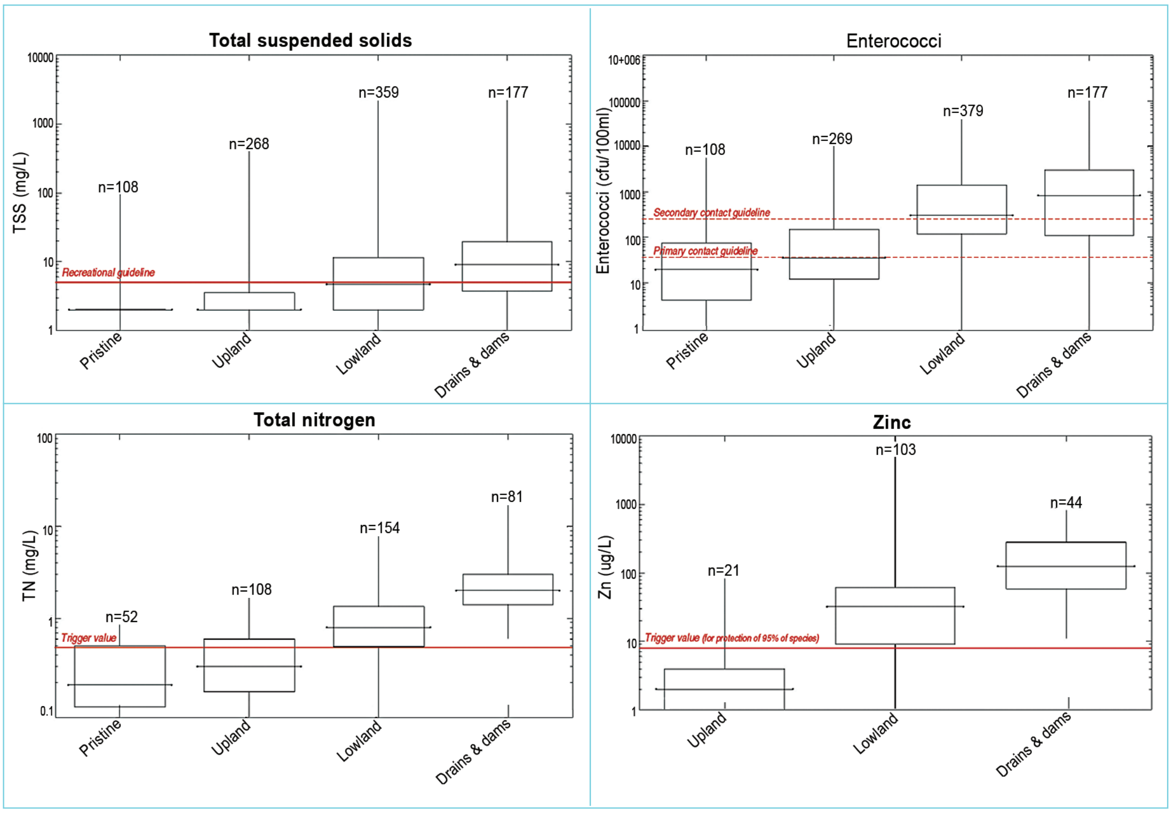


Figure 4.9: Summary of data from DEP Rivulet and Stormwater Monitoring Program (2002-2005)



system continues to be the main pathway by which litter is delivered to the estuary. Likewise, it is estimated that between 40 and 70% of the total suspended solids load delivered to Derwent estuary is derived from stormwater (see **Section 4.6**).

4.3.3 Litter

Litter is visually and aesthetically unpleasant and constitutes a hazard both to human health (e.g. broken glass, used syringes) as well as to marine life (e.g. plastics and cigarette butts). The problem of litter accumulation along the Derwent's foreshore has been cited as one of the community's greatest concern. For example, in the DEP's Community Survey in 2007, respondents ranked litter second in terms of greatest environmental threats to the Derwent estuary, following pollution from local industry.

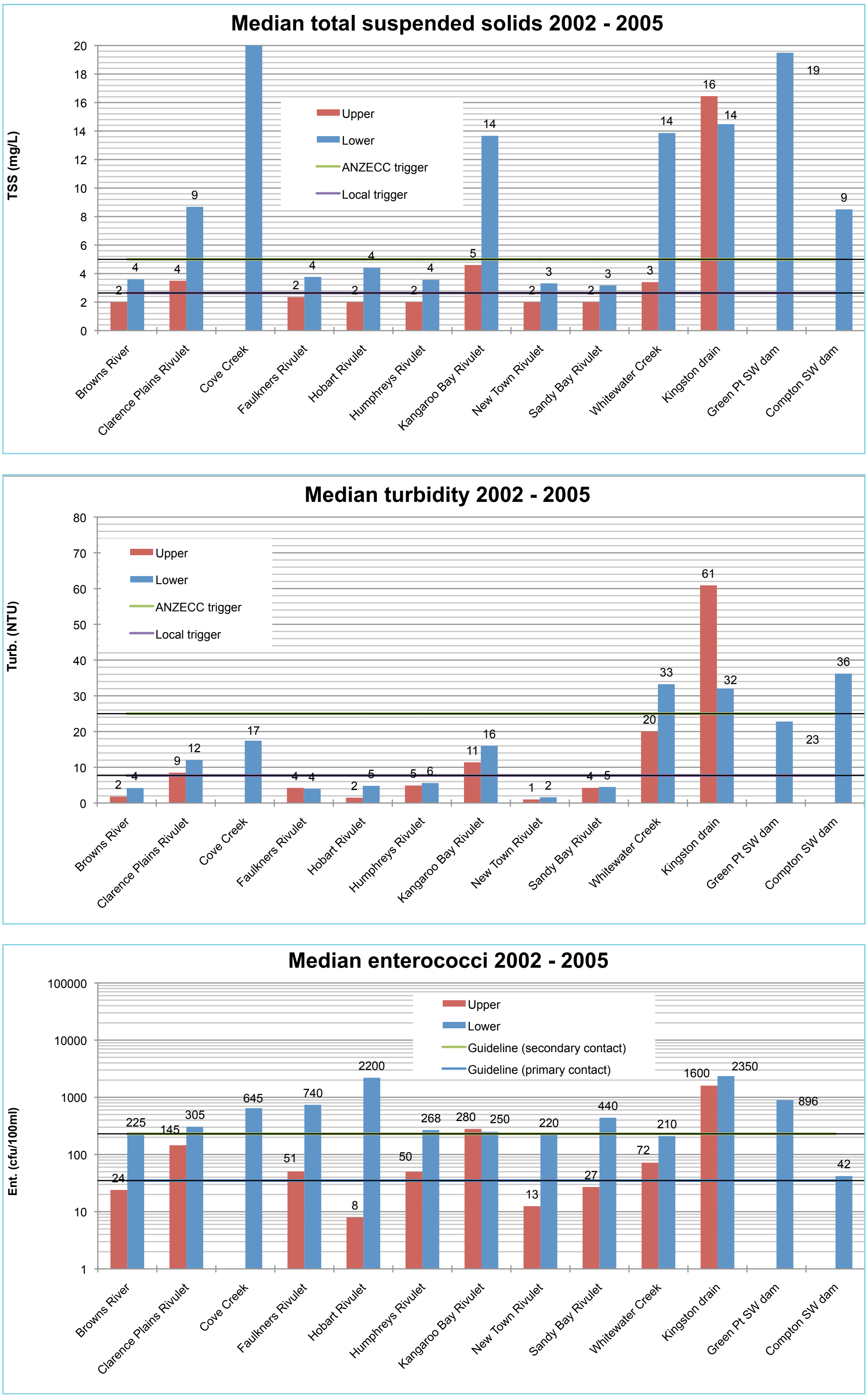
The *DEP Rivulet and Stormwater Monitoring Program* did not monitor litter and until recently there has been little quantitative information about the amount and types of litter discharged by the stormwater system, but more recent local council projects have provided some of this data. Hobart City Council weighed the litter captured in stormwater litter traps in Hobart's central business district (CBD) during 2003-2004. Based on this monitoring it is estimated that annually 330 kg of litter per hectare is discharged to the urban stormwater system. This highlights that stormwater is the main source of litter delivered to the Derwent estuary.

Some types of litter are particularly prevalent in the stormwater litter stream. A six-month stormwater project in Sullivans Cove found 36,000 litter items were collected from 63 stormwater traps with cigarette butts accounting for over 50% of littered items counted.

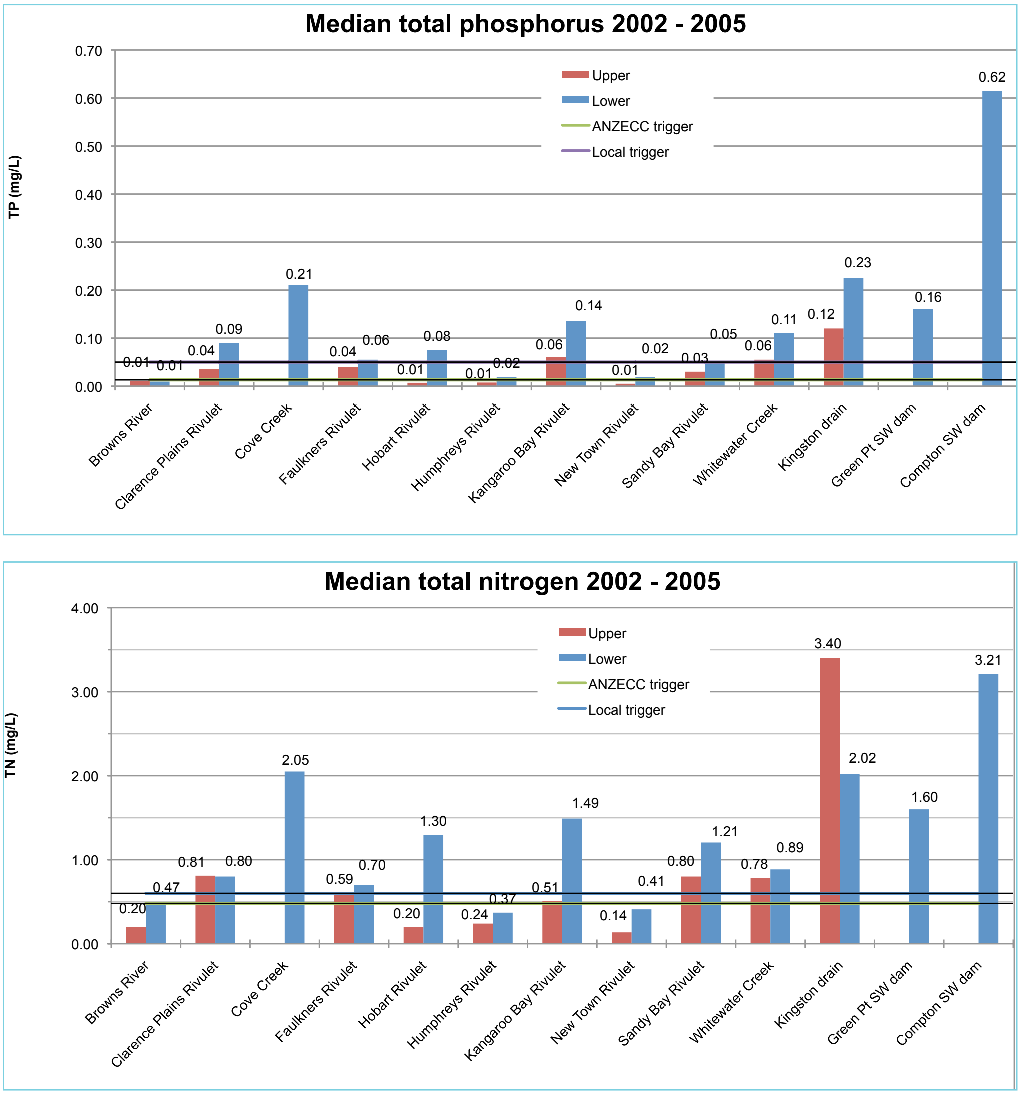
Several public stormwater litter education and infrastructure projects have been conducted to reduce the disproportionate amount of cigarette butt litter found in stormwater including *Cigarette Butt Litter Reduction Project for Hobart's CBD* in 2004, *Butt Free City 2005-2006* and *Reduction of Cigarette Butt Litter for Hobart Waterways* in 2006. These projects have been effective, reducing litter from entering the stormwater system and represent coordinated non-structural methods that reduce stormwater pollution.

There has been considerable community interest and activity centred on the clean-up of foreshore litter, through the annual *Clean Up Australia Day* programt, *Keep Australia Beautiful Week* and efforts of local Coastcare and other community groups. The community

Figure 4.10: Monitoring results for Derwent rivulets and stormwater dams (2002-2005)



Continued – Figure 4.10: Monitoring results for Derwent rivulets and stormwater dams (2002-2005)



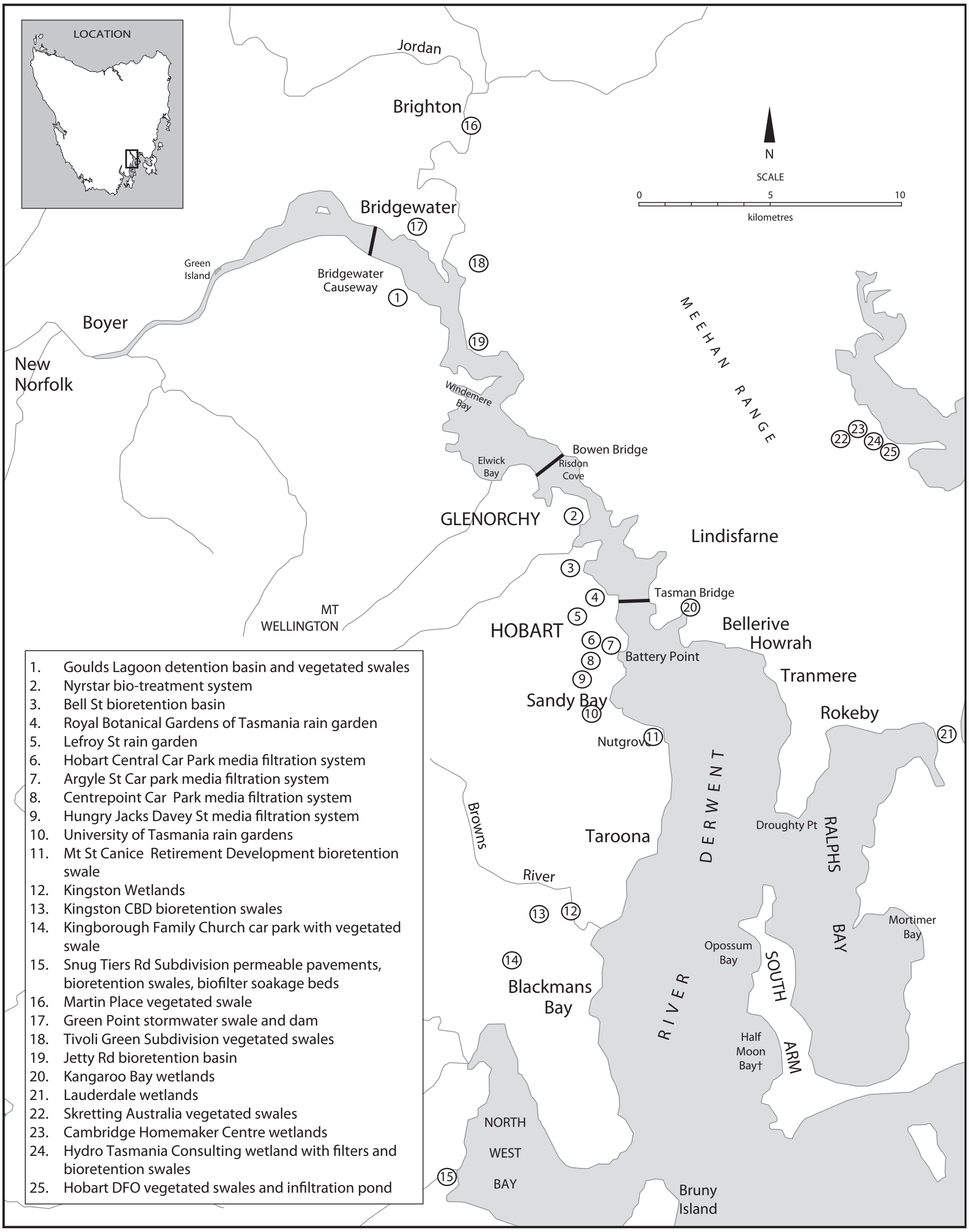
based litter clean-ups provide immense benefits to the estuary, as well as educate the broader community about the environmental and social impacts of littering. The litter clean-up efforts improve the visual amenity of the Derwent estuary foreshore, and it has been noted that this further influences the public's littering behaviour (i.e. cleaner areas tend to attract less litter).

4.3.4 Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) is the design of stormwater infrastructure that aims to minimise impacts of urbanisation on waterways and estuaries. This is achieved by source control strategies that treat, store, and infiltrate stormwater runoff onsite before it can affect receiving waters, offering a change from the traditional approach that encourages rapid discharge of stormwater to the environment. WSUD incorporates specifically constructed elements including permeable pavements vegetated swales, biofiltration systems ('raingardens'), green roofs and stormwater treatment wetlands within the building and subdivision design.

The DEP has been a strong supporter of WSUD in Tasmania, producing Tasmania's first Water Sensitive Urban Design manual and supporting a variety of projects across the Hobart metropolitan area. During the past five years over twenty major WSUD systems have been installed by local councils and industry within the Derwent estuary region at the locations shown in **Figure 4.11**. Many of these projects were supported in part by Australian Government grants, in particular *Natural Heritage Trust* and *National Water Initiative* programs such as the *Community Water Grants*.

Figure 4.11: Major WSUD projects in the Derwent estuary region installed between 2005-2008



1. Goulds Lagoon detention basin and vegetated swales
2. Nyrstar bio-treatment system
3. Bell St bioretention basin
4. Royal Botanical Gardens of Tasmania rain garden
5. Lefroy St rain garden
6. Hobart Central Car Park media filtration system
7. Argyle St Car park media filtration system
8. Centrepoint Car Park media filtration system
9. Hungry Jacks Davey St media filtration system
10. University of Tasmania rain gardens
11. Mt St Canice Retirement Development bioretention swale
12. Kingston Wetlands
13. Kingston CBD bioretention swales
14. Kingborough Family Church car park with vegetated swale
15. Snug Tiers Rd Subdivision permeable pavements, bioretention swales, biofilter soakage beds
16. Martin Place vegetated swale
17. Green Point stormwater swale and dam
18. Tivoli Green Subdivision vegetated swales
19. Jetty Rd bioretention basin
20. Kangaroo Bay wetlands
21. Lauderdale wetlands
22. Skretting Australia vegetated swales
23. Cambridge Homemaker Centre wetlands
24. Hydro Tasmania Consulting wetland with filters and bioretention swales
25. Hobart DFO vegetated swales and infiltration pond

4.3.5 Stormwater management initiatives

Since 2003, the DEP has coordinated and supported a variety of initiatives to reduce stormwater pollution to the Derwent estuary, through networking and training, technical support and implementation of key projects, as described below:

Stormwater Task Force

This working group includes specialists from local councils and the State Government and meets quarterly to share stormwater management ideas and experiences, review management priorities and coordinate monitoring activities.

Model Stormwater Management Plan

The DEP worked closely with the Stormwater Task Force, Hobart and Glenorchy City Councils, and the New Town Rivulet community group to prepare the *New Town Rivulet Stormwater Management Plan* (DEP 2004). This plan was intended as a guide or 'model' document for local governments, and details best practice options to improve the management of stormwater, both in the catchment and within local council planning and development frameworks. It may also assist in the prioritisation of expenditure.

Water Sensitive Urban Design Manual

The *WSUD Engineering Procedures for Stormwater Management in Southern Tasmania* (DEP 2006) describe appropriate methods for the detailed design of some common WSUD stormwater management measures, including advice on sizing of WSUD elements and maintenance appropriate for southern Tasmania. This project was funded through a grant from NRM South.

Sediment and erosion control on construction sites

Soil erosion from building and construction sites is a major source of sediment pollution to the Derwent estuary. In 2009, the DEP completed a project focusing on this issue, supported by a grant from NRM South. New guidelines – *Soil and Water Management for Building and Construction Sites* – were produced, detailing current best practice sediment and erosion control measures, for use by the building and construction industry and local councils. These effectively replaced: The *Soil and Water Management Code of Practice for Hobart Regional Councils (1999)* and *Guidelines for Soil and Water Management (1999)*. Sediment control kits were also provided to the local councils, along with training to explain how they work, so they can lead the way in improving work practices. The sediment control kits contain filter socks and filter bales filled with organic mulch to capture and treat sediment and pollutants that would otherwise end up in the stormwater system or urban waterways. More than 1,000 filter socks and filter bales were issued and over 100 local council staff have been briefed on their use.

Starting in 2009, the DEP has received additional grant funding through the Australian Government's *Caring for Our Country* grant scheme to support: implementation of WSUD at five high-profile sites around the Derwent estuary; installation of infrastructure that will capture and collect litter at Humpheries Rivulet; and support for the implementation of soil and water management on construction sites.

State Government – Living Environment Program

The Environment Division's *Living Environment Program* (2005 – 2008) included a number of environmental initiatives aimed at enhancing the quality of the urban environment and increasing awareness of urban environmental issues. Stormwater-related activities included support for a state stormwater officer and two regional officers, development of a *State Stormwater Strategy*, an extension of the southern Tasmanian WSUD engineering guidelines to cover the whole of the state, as well as support for stormwater and WSUD training workshops and forums.

The *State Stormwater Strategy* (currently in draft form) seeks to set performance criteria for stormwater discharges from new developments in accordance with similar criteria from interstate and overseas, specifically:

- 80% reduction in the average annual load of Total Suspended Solids (TSS);
- 45% reduction in the average annual load of Total Phosphorus (TP);
- 45% reduction in the average annual load of Total Nitrogen (TN).

The reductions are relative to that arising from traditional urban subdivision design that uses standard stormwater conveyance.

Local council initiatives

Local councils within the Derwent estuary region have investigated, trialled and adopted a range of new stormwater technologies and best practices. In some instances the councils have pioneered new treatment systems and quickly adopted their application ahead of the rest of Australia. The majority of WSUD systems shown in **Figure 4.11** have been installed by councils in the Derwent estuary.

A big success story in terms of cost effectiveness and delivery of tangible stormwater quality improvements has been stormwater litter traps. These are baskets, trays, bags or screens placed just below the entrance of the stormwater pit. Stormwater litter traps are inexpensive to install and can capture a high percentage of litter, gross pollutants and coarse sediment (95% gross pollutants, 90% coarse sediment), but they require regular maintenance. Over 500 stormwater litter traps have been installed by Hobart City Council throughout its commercial areas since 2002, representing one of the largest installations of these devices in Australia. They capture approximately 136 tonnes of litter, gross pollutants and coarse sediment per year, preventing this material from entering the Derwent. Further litter capture occurs where much of the stormwater is ultimately discharges into the estuary – with a large Bandalong floating litter trap on the outlet of the Hobart Rivulet at Macquarie Point. Another 40 stormwater litter traps have been fitted in Moonah and Glenorchy CBD by Glenorchy City Council and over 300 traps have been installed by private industry throughout the Derwent estuary region. In Clarence, 60 litter traps were installed at Cambridge Homemaker Centre to pre-treat the runoff from roads and car parks prior to discharge into a constructed wetland for tertiary treatment.

It has been promising to observe an emerging trend towards distributing stormwater infrastructure within a development or catchment, creating a 'stormwater treatment train' – consisting of a series of treatment systems that complement one another to achieve clean stormwater outcomes. They function by treating solid pollutants first, suspended pollutants second and soluble pollutants last. The treatment trains dispersed throughout a catchment are more effective for improving stormwater quality (when based on capital expenditure), than end-of-pipe systems that need to be large (and often expensive) in order to accommodate and treat higher flows from the catchment. Stormwater treatment trains have been installed in a number of municipalities. In Brighton a gross pollutant trap (capturing sediment and litter) has been installed above a stormwater pond at Green Point.

In Kingston an artificial wetland (containing a stormwater treatment train) has been created. This wetland receives some road runoff that has already been pre-treated by flowing along a 'vegetated swale' in the main shopping district (Channel Highway). The efficiency of the artificial wetland to treat more runoff from the adjacent urban catchment has been enhanced through the construction of a stormwater detention basin (in the Denison Street Reserve), which prevents some stormwater bypassing the wetland during high flow events. This is all part of the 'Kingston Integrated Stormwater Strategy', whereby different WSUD elements have been located throughout a catchment for improved stormwater treatment.

Over the last five years, several cutting-edge stormwater treatment systems that are a hybrid between structural systems and WSUD elements have been installed in the Derwent estuary region. Media filtration systems are a new type of stormwater treatment for Australia that combines the structural design of Gross Pollutant Traps (GPTs) with pollutant removal mechanisms found in WSUD. These devices are passive, flow through treatment systems consisting of a precast vault that houses cartridges filled with a filter media (e.g. perlite, zeolite and iron infused media or a combination of any of these) that trap pollutants including suspended solids, dissolved metals, hydrocarbons and nutrients including soluble phosphorus. The only comparable treatment technology is sand filters which require a large footprint. Media filtration systems are an appropriate treatment device for car parks, commercial and industrial developments. They have been installed by Hobart City Council in their Argyle, Hobart Central and Centrepoint multi-storey car parks and a three cartridge unit has been installed at Hungry Jacks in Davey Street, Hobart.

A number of new developments and subdivisions have seen the installation of GPTs in residential areas. While these provide appropriate treatment at industrial and commercial sites, the effectiveness of this treatment option in subdivisions is questioned, as their target pollutant – litter, is typically at much lower volumes in residential areas. Furthermore, GPTs need repeated cleaning; if they are not regularly maintained they can add to the pollutant load due to biochemical reactions between captured pollutants (dissolved and in suspension) washing out of the trap in the next storm. WSUD elements such as swales are more effective, in terms of pollutant removal and maintenance requirements for new developments and subdivisions.

4.4 Reported spills and incidents

Pollution spills and other incidents are required to be reported to the EPA, and are recorded and categorised in a database which is maintained by the Environment Division. The majority of reported spills and incidents are associated with sewage and oil spills. The following is a summary of sewage and oil spills within the DEP region between 2003 and 2008.

4.4.1 Sewage spills

Sewage spills often occur at times of heavy rain when sewerage infrastructure becomes stressed with influx of stormwater or due to power failures. When sewage spills occur from sewage treatment plants, broken pipes or from pump stations, they are required to be reported to the EPA. However, in many cases the volume of the spill is sometimes unknown or roughly estimated. Hence it is not possible to quantify the volume of sewage and associated pollutants spilled to the estuary each year. Some sewage spills can be in the order of millions of litres, resulting in significant localised impact. The number of reported sewage spill incidents, which may have reached the Derwent

Table 4.8: Summary of reported sewage spill incidents in, or near, the Derwent estuary

	2003	2004	2005	2006	2007	2008
Spills/overflows at STPs	22	7	8	8	8	6
Pump station overflows	8	6	21	3	6	6
Leaking/blocked pipes or damaged infrastructure	1	9	25	5	23	17
Total	**31**	**22**	**54**	**16**	**37**	**28**
Reported volume spilled (Megalitres)	19.4	1.5	3.4	0.17	3.14	4.4

estuary, are listed in **Table 4.8**. The reported volumes are minimum values only, as the majority of reported incidents do not include this information.

4.4.2 Oil spills

Most reported oil and fuel spills to the Derwent estuary are small land-based spills that flow to stormwater drains or are spills of diesel related to shipping and boating operations. Larger spills occasionally occur, particularly when fuel storage tanks leak or malfunction, causing discharge to the stormwater system. A summary of reported oil spills from Jan 2003 to Dec 2008 is provided in **Table 4.9**.

Table 4.9: Summary of reported oil spill incidents in, or near, the Derwent estuary

	2003	2004	2005	2006	2007	2008
Reported oils spills in or reaching the Derwent estuary	16	11	3	1	3	8

4.5 Landfills, tips and contaminated sites

4.5.1 Landfills and tips

Landfills may contribute pollutants to water bodies in the form of leachate, surface runoff, sediment and wind-blown rubbish. Refuse disposal sites are regulated by the EPA under the *Environmental Management and Pollution Control Act 1994* (EMPCA) and must meet specified permit conditions, which typically include leachate and surface water management, and monitoring of leachate, groundwater and nearby waterways. Parameters which are commonly monitored include nitrate, ammonia, phosphate, pH, BOD, chemical oxygen demand (COD), faecal indicator bacteria, metals and organic contaminants. Leachate quality varies from site to site depending on the site design, refuse composition, water content, stage of decomposition, temperature, and oxygen availability. Some contaminants which may be present in leachate are hazardous even in very low concentrations. These include chlorinated hydrocarbons, aromatic solvents, phenolic compounds, pesticides and herbicides, and metals such as cadmium, mercury and lead.

Figure 4.12 shows the locations of active and closed landfills, former rubbish tips, industrial landfills and industrial stockpiles around the Derwent estuary (further details are summarised in **Table 4.10**). There are currently three active landfills in the Derwent estuary region: McRobies Gully (Hobart), Jackson Street (Glenorchy), and Peppermint Hill (New Norfolk). McRobies Gully (22 ha) and Jackson Street (23 ha) are of a similar size. Leachate from these two sites is collected and diverted to WWTPs, and monitoring of leachate, ground-water and surface water is routinely undertaken at both sites. Under normal operating conditions, monitoring results suggest that there has been no recent pollution of Humphries Rivulet or Hobart Rivulet associated with these landfills. However during prolonged storm events or water pipe/weir blockages, the leachate pond at McRobies Gully may be over-topped, or stormwater may be diverted around the leachate pond, resulting in the release of some diluted leachate into the Hobart Rivulet. To address this issue, stormwater diversion drains are being constructed to direct clean water from the upper catchment around the site, without coming into contact with the landfill. The Peppermint Hill landfill has a retaining bund and leachate collection ponds, which are monitored quarterly. Derwent Valley Council has lined the leachate ponds and there are plans to connect the outflow to the WWTP in 2010, where it will receive further treatment. During heavy rains, surface water and overflows from the leachate ponds may enter the Derwent via a small stream to the west of the landfill.

The life expectancy of McRobies Gully landfill site is until 2017, whereas Jackson Street has capacity until 2029. The EPA's Landfill *Sustainability Guide* (2004) sets out specific requirements for management of Tasmanian landfills. Landfill operators have until 30 June 2009 to achieve compliance with the guide or to demonstrate to the EPA that comparable reductions in environmental risk can be achieved by other solutions.

Two major landfills sites in the region have been closed in the past ten years at Chapel Street, Glenorchy (closed 1999) and Lauderdale, Clarence (closed 2001). Both sites have been capped with low permeability materials and revegetated. The Chapel Street site has a leachate collection system (connected to sewer), however, during heavy rains some leachate may be discharged to Humphries Rivulet. There are also potential issues related to landslip risk and groundwater contamination at this site. The Lauderdale site does not have a leachate collection system, and groundwater monitoring is no longer routinely carried out. Groundwater investigations have suggested that some leachate may be discharged along the southern margin of this former landfill site.

Approximately ten old landfill areas are known to exist along both sides of the estuary as described by Tamvakis (1994). Most of these sites (e.g. New Town Bay, Prince of Wales Bay, Geilston Bay, Lindisfarne Bay, Kangaroo Bay and Wentworth Park) were former tidal flats, wetlands, saltmarshes or coastal lagoons, which were used as rubbish tips. Many of these sites have been reclaimed as parks, playing fields or wharves. There have been few investigations and little monitoring of these old landfill sites, and the potential for groundwater contamination and seepage to the estuary is unknown. The *DEP Environmental Management Plan* (2009) has recommended a risk-based assessment of potential contamination associated with historical tip sites located in close proximity to the estuary. This is particularly relevant to those sites in the vicinity of industrial areas (e.g. New Town Bay and Prince of Wales Bay) as well as areas identified as being at risk due to projected sea-level rise (e.g. Lauderdale).

4.5.2 Contaminated sites

Land and groundwater contamination associated with contaminated sites may negatively impact water quality within the Derwent estuary. Contaminated sites and potentially contaminating activities can be identified by the EPA, using several different databases. Registered contaminated sites are listed on the *Contaminated Sites* database, while some 'potentially contaminating activities' can be identified through the *New Environmental Licensing and Monitoring System* (NELMS) and the *Environmentally Relevant Land Use Register* (ERLUR) which contains historical information on specific land uses or potentially contaminating activities. As discussed below, these databases only contain a subset of contaminated sites and activities within the region.

Registered contaminated sites

The EPA's *Contaminated Sites* database contains records of a limited number of sites, including sites that have been assessed by the Environment Division, because they are being redeveloped to a more sensitive use, or because they have been found to be posing a risk to human health or the environment, and the Division has been notified of that potential risk. Therefore, the database does not list all sites that are, or may be contaminated. A query of the *Contaminated Sites* database undertaken by the EPA for the DEP area (**Figure 1.1**) identified thirty-five registered sites. The majority of these sites are located in urban and industrial zones. As illustrated in **Figure 4.13**, twenty-five of these sites are associated with petroleum storage, six with a variety of other uses, two with large industrial premises (Nyrstar Hobart smelter and Norske Skog paper) and two with spills. The large industrial sites are considered to have a higher likelihood of impact on receiving waters than the smaller sites (see **Section 4.2**) for a review of site contamination issues at Nyrstar and Norske Skog). It should be noted that there are likely to be more sites that have land and/or groundwater contamination that the EPA is not currently aware of, as they have either not yet been assessed, or notification of contamination has not been provided to the EPA as required under the EMPCA.

'Potentially contaminating activities' may be associated with either large or small scale industrial and commercial activities which represent a high risk of land and groundwater contamination. Potentially contaminating activities include the storage of dangerous goods in above-ground and under-ground storage tanks (ASTs and USTs), large and small waste depots (e.g. landfills), and some agricultural activities. For a more comprehensive list, refer to the EPA *Information Bulletin Potentially Contaminating Activities*, *Industries and Land uses*.

The ERLUR and NELMS databases were searched to evaluate the total number of records for potentially contaminating activities, by activity type. The ERLUR database primarily contains information on under-ground and above-ground storage tanks installed prior to 1992 (more recent records are kept by Workplace Standards Tasmania), and small scale waste depots. The NELMS database contains records for all Level 2 premises regulated by the EPA, including large industries, WWTPs and landfills. Potentially contaminating activities identified through these databases are described in further detail below and the number of sites for each activity type are shown in **Figure 4.14**.

Figure 4.12: Refuse disposal sites and industrial stockpiles around the Derwent estuary

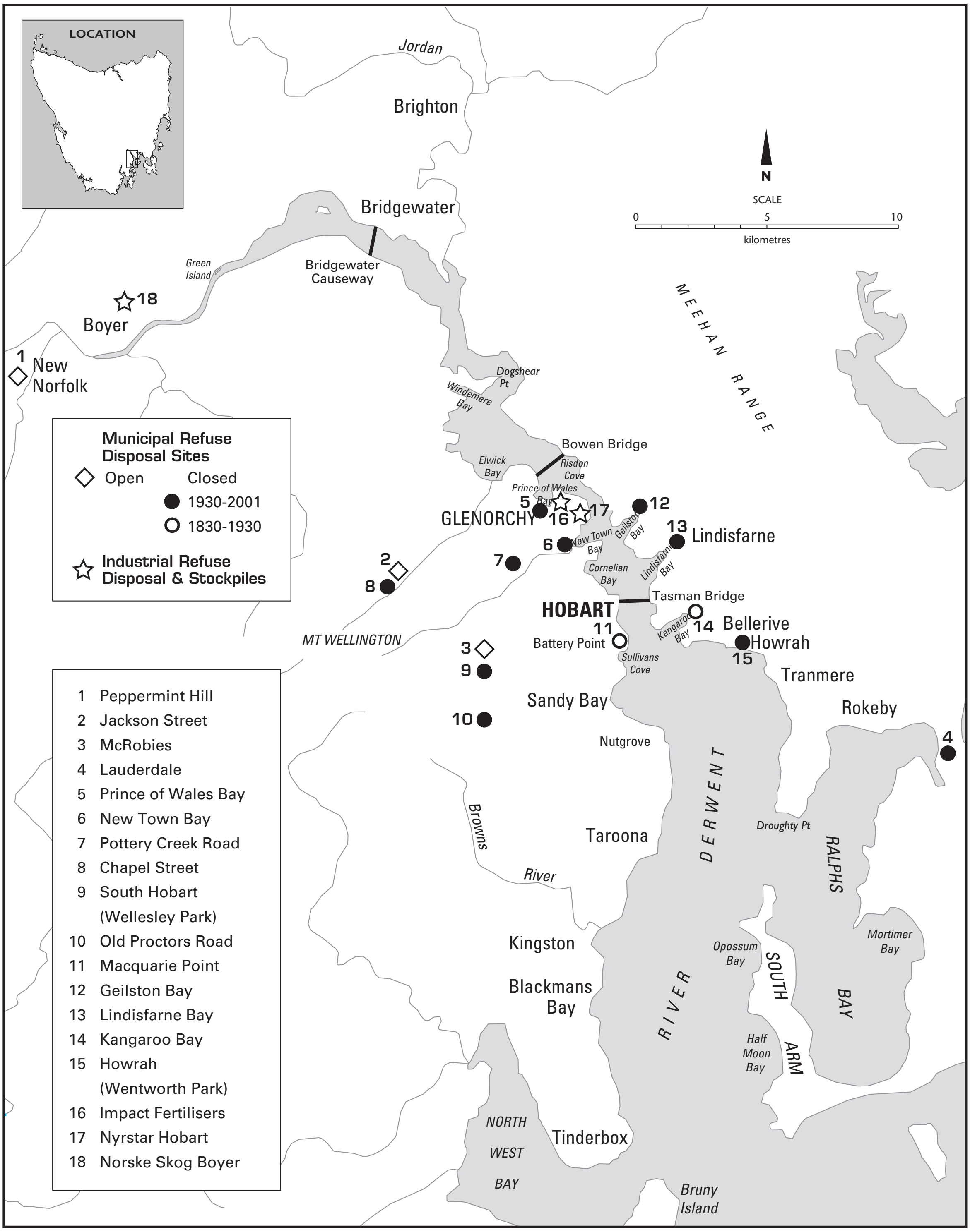


Table 4.10: Landfills, rubbish tips and industrial stockpiles in the DEP area

MUNICIPAL LANDFILLS – RUBBISH TIPS

Active landfills as of 2009

1. **Peppermint Hill, New Norfolk**
   1977 – present 5 ha
- Filling rate limit: 15,000 m3/yr.
- The tip has surface diversion of water flow, a retaining bund, leachate collection ponds and quarterly sampling of surface water; three groundwater monitoring bores recently installed.

2. **Jackson Street, Glenorchy**
   1986 – present 23 ha
- Previously a quarry site.
- Filling rate: 120,000 m3/yr (est.).
- Perimeter drains divert surface runoff away from the tip site. Stormwater pipes at the tip site are directed to a leachate pond which is connected to sewer. The pond may overflow to the stormwater system during heavy rain. Surface water is monitored every 6 months at the site, ground-water every 3 months and leachate every month.

3. **McRobies Gully, South Hobart**
   1975 – present 22 ha
- Previously bushland
- Filling rate: 120,000 m3/yr
- There is a cement leachate pond with an overflow to the sewerage system downstream of the tip site.
- Works have recently been undertaken to lower the water table within the tip. Groundwater monitoring is routinely undertaken at 18 bore holes.
- A gas extraction system is in place that converts methane to electricity.

Recently closed landfills

4. **Lauderdale**
   1970 – 2001 23 ha
- Previously a saltmarsh area.
- The site has a clay/sand cover overlain with sewage sludge, green waste and planted with grasses, shrubs and trees
- During operation leachate was monitored every six months from 16 bore sites on and around the site.

8. **Chapel Street, Glenorchy**
   1971 – 1987 and 1996-1999 9 ha
- Previously a quarry site, now being rehabilitated as urban bushland and a neighbourhood park.
- Site runoff diverted to sewer. Site leachate is tested quarterly together with ground-water levels from eight bores.

Historical landfills

5. **Prince of Wales Bay, Derwent Park**
   1920 – 1964
- First used as an illegal dump, later taken over by council as a municipal tip.
- Previously Derwent estuary tidal flats, now softball and hockey playing fields.

6. **New Town Bay**
   1920 – 1963
- First used as an illegal dump, later taken over by council as a municipal tip.
- Previously Derwent estuary tidal flats, now rugby fields.

7. **Creek Road, New Town**
   1961 – 1967 5 ha
- Previously urban bushland, now parkland.

9. **South Hobart**
   1960 – 1967 2 ha
- First used as an illegal dump, later taken over by council as a municipal tip.
- Previously a quarry site, now soccer and playing fields.

10. **Old Proctors Road, Mt. Nelson**
    1967 – 1974 1.7 ha
- Previously a quarry site now school playing fields.
- Has a leachate pond and a runoff collection pond. This was the first Hobart tip to have such a facility. Leachate has been tested regularly by council since 1977.

11. **Macquarie Point, Hobart**
    1830 – 1938
- Large council operated site.
- Previously part of the Derwent River, now a wharf site.

12. **Geilston Bay**
    1966 – 1970
- First used as an illegal dump, later taken over by council as a municipal tip for land reclamation.
- Previously Derwent estuary tidal flats, now recreation area including parkland.

13. **Lindisfarne Bay**
    1950 – 1964
- First used as an illegal dump site then taken over by council as a municipal tip for land reclamation.
- Previously Derwent estuary tidal flats, now playground and parkland.

14. **Kangaroo Bay, Bellerive**
    1920 – 1975
- First used as an illegal dump site then taken over by council as a municipal tip.
- Previously Derwent estuary tidal flats, now parkland.

15. **Wentworth Park, Howrah**
    1962 – 1969
- Previously mined sand dunes, now playing fields, parks and playgrounds.

INDUSTRIAL STOCKPILES AND LANDFILLS

Impact Fertilisers

30 ha
- Large phosphate rock stockpile.
- Most stormwater captured in stormwater ponds and reused, occasional overflows to the estuary occur during heavy rain.
- Ground-water investigations underway.

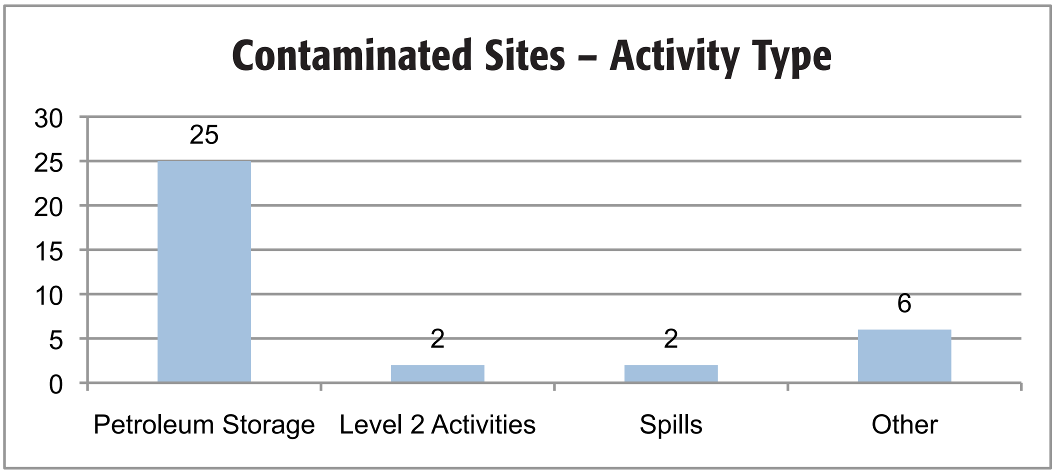
Nyrstar Hobart Smelter

1917 – present 290 ha
- Large areas of industrial landfills and stockpiles; most now encapsulated, covered or removed.
- Extensive stormwater and ground-water monitoring
- Most stormwater and some groundwater captured/treated.

Norske Skog Paper

1941 – present 60 ha
- Large areas of industrial landfills and stockpiles.
- Stormwater and groundwater monitoring.
- Leachate from main landfill captured and treated in effluent treatment.

Figure 4.13: Number of known contaminated sites in the DEP area categorised by activity type



Storage tanks

The storage of dangerous goods (e.g. petroleum) in ASTs and USTs is considered a potentially contaminating activity. Contamination is often caused by leaks from tanks and is most commonly associated with service stations and fuel depots. USTs have the potential, and a high likelihood, of causing substantial soil and groundwater contamination if a leak occurs. Often small leaks go undetected over many years and petroleum hydrocarbons can accumulate in soil and groundwater to levels that may present a significant threat to both the environment and human health.

Level 1 Waste depots

Level 1 waste depots are generally inactive, small scale waste management or disposal sites that are regulated by local councils. Even though waste depots are usually small in size, they still have the potential to release pollutants into the environment and cause environmental harm or nuisance.

Level 2 Activities

As discussed previously, Level 2 Activities are generally larger scale industrial activities that are regulated by the EPA. These include activities such as WWTPs, sawmills, quarries, large landfills and waste depots. It is noted that very few Level 2 Activities are currently listed as 'contaminated sites', however, as some are considered to have a high potential for causing soil or groundwater contamination they are included here as potentially contaminating activities. Out of the 83 suburbs searched within the DEP area, 65 sites were identified as hosting Level 2 Activities.

Other Level 1 Activities

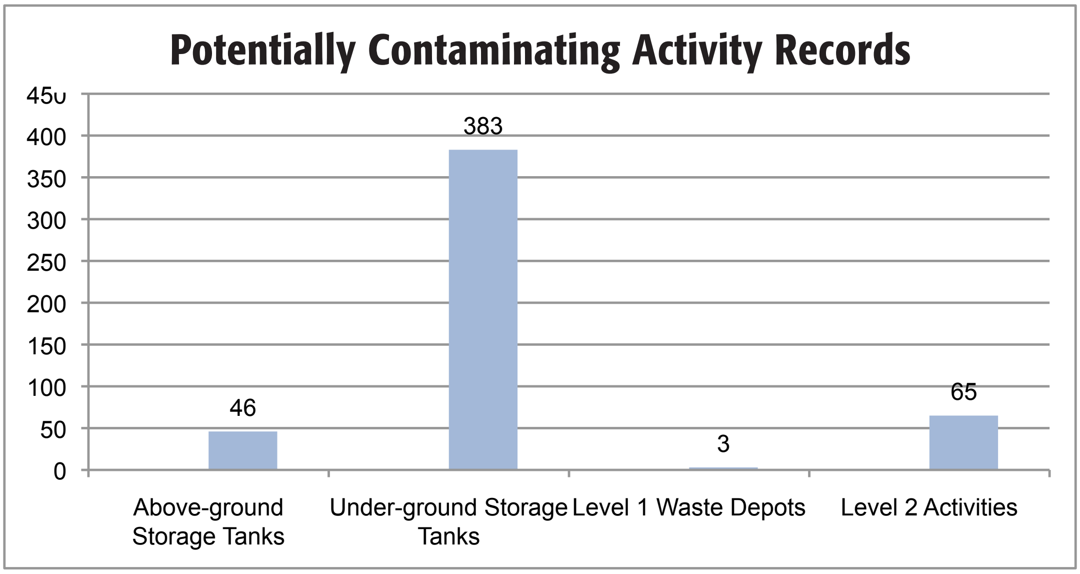
Other Level 1 Activities undertaken within the DEP area include activities such as manufacturing, metal finishing or galvanising works, scrap yards, and boat building facilities and slipways. These potentially contaminating activities are regulated by local council. While the Contaminated Sites Unit has not been notified of any contamination from the majority of these industries, many of these sites have probably not been assessed for land or groundwater contamination, and as such, the impact from these sites on the environment and therefore to the estuary, is largely unknown.

4.6 Summary of pollution loads 2003-2008

Since 2003, there have been several significant changes in pollutant loads to the Derwent estuary, particularly with respect to reductions in organic matter discharged by industry and nutrients discharged by WWTPs. These reductions are due, to a large degree, to secondary effluent treatment at the Norske Skog paper mill as well as effluent reuse at several WWTPs, in particular Rosny (refer to **Section 4.1**).

A comparison of estimated mass emissions from major sources (i.e. industries, WWTPs, stormwater –greater Hobart catchment run-off, and the River Derwent (above New Norfolk)) for several key pollutants from 2003-2008 is provided in **Figure 4.15**. These figures should be considered as indicative only, as some of the information used in these is incomplete and requires further development. Nonetheless, some useful patterns and

Figure 4.14: Records relating to potentially contaminated activities in the project area.

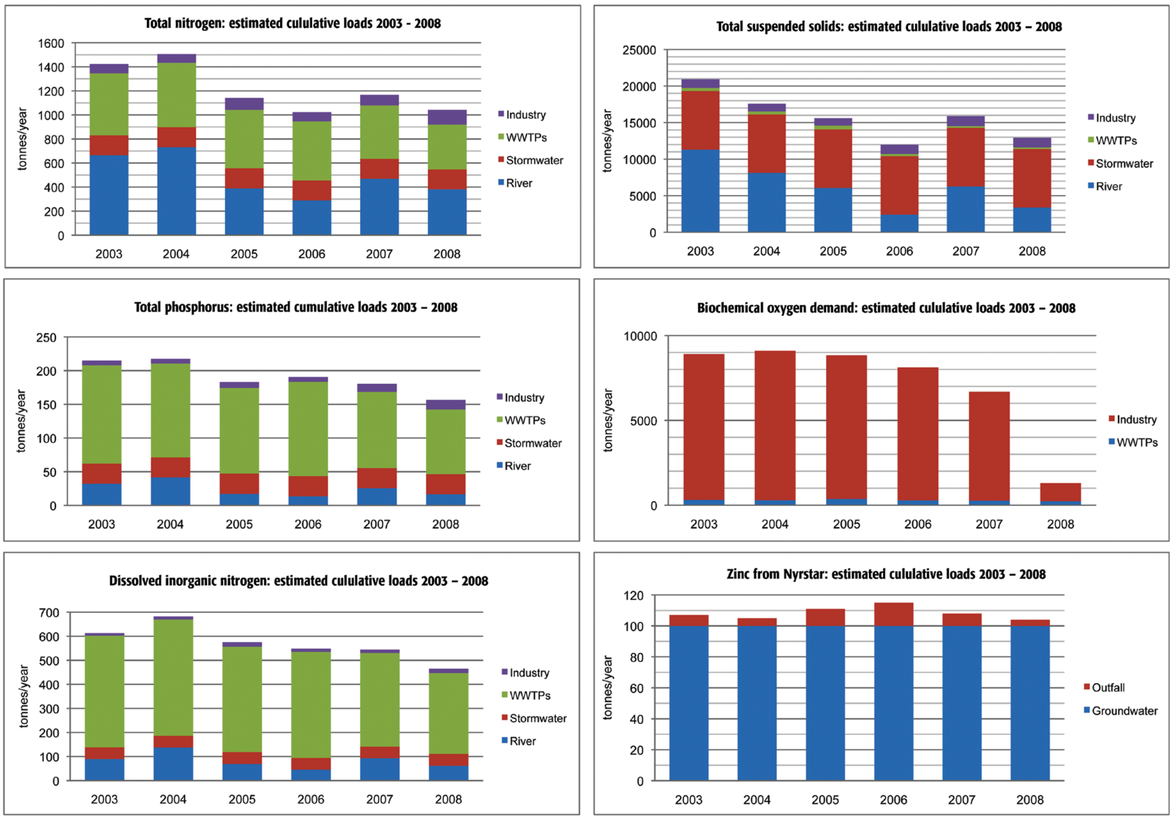


Note that the EPA only holds records of above- and under-ground storage tanks prior to 1992. Therefore, the numbers below likely do not represent the current number of storage tanks located within the DEP area.

trends are evident. Key points over the five year period 2003-2005 include the following:

- WWTP-derived nutrient discharges to the estuary declined by about 30% as a result of improvements in sewage treatment including reuse;
- BOD emissions from the Norske Skog mill declined by over 80%, following implementation of secondary treatment;
- the majority of TSS and TN are associated with stormwater run-off and catchment loads carried by the Derwent River; and
- zinc loads are primarily associated with groundwater emissions at the Nyrstar Hobart smelter.

Figure 4.15: Recent trends in pollutant loads to the Derwent estuary (2003-2008)



NOTES: Catchment loads derived from River Derwent flows at Meadowbank and monthly monitoring data at New Norfolk. Stormwater loads derived from MUSIC modeling carried out by the DEP and regional stormwater monitoring data. These are based on 2003 meteorological conditions (average rainfall year) and does not reflect interannual variability.

5.0 INTEGRATED STUDIES

Several major integrated studies of the Derwent estuary have been carried out since 2003, primarily in association with the *Derwent Estuary Water Quality Improvement Plan*, as discussed below. These studies focused on heavy metals and nutrients and included sediment investigations, toxicity experiments and biological surveys. In addition, a suite of high resolution estuarine models have been developed (hydrodynamics, sediment transport, toxicants and nutrient response), providing improved system understanding as well as predictive capacity.

5.1 Heavy metals: Derwent Estuary Water Quality Improvement Plan (Stage 1)

In 2007, the DEP published the *Derwent Estuary Water Quality Improvement Plan for Heavy Metals* (WQIP) as a basis for managing heavy metal contamination in the estuary. This project was supported by the Australian Government's *Coastal Catchments Initiative* program, with additional resources provided by the Derwent Estuary Program (DEP) partnership. The WQIP report reviewed heavy metal sources and loads, set environmental targets and recommended actions to reduce and manage heavy metals in the Derwent. Detailed estuarine models were developed to support the WQIP and extensive sediment investigations were carried out.

Zinc was selected as the indicator for the WQIP as it is by far the most abundant heavy metal in the Derwent and can be readily measured in water, sediments and biota, thus enabling the development of calibrated estuary models. Furthermore, levels of most other heavy metals show a strong correlation with zinc levels, and management actions proposed to address zinc contamination should address most other metals as well. A water column target of 15 µg/L total zinc was selected, corresponding to the ANZECC trigger level to protect 95% of species (slightly-to-moderately disturbed system). This target will be refined over time, as further information becomes available (DEP 2007).

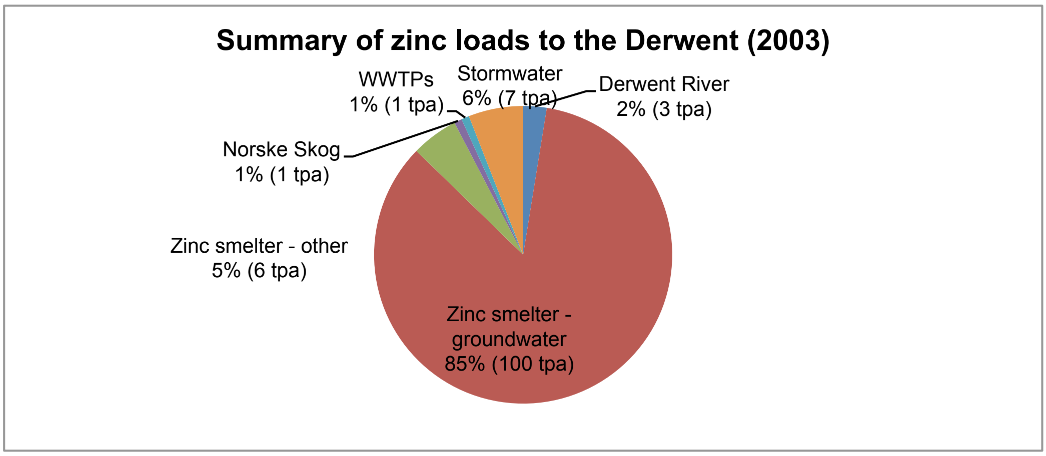
5.1.1 *Heavy metal sources and loads*

An assessment of heavy metal loads discharged to the estuary was carried out, including major industries, wastewater treatment plants (WWTPs), urban stormwater, tips and landfills and the Derwent River catchment. As shown in **Figure 5.1**, the single largest source was found to be the zinc smelter, in particular the groundwater contamination at the site which accounts for the majority of the current load. The second largest source was identified as urban stormwater run-off. In the past, heavy metal loads were much higher and were primarily associated with the zinc smelter (established in 1917) and the Boyer newsprint mill (established 1941). Further details are provided in the full report (DEP 2007).

5.1.2 *Sediment investigations*

The large area of contaminated sediments in the Derwent estuary (**see Section 7.0**) raises a number of important questions for future management. For example, are sediments a major internal source of metals to the water column? Are there conditions under which sediments could become a major source? What are the ecological implications of these contaminated sediments in terms of both toxicity and bioaccumulation? Can anything be done to remediate sediments or to reduce ecological and human health risks? A series of investigations and experiments were carried out as part of this project to address these questions.

Figure 5.1: Estimated zinc loads discharged to the Derwent in 2003



Sediment geochemistry, process studies and toxicity

Using surface sediment data collected in 2000 and multi-variate techniques, the Derwent was divided into six zones reflecting similarities in sediment heavy metal concentrations (Zn and Hg), total organic content (TOC) and grain size, as illustrated in **Figure 5.2**. Composite sediment samples were then collected within each zone and a number of analyses and process studies were carried out to better assess metal mobility, bioavailability and toxicity. These investigations showed some unexpected results. Although the levels of heavy metals in sediments ranged from low to extremely high, heavy metals measured within the interstitial porewaters from all samples were relatively low. Seawater elutriate and sediment resuspension experiments also suggested that heavy metals released during mixing were rapidly removed from solution. A preliminary evaluation of the biological effects of heavy metal contamination resulted in mixed findings. Initial toxicity screening using Microtox suggested that sediments and pore waters were not highly toxic; however, tests using more sensitive species indicated significant sediment toxicity in some areas. See Koehnken and Eriksen (2004) and Butler *et al*. (2005) for details.

Targeted surveys

Several surveys were also carried out to fill key information gaps, as described below. Full details are provided in Koehnken and Eriksen (2004).

- Sediment samples were collected from ***intertidal areas*** in the Derwent estuary, with particular regard to major public reserves, recreation areas and other relevant sites. Heavy metals levels were assessed against health-based investigation levels for residential developments, parks and other open spaces (NEPC 1999). Sediment composition changed gradually with distance upriver from sandy to muddy to very fine silt, and metal levels generally increased as the percentage of silt increased. With the exception of lead levels in Prince of Wales Bay, metal concentrations in intertidal sediments were below National Environment Protection Council criteria. However, the *Interim Sediment Quality Guidelines* (ANZECC 2000) were routinely exceeded for lead, mercury and zinc, with sites on the western shore having the poorest intertidal sediment quality.

- The ***wreck of the Lake Illawarra*** lies at the base of the Tasman Bridge in 40 metres of water with a full cargo of zinc concentrate, and had been identified as a potential source of zinc to the water column. Water samples collected at various depths and tidal conditions – both upstream and downstream of the wreck – showed no evidence that the wreck is leaching zinc or other heavy metals.

- An investigation of ***heavy metal concentrations in cores*** collected from four sites around the estuary indicated that at middle estuary sites, metal levels peak at a depth of approximately 20 cm below the surface – corresponding to the period of highest industrial emissions. The maximum metal levels recorded in a core taken from the upper estuary occurred at 6-9 cm below the surface. The cores were also used to estimate sedimentation rates over the past 100 years, which were found to range from approximately 5 mm/year in the middle estuary to 10 mm/year in the upper estuary near Bridgewater.

Key findings

Metals in Derwent estuary sediments appear to be strongly bound, and are not readily leached to the overlying water column under normal, quiescent conditions. Internal loading of heavy metals from sediments thus appears to be a relatively minor source as compared to external point and diffuse sources (e.g. zinc smelter site). This appears largely due to the abundance of sulphides, iron and organic matter in Derwent estuary sediments. Based on summer and winter redox surveys, there does not appear to be any major seasonality associated with releases from sediments. There are however, conditions under which sediments could potentially become a significant heavy metals source and management provisions may be needed to avoid these conditions, in particular, episodes of sediment hypoxia/anoxia and uncontrolled dredging and dredge disposal.

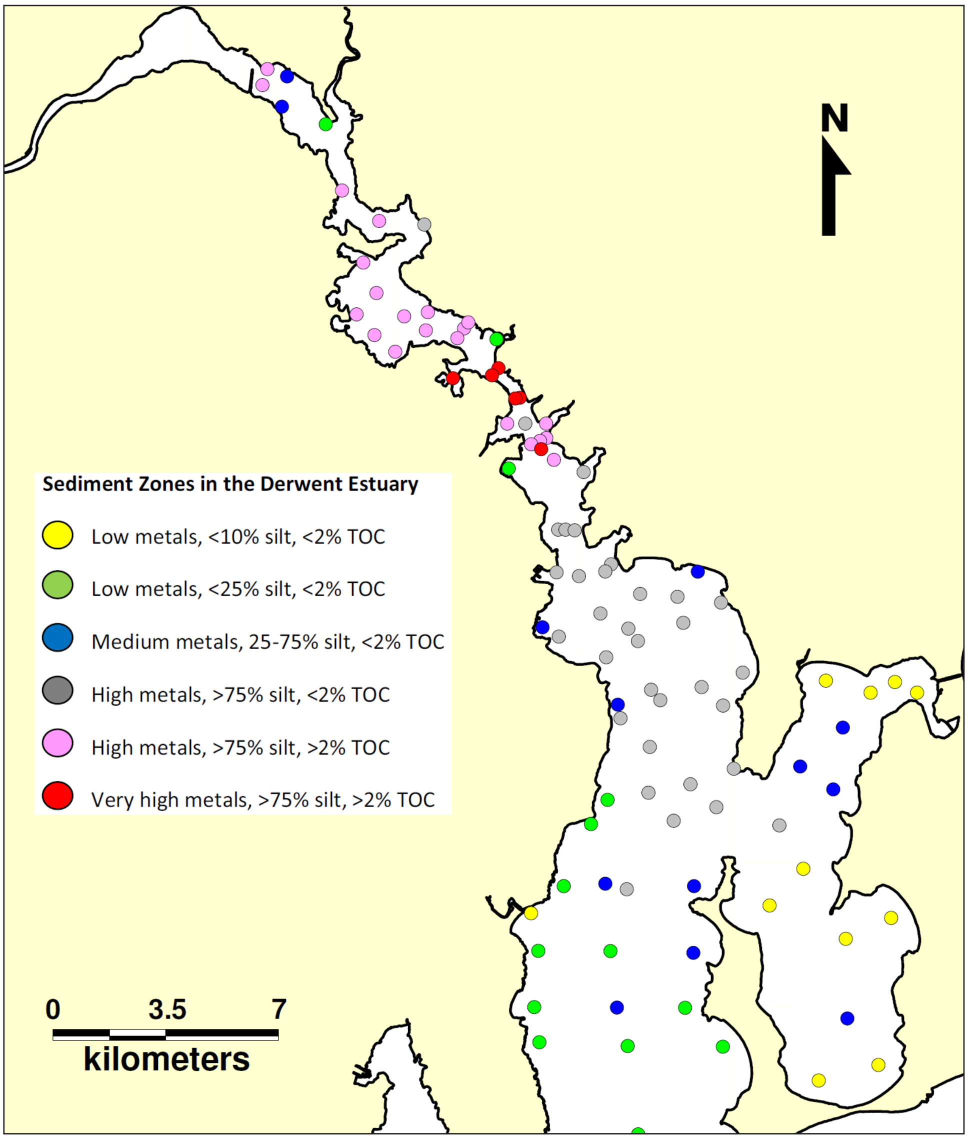
5.1.3 Estuarine models

The WQIP supported the development of a suite of high resolution numerical models by scientists at CSIRO Marine Research. These models have greatly improved our understanding of Derwent estuary hydrodynamics, sediment and zinc transport, while also providing an excellent basis for the evaluation of a range of management scenarios.

Hydrodynamic model

The Derwent estuary hydrodynamic model provides an understanding of the physical dynamics of the estuary (water transport, mixing regimes and temperature/salinity distributions) and the relationship between process occurring on different time and space scales. This 3-dimensional non-stationary, non-linear hydrodynamic model forms a base into which sediment, contaminant and biogeochemical models have been coupled. The high resolution model grid, shown in **Figure 5.3**, provides excellent spatial and vertical coverage over most of the estuary. Long period simulations were required (>1 year) to assess the impact of contaminants on the aquatic environment, and these

Figure 5.2: Six sediment zones within the Derwent estuary based upon heavy metal (Zn and Hg), % silt and % TOC



Source: data from Koehnken and Eriksen (2004).

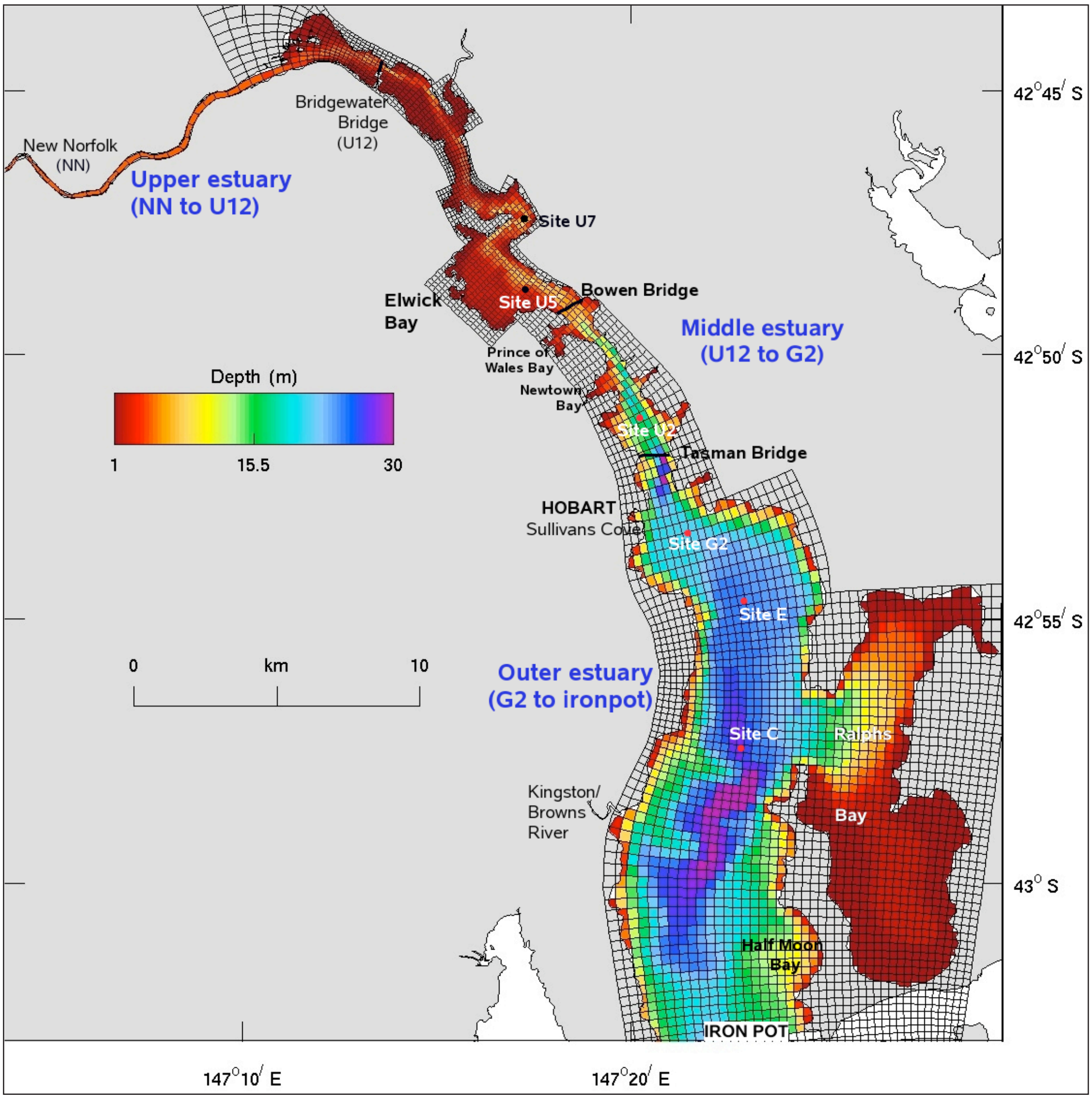
simulations required acceptable run time ratios of greater than 100:1 (i.e. 100 model days in 1 day real time). The model was forced with river flow from the River Derwent, wind stress, and surface elevations, temperature and salinity on the seaward limits of the estuary. These seaward boundary conditions were derived from a larger scale model of the region and direct measurement. For full details on model development and implementation, see Herzfeld *et al*. (2005).

Sediment and zinc transport model

A 3-dimensional fine-resolution numerical model was developed and implemented to simulate fine sediment and zinc transport in the Derwent estuary (Margvelashvili *et al*. 2005). The model is fully coupled to the hydrodynamic model described above and solves advection-diffusion equations for the mass conservation of zinc and sediments taking into account bottom exchanges due to resuspension and deposition. It represents zinc as dissolved and sediment-attached fractions, and employs a first order kinetic reaction approach to simulate the contaminant cycling between the solid and liquid phases.

The sediment model was initialised with seabed sediment data (derived from the 2000 DEP/TAFI survey) and calibrated against measured suspended sediment concentrations. The calibrated model was applied to simulate fine sediment transport under varying river

Figure 5.3: Model grid and bathymetry of the Derwent estuary



Source: Herzfeld et al. (2005).

flow regimes. Under low and moderate flow conditions (Q<150 m^3/s), the model predicts a net upstream flux of fine sediment in the Derwent estuary due to tidal resuspension and baroclinic (salt-wedge) circulation. During high discharge events (Q>500 m^3/s), enhanced resuspension of bottom sediments in the upper and middle estuary develops a plume of concentrated suspension that propagates downstream with fresh water. As this plume and its associated freshwater layer mix with the underlying salt-wedge, sediments flocculate out and settle onto the sea bed (Margvelashvili *et al*. 2005).

The Derwent estuary is a stratified, salt-wedge estuary, with mean flow directed upstream in bottom waters and downstream in surface waters. As a result of this estuarine circulation, combined with tidal mixing, zinc gradually spreads along the estuary out of the area of highest contamination, with the net fluxes directed upstream above Elwick Bay and downstream below Tasman Bridge. During flood events, the model indicates that the contaminant maximum in the water column is flushed downstream and diluted in the lower estuary. While the concentration of the dissolved zinc drops during runoff events, total zinc levels increase sharply, due to enhanced resuspension of zinc attached to sediments. Thus, particulate zinc, along with bottom sediments, are transported from the upper estuary downstream to the middle and lower estuary during flood events. So one can think of the distribution of zinc in bottom sediments as being controlled by a balance between low to moderate flow periods, during which some zinc is slowly transported upstream by the estuarine circulation, and high flow events during which sediments and attached zinc are transported downstream (Margvelashvili *et al*. 2005).

A series of model runs were conducted to examine the ability of the model to reproduce observed distributions of dissolved and particulate zinc in the estuary water column under different assumptions. It is possible to assert with a fair degree of confidence that the estuary currently exports around 100 tonnes of dissolved zinc per annum, however the model alone is not able to discriminate between external loads, and efflux from bed sediments. For further discussion, see Margvelashvili *et al*. (2005).

5.1.4 WQIP management recommendations and actions

The WQIP recommended a number of management actions to further reduce heavy metal loads to the Derwent, manage contaminated sediments and reduce seafood safety risks. These include:

- further capture and remediation of contaminated groundwater and stormwater at the zinc smelter site (2009 status: in progress);
- development of dredging guidelines and protocols to limit the disturbance of contaminated sediments (2009 status: in progress);
- management of nutrient loads so as to avoid or limit low oxygen levels, which could cause a release of sediment-bound heavy metals (2009 status: under investigation);
- more detailed studies of heavy metals in fish and biota (2009 status: in progress); and
- improved community information and awareness about seafood safety (2009 status: completed).

5.2 Heavy metals: comparative survey of benthic communities – Derwent and Huon

A detailed survey of benthic invertebrate communities in the Derwent and Huon estuaries was carried out by scientists at the University of Tasmania, with support from NRM South (Macleod and Heliodoniotis 2005). The Huon provides an important reference point for the Derwent, as it has similar biogeochemical, physical and climatic characteristics, but is much less developed with respect to urban and industrial activities. Results indicated that, contrary to expectations, heavy metal contamination was not the overriding factor controlling benthic infaunal community composition in the Derwent estuary as a whole, although both heavy metals and organic enrichment had a significant influence in localised areas. Factors such as geomorphology, salinity, depositional character and organic content appeared to play a more significant role. Areas with high levels of heavy metals in sediments sustained abundant benthic invertebrate populations, suggesting that either the bioavailability of the metals was low, or that those organisms are not particularly sensitive to the high metal levels. The underlying mechanisms that would be required for the invertebrates to tolerate high metal levels in the sediments (i.e. excretion, complexation, or avoidance) may have significant implications for metal bioaccumulation in these and other organisms found in the Derwent. See Macleod and Heliodoniotis (2005) for further details.

The issue of bioaccumulation (the potential for heavy metal accumulation up the food chain), rather than toxicity or direct metal fluxes, is perhaps a more significant concern in the Derwent estuary, as suggested by continued high metal concentrations in shellfish and fish (**see Section 8.0**). To assess heavy metal bioaccumulation pathways up the food chain, it was recommended that a wider range of marine species be collected and analysed as part of a study at a range of different trophic levels (**see Section 5.3.3** for further discussion).

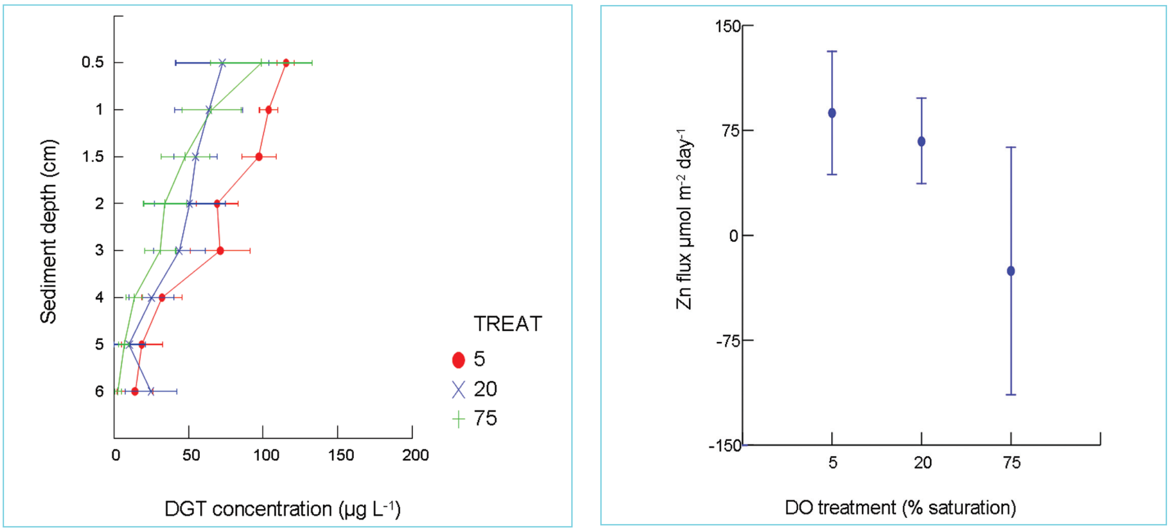
5.3 Heavy metals: Derwent Estuary Water Quality Improvement Plan (Stage 2)

The Stage 1 WQIP highlighted several key areas where further information and understanding of heavy metal processes in the Derwent was needed, and also recommended that estuarine models be extended to incorporate nutrients, as the nutrient status of the estuary could potentially influence the stability of sediment-bound metals. In 2007, the Australian Government supported a second stage *Water Quality Improvement Plan* (Stage 2 WQIP) to address these issues. Heavy metal investigations into sediment chemistry, bioaccumulation and toxicity are summarised below, while nutrient-response modelling is discussed in **Section 5.4**.

5.3.1 Heavy metal mobility under varying oxygen conditions

A key objective of the Stage 2 WQIP was an improved understanding of sediment processes – in particular how dissolved oxygen (DO) levels may affect the mobility and bioavailability of sediment-bound metals, and the degree to which sediments may act as a source or sink of heavy metals under current and potential future conditions.

Figure 5.4: The effects of changing DO levels (5%, 20% and 75%) of overlying water on zinc flux in a sediment core from Geilston Bay



Source: Banks and Ross (2009).

Plot a) (pore waters) shows sediment core depth profiles of zinc concentrations as measured by DGTs after 24 hrs deployment, and
Plot b) (overlying water column) shows the difference in metal concentration betweem the start and finish of the 4 hr incubation (relative to zero, error bars = standard error of mean, n=5)

This was achieved through a series of innovative laboratory and field-based experiments described below. See Banks and Ross (2009) for further details.

Laboratory incubations were conducted on sediment cores collected from a representative site in the middle reaches of the Derwent estuary, near the mouth of Geilston Bay. The DO content of the overlying water was manipulated in three treatments, at 75%, 20% and 5% oxygen saturation. A DO of 75% represents the ambient bottom water saturation level on the day the sediment was collected, DO of 20% represents an oxygen depletion event and mild hypoxia and a DO of 5% represents severe hypoxia such as can occur due to eutrophication events. Metal mobilisation was measured using diffusive gradient thin-film (DGT) probes and conventional pore water extraction techniques. In addition, a suite of geochemical techniques such as microsensor profiling, sediment characterisation and sulphide analyses were employed (Banks and Ross 2009).

Results showed that reductions in bottom water DO saturation can lead to significant increases in the aqueous fraction of zinc, copper and cadmium rendering these metals potentially more bioavailable. **Figure 5.4** illustrates how zinc concentrations in porewaters are influenced by varying DO levels and also suggests some net flux of zinc from sediments to the overlying water column under low DO conditions. Another interesting result was the relatively rapid rate of response between water column and sediment DO levels, with sediment DO levels showing a rapid depletion within 4 hours. This is likely due to the relatively high porosity of surface sediments from Geilston Bay.

This study also found that although sediments collected from the study site had very high concentrations of heavy metals – particularly zinc, copper and lead – the majority (90%) of the zinc and copper load remained insoluble in a weak acid solution (1M HCL) and would therefore most likely be biologically unavailable to organisms. Lead was found to be somewhat more acid-soluble, with up to 30% released. Measured pore water concentrations were in keeping with these results, and suggest that under steady state conditions toxicity levels for most metals, excluding zinc, are within recommended targets. These results indicate that the bulk of the total metals in the sediment are not bioavailable and as such, it is only the remainder that has the potential to become available under certain conditions (Banks and Ross 2009).

The Geilston Bay sediment core experiments demonstrated that altering the geochemistry of the sediment, in this case by lowering the DO saturation of the overlying water, significantly affected the availability of the remaining metals. Reducing the DO led to an increase in pore water concentrations of zinc, copper and cadmium, most likely as a result of the solubilisation of solid phase metals.

5.3.2 Whole sediment toxicity experiments using the native brittlestar *Amphiura elandiformis*

This study was designed to address several key information gaps identified in the Stage 1 WQIP, specifically:

- Can suitable benthic indicator species be identified as a measure of sediment 'health' in the Derwent estuary?
- How sensitive are these species to the heavy metal levels measured in Derwent estuary sediments and how does this compare to the *Interim Sediment Quality Guidelines* (ISQG) (ANZECC 2000)?

The native brittlestar, *Amphiura elandiformis* is an endemic Tasmanian ophiuroid species that has previously been identified as an indicator of sediment quality in south eastern Tasmanian estuarine systems, where it is widespread in clean soft sediments. It is found in some parts of the Derwent estuary and is abundant in the nearby Huon estuary. Copper was chosen as the reference toxicant for this study because it is a significant contaminant in the Derwent and is known to be highly toxic to a range of marine organisms (hence its common use as an antifoulant). In addition, it is one of the most widely researched toxicants, and as such toxicity data for a wide range of species is available. Copper also has a significantly shorter equilibration period when added to sediments in the laboratory, than other metals of interest in the Derwent estuary, and thus could be accommodated within the timeframe of the study. Two separate sediment toxicity assessments were conducted and are summarised below. A more detailed discussion of these experiments is presented in Eriksen *et al*. (2008).

Experiment 1: Artificial copper contamination of clean sediments – toxic response in brittlestar

Relatively uncontaminated reference sediments obtained from the Huon estuary were artificially contaminated (spiked) with copper in the laboratory. Experiment 1 adapted established protocols for sediment spiking to enable treatment and testing of larger sediment volumes for copper toxicity. The experiment was conducted such that three different copper concentrations were obtained (65, 270 and 1000 mg Cu/kg of sediment). Standard ten-day whole sediment toxicity tests were then carried out to evaluate the response of brittlestars to varying levels of copper contamination.

The toxicity results clearly indicated that the brittlestar *Amphiura elandiformis* is sensitive to elevated copper levels in sediments and is a useful environmental indicator species. At concentrations greater than 270 mg Cu/kg, there was a significant toxicity effect on these brittlestars and consequently it is extremely unlikely that this species would occur naturally under such conditions. Given that this species is mobile, it would remove itself from contaminated areas. Therefore where brittlestars are observed it is likely that sediment copper concentrations will be less than 270 mg Cu/kg. The sediment spiking test results confirmed the relevance of the ISQG for local Tasmanian conditions. No sub-lethal effects were observed where concentrations were at or below 65 mg/kg, while concentrations above 65 mg/kg caused significant behavioural effects, severe autonomy and mortality.

Experiment 2: Comparative assessment of brittlestar toxicity in Derwent estuary sediments

Contaminated sediments from the Derwent estuary were collected and assessed for toxicity using the brittlestar *Amphiura elandiformis*. Copper levels in the Derwent sediments were 165 mg/kg (i.e. lower than the mid-level spiking undertaken in Experiment 1) however, the Derwent sediments also contained elevated levels of zinc, mercury, lead and cadmium. The brittlestar response in the Derwent sediments was indicative of a high degree of toxicity, as compared to the response observed for comparative levels of copper in Experiment 1. It is likely that this increased response in the Derwent sediments was due to the presence of other toxicants, contributing to a synergistic effect.

These experiments developed innovative techniques for spiking and testing large volumes of sediments and offer a promising approach for investigating the toxicity of heavy metals. Additional tests were also undertaken to investigate the effect of sediment manipulations (sieving, defaunating) to evaluate whether different sediment treatment methodologies during the experiments had an influence on the brittlestar toxic response. The experiments provided basic metal toxicity data for the brittlestar species (*Amphiura elandiformis*) and confirmed the suitability of this species as a potential indicator of sediment health. The results also suggest that the ISQG for copper appear to be appropriate to south eastern Tasmanian waters, and indicate that Derwent sediments from the middle estuary may be toxic to more sensitive benthic species such as the native brittlestar due to synergistic effects.

5.3.3 Survey of baseline metal levels in marine species

A pilot study was undertaken into baseline heavy metal levels in selected faunal trophic groups from the Derwent estuary and surrounding areas by Swadling and Macleod (2009). Samples were collected from three sites within the Derwent (Geilston Bay, Ralphs Bay and the Upper Derwent), as well as from reference sites in the Huon estuary and offshore from Bruny Island. Seventy-one samples were collected, processed and analysed for a range of heavy metals including arsenic, copper, lead and zinc. Unfortunately analysis of mercury was beyond the funding available for this study. The analyses focused on the following trophic groups:

- benthic deposit feeders (e.g. polychaetes, amphipods, ghost shrimp, molluscs);
- epibenthic deposit feeders (e.g. crabs, seastars, molluscs/snails);
- epibenthic filter feeders (e.g. oysters, mussels, tunicates);
- predatory species (e.g. polychaetes, ribbon worms, skates and dogfish);
- primary producers (e.g. phytoplankton, macroalgae, seagrass); and
- pelagic grazers (e.g. zooplankton).

This survey provided a broad snapshot of the relative metal burdens associated with the main biotic groups in the Derwent estuary, providing useful baseline data with which to assess differences in metal loadings between regions, sites and species. While it was limited in both temporal and spatial representation, it is highlights some interesting differences between trophic levels and raised some significant questions. On the whole, the study suggests that environmental conditions (i.e. sediment loadings) provide a good indication of the infaunal/epifaunal loads for secondary trophic level organisms, however the picture is more complicated with the higher trophic levels. Furthermore, the lower order trophic levels did not provide a clear explanation for the metal levels in higher order species, and it is clear that further information is needed to put these results into context. In order to track bioaccumulation pathways, a comprehensive dietary analysis of key species, coupled with detailed ^{15}N analysis to assign trophic level, was recommended as a promising approach. The study confirmed that oysters are sensitive indicators for zinc contamination, and identified several other species that may also be suitable bioindicators of metals levels in the Derwent estuary (e.g. ascidians). See Swadling and McLeod (2009) for details.

5.4 Nutrients: Derwent Estuary Water Quality Improvement Plan (Stage 2)

In 2007, the Australian Government supported a second stage *Water Quality Improvement Plan* (Stage 2 WQIP) that included the development and implementation of a nutrient response model and the use of this model to assess a series of nutrient management scenarios.

Preventing eutrophication is a key management goal of the DEP (DEP 2009). Eutrophication of aquatic systems occurs when inputs of nutrients and organic matter increase over time, and may result in 'blooms' of nuisance and toxic algal species, nuisance weed growth, loss of seagrass beds, low DO levels, fish kills and odours. In the Derwent, this may be compounded by the release of sediment-bound heavy metals during low oxygen events. See **Section 6.1** for details.

A review of chlorophyll *a* and nutrient data collected through the DEP's ambient water quality monitoring program between 2003 and 2008, together with observations from other sources, suggests that the estuary may be experiencing some symptoms of increasing eutrophication, such as:

- reported increases in intertidal macroalgae (*Ulva*) beds in the middle estuary, and filamentous/epiphitic algae in the middle and upper estuary;
- observations of extensive subtidal filamentous algal beds in Ralphs Bay (Aquenal 2008a); and
- elevated chlorophyll *a* levels throughout all upper estuary monitoring sites during autumn 2008 (i.e., the first time chlorophyll *a* measured above ANZECC (2000) trigger level of 4 mg/L simultaneously at these sites).

The risk of eutrophication may be exacerbated by differences in river flows. Decreased River Derwent flow can cause a decline in total nitrogen (TN) loading (**see Section 6.1.8**) however, low river flow can also contribute to declining DO levels at depth in the upper estuary, which can result in the release of nutrients from estuary sediments. Differences in River Derwent flow also influence organic loading and the aquatic light environment, which also influence eutrophication risk. Recent observations associated with low river flow include:

- increasing periods of low DO at depth in the upper estuary (summer and autumn) and occasional episodes of low DO at sites in the middle and lower estuary; and
- increasing concentrations of ammonium and dissolved reactive phosphate at depth, particularly in the upper estuary.

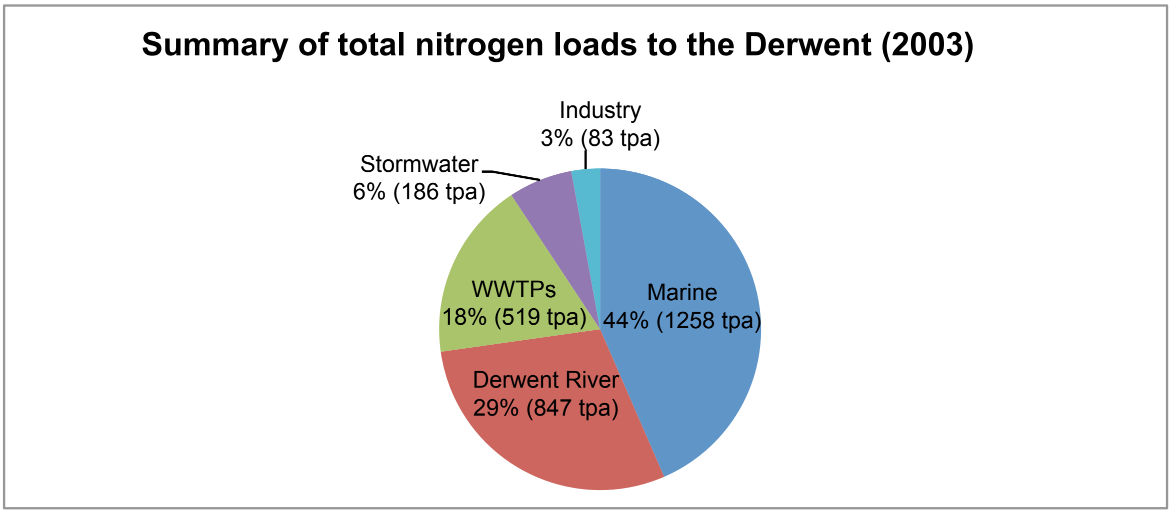
The likelihood of Derwent estuary eutrophication may also increase due to higher nutrient loads entering the estuary entrance, such as increasing ammonia levels observed at depth (possibly associated with aquaculture expansion in the channel) (Wild-Allen *et al*. 2009).

Further work is recommended to confirm and quantify some of the above observations and trends.

5.4.1 *Nutrient sources and loads*

As part of the nutrient response model development, nutrient inputs to the estuary were quantified, including wastewater treatment plants, industries, urban stormwater, the River Derwent catchment and marine waters, as shown in **Figure 5.5**. Marine waters and

Figure 5.5: Estimated annual nitrogen loads to the Derwent estuary in 2003 (in tonnes)



Source: Wild-Allen et al. (2009)

the River Derwent catchment (above New Norfolk) accounted for the majority of nitrogen loads, followed by WWTPs, stormwater and industries.

Nutrient loads associated with WWTPs and industries (see **Section 4.0**) tend to be relatively constant from year to year. In contrast, nutrient loads associated with catchment run-off may vary considerably from year to year (Wild-Allen *et al*. 2009). During an average River Derwent flow year (e.g. 2003), nutrients contributed an estimated 29% (847 tonnes/year) of the annual nitrogen load to the system, while during a low flow year (e.g. 2007) this contribution may drop to 7% (202 tonnes/year).

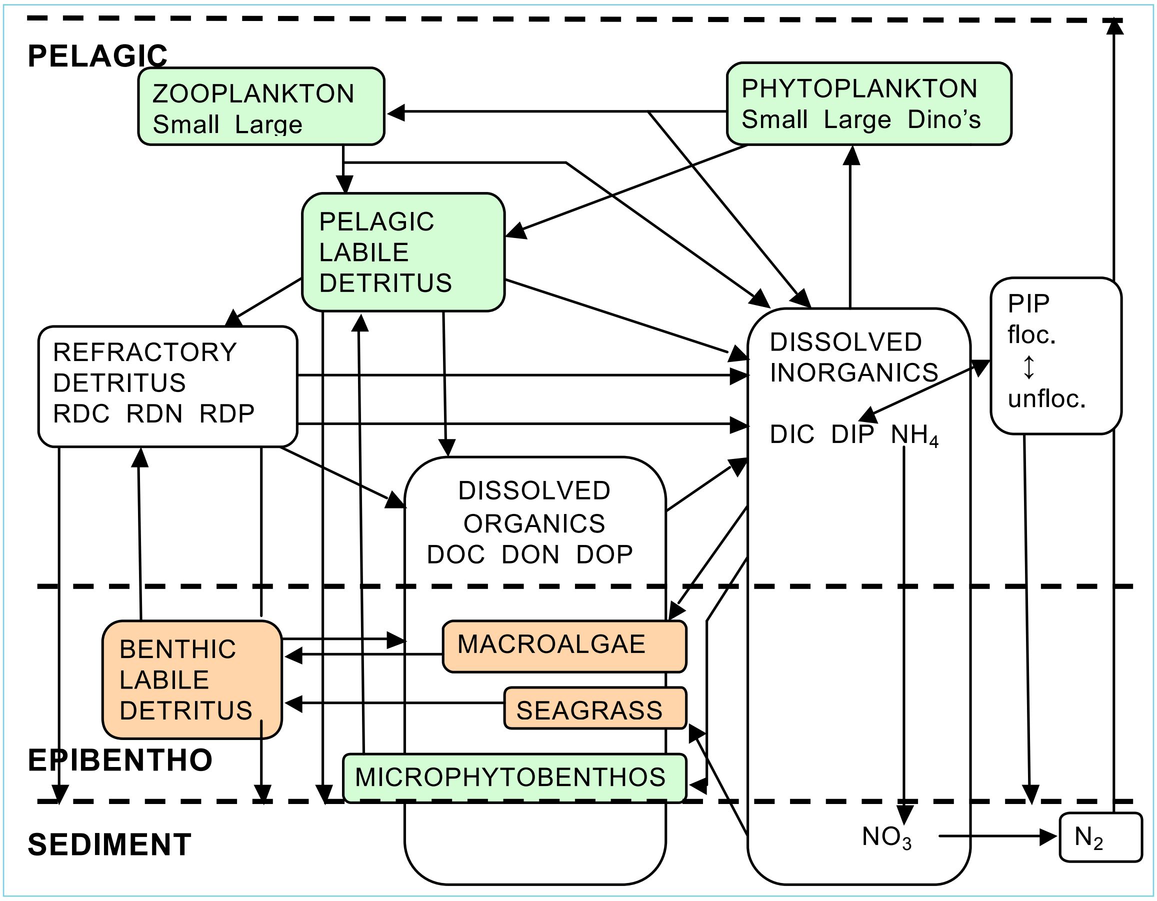
Marine sources of nutrients are derived from a combination of processes, particularly seasonal (winter) northerly movement of nutrient-rich Southern Ocean waters as well as nutrients associated with aquaculture activities. Nutrient dynamics associated with aquaculture production have been recently investigated through a major Aquafin-CRC project that included the development of detailed hydrodynamic and biogeochemical models for the Huon/Channel area (Volkman *et al*. 2009). A finding of particular relevance to the Derwent estuary was that the net transportation of water between the two systems is from the Channel northwards into the Derwent, carrying with it nutrients derived from the increasing numbers of salmon farms. This effect has been observed at DEP monitoring station B1 – situated in the lower Derwent estuary east of the Tinderbox Peninsula – where ammonia levels have doubled since 2003 (Wild-Allen *et al*. 2009). It is difficult to partition marine nitrogen inputs between natural and aquaculture related sources, as it is unclear how much of the Channel-derived nutrients are processed within the Channel and/or entrained within the Derwent or Storm Bay. However, the Aquafin CRC study indicates that fish farm wastes accounted for an estimated 843 tonnes of nitrogen in 2002 and were projected to reach 1747 tonnes in 2009, based on planned aquaculture expansion (Volkman *et al*. 2009).

5.4.2 Derwent estuary nutrient response model

A key objective of the Stage 2 WQIP was to implement a high resolution 3D biogeochemical model of the estuary, calibrate the model against observations taken throughout the region and better characterise the cycling of carbon, nitrogen, phosphorus and DO in the estuary. The calibrated biogeochemical model (based on 2003 baseline conditions) was then used for scenario simulation of alternative management strategies and to reconstruct former conditions in the estuary prior to urbanisation, as described in **Section 5.4.3**. The following discussion is derived from the executive summary of Wild-Allen *et al*. (2009a). See the full report for details.

The CSIRO EMS (Environmental Monitoring Suite) includes a 3D coupled hydrodynamic, sediment and biogeochemical model. In 2005 the hydrodynamic and sediment models were implemented for the Derwent estuary and calibrated against observations made in 2003 to simulate a seasonal cycle of hydrodynamics, sediment transport and absorption/desorption of zinc. In this project, the existing models were augmented with the biogeochemical model in EMS to simulate the cycling of carbon, nitrogen, phosphorus and associated DO, through dissolved and particulate organic and inorganic phases. The model includes four types of phytoplankton, two types of macrophytes, two types of zooplankton and four types of particulate detritus; dissolved organic and inorganic nutrients and carbon are also included. These model components are illustrated in **Figure 5.6.**

Figure 5.6: Schematic diagram of the biogeochemical model compartments, links and vertical layers



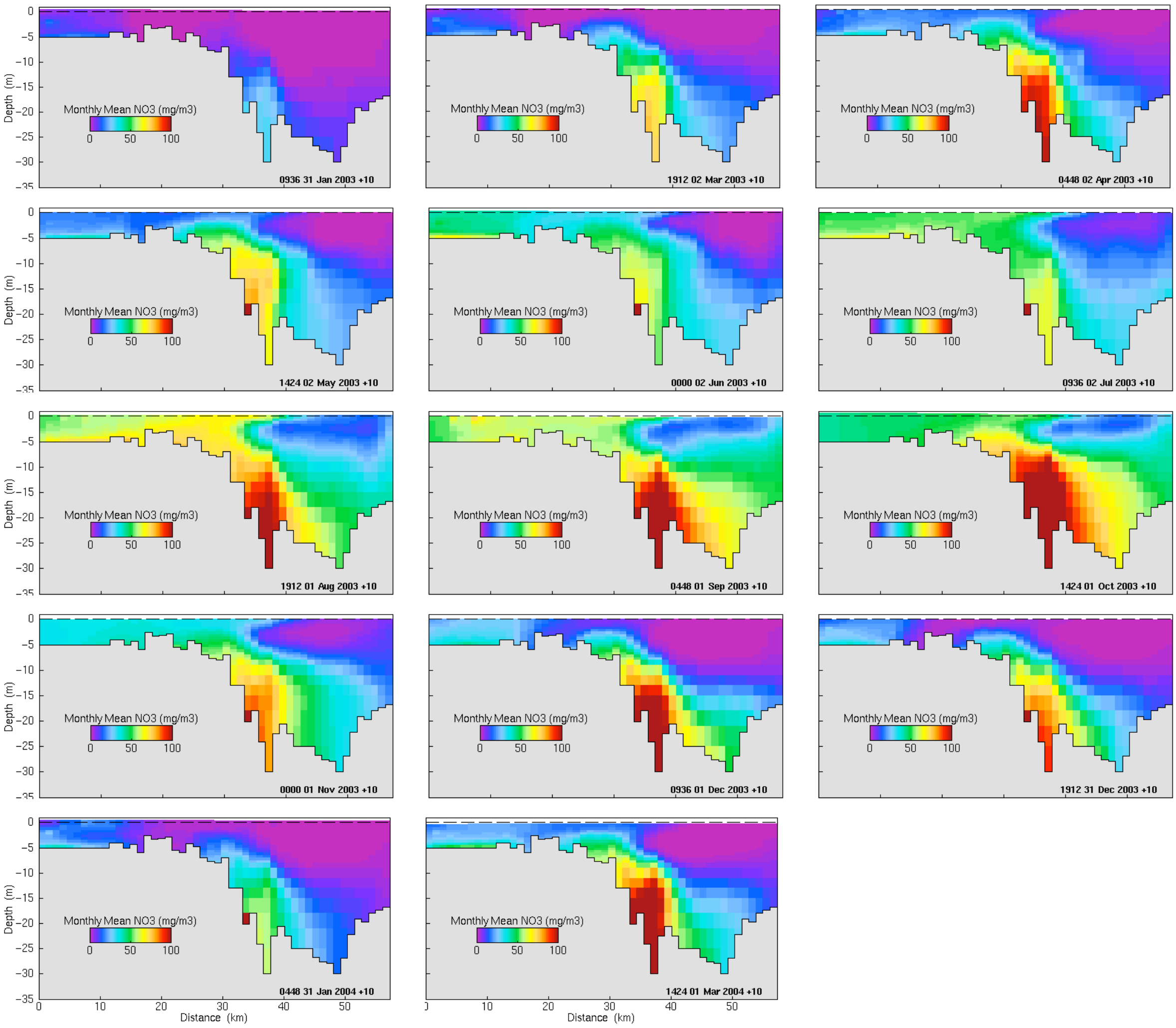
Green compartments have fixed nutrient content at Redfield ratio (106C:16N:1P); brown compartments are fixed at Atkinson ratio (550C:30N:1P).

Source: Wild-Allen et al. (2009).

Model parameters were derived from observations, literature values and previous model simulations. The model ran from January 2003 for 14 months with tracer concentrations initialised from observations of nutrients, phytoplankton and DO. Other model variables were initialised with uniform low concentration. The hydrodynamical model was forced with River Derwent flow, local meteorology and incident irradiation. For the biogeochemical model, boundaries at New Norfolk and across the estuary at Iron Pot were implemented with an upstream condition for inflowing concentrations of model tracers specified from time series derived from observations. Point source nutrient loads into the estuary in 2003 from industry and wastewater treatment plants (WWTPs) were estimated from data supplied by the DEP/DPIPWE, local industry and local government. Stormwater loads were derived from greater Hobart catchment modelling results and observations provided by the DEP.

The model was validated against observations made throughout the estuary in 2003 obtained from the DEP. Observations of nitrate, ammonia, dissolved inorganic phosphorus (DIP), chlorophyll and DO in surface and bottom waters were directly comparable with the model output. There were no observations of macrophytes, phytoplankton group assemblages or zooplankton for 2003, although some information on broad patterns was gathered. Validation criteria were set for the conservation of mass and reproduction of the observed timing and amplitude of the seasonal cycle in dissolved nutrients, chlorophyll and DO. The model achieved all validation criteria and simulated the observed biogeochemical dynamics of nitrate, ammonia, DIP, chlorophyll, dissolved organic carbon (DOC) and DO in most parts of the estuary very well. In the upper estuary, complex channel bathymetry was not well resolved by the relatively coarse model grid and model results in this area should be treated with more caution.

Figure 5.7: Cross section of monthly mean concentration of nitrate along the axis of the Derwent estuary (from New Norfolk to Iron Pot)



Source: Wild-Allen et al. (2009).

Model results show a persistent salt-wedge structure in the upper estuary which intersects the sea bed upstream of Elwick Bay (near ambient water monitoring site U7). Modelled nutrient concentrations were greatest in the bottom waters of the mid-estuary adjacent to the salt wedge front, as illustrated in **Figure 5.7**. Nutrients appear to accumulate in this area from point source loads and remineralisation of organic material which recirculates in the estuarine currents. Simulated nutrient concentrations were elevated in winter and reduced in surface waters in other seasons due to phytoplankton assimilation. DIP concentrations exceed Redfield ratio in summer indicating that modelled primary production in the estuary is controlled by access to nitrogen and irradiance for photosynthesis.

Modelled chlorophyll concentrations were highest in the mid-estuary and along the shoreline in regions of elevated nutrient supply. Sustained periods of high chlorophyll occur in all seasons in subregions of the estuary depending on the modelled availability of light and nutrients. In the upper estuary, coloured dissolved organic matter (CDOM) and opaque industry effluent limit the propagation of light and photosynthesis through the water column, and modelled chlorophyll concentrations are generally low. Simulated phytoplankton biomass showed seasonal succession with dinoflagellates dominating in summer and autumn, large phytoplankton in winter and mixed populations in spring, throughout much of the estuary.

Modelled photosynthetically active radiation reaching the epibenthos was greatest in the shallow waters of the lower estuary and Ralphs Bay, in Elwick Bay and in shallow waters of the upper estuary. The model favoured macrophyte growth in these areas, however it does not resolve gradients in substrate type, disturbance or recruitment and results should be interpreted as potential rather than actual areas of macrophyte growth. The model simulated potentially favourable conditions for seagrass growth in Ralphs Bay whilst there was the potential for epiphytic macroalgae to dominate in the middle and upper estuary due to elevated water column nutrients.

Modelled DO levels were reduced in bottom waters in the estuary, particularly in autumn. Regions of low DO saturation were simulated adjacent to the salt wedge front, similar to the distribution of elevated nutrient concentration and likely associated with local remineralisation of organic material. Modelled surface sediment DO concentrations were lowest in the mid and lower reaches with 10 percentile monthly concentrations falling below 40% saturation in autumn and spring.

The modelled nitrogen budget for the estuary showed that in 2003 the depth-integrated daily flux of nitrogen across the marine boundary was the largest flux into the region (44%), followed by the Derwent River (29%), WWTP inputs (18%), stormwater (6%) and industrial loads (3%). The largest loss of nitrogen from the estuary is thought to be through denitrification (59%) with depth-integrated daily flux of nitrogen across the marine boundary accounting for 41% of export. During 2003 the net accumulation of nitrogen in the estuary was relatively minor (44 tN/yr), which suggests the estuary was in near steady state in regards to this nutrient.

Modelled annual mean chlorophyll concentrations in the top 0-11 m of the water column (for 2003) were used to classify the estuary by area as 18.3% mesotrophic and 81.7% eutrophic, as shown in **Figure 5.8**. The modelled mesotrophic areas (with annual mean chlorophyll 1-3 µg/L) include the upper estuary where light limits phytoplankton growth, and the lower estuary and southern Ralphs Bay, where near-surface nutrient concentrations were depleted for much of the year. The modelled eutrophic region (with annual mean chlorophyll >3 µg/L) included the mid- and lower estuary and the remainder of Ralphs Bay. (Note: the >3 ug/L definition of eutrophic used in this study is somewhat more conservative than the 4 µg/L ANZECC trigger levels for chlorophyll referred to in **Section 6.1.1**).

Recommendations for future work include utilising modern instrumentation in the estuary to collect biogeochemical observations over a greater diversity of time and space scales. In addition, observations of phytoplankton, zooplankton and macrophyte properties would allow these aspects of the model to be better constrained. This study suggests denitrification plays a key role in maintaining the 'health' of the ecosystem and it is important to validate the algorithms and parameterisations included in the model with more detailed observations. The current modelling study is limited to a specific year and set of environmental conditions. It would be wise to extend the simulated period to place it in the context of natural inter-annual variability. This could be efficiently achieved through the implementation of a near real time operational biogeochemical model which is routinely updated with the most recent advances in science.

5.4.3 Derwent estuary nutrient response model: scenario testing

The calibrated 2003 biogeochemical model (Wild-Allen *et al*. 2009) was used to address three management scenarios. The scenarios were:

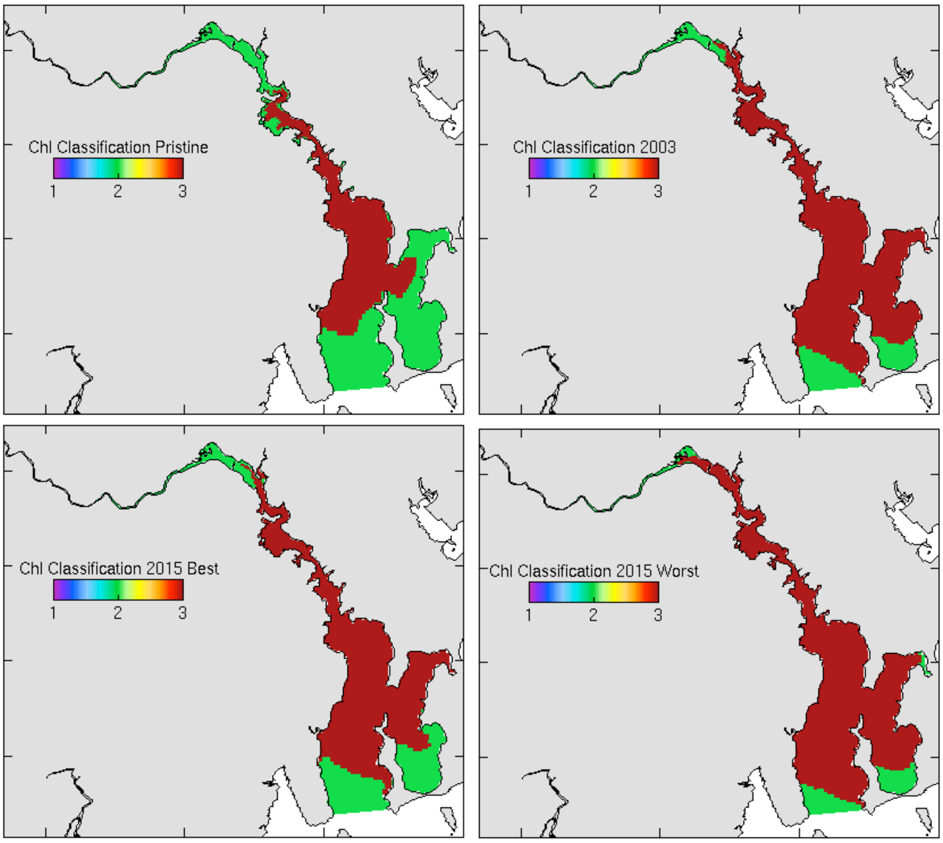
1) a near-pristine scenario excluding anthropogenic nutrient loads;
2) a 2015 active management scenario assuming improved treatment of industrial effluent, WWTP reuse, and marine nutrients constrained to 2003 concentrations; and
3) a 2015 business-as-usual scenario including reduced River Derwent flow, improved treatment of industrial effluent, increased WWTP loads and marine nutrients increased to observed 2008 concentrations.

The following discussion is derived from Wild-Allen *et al.* (2009b). All model simulations demonstrated broad similarities in seasonal nutrient characteristics and phytoplankton succession with highest biological productivity and nutrients simulated in the middle reaches of the estuary. There appears to be natural accumulation of nitrogen in the upper and middle estuary in winter and persistent elevated chlorophyll concentrations in the middle reaches associated with the dynamics of the salt-wedge front. There were also lower DO levels in bottom waters and surface sediments (seasonal mean saturation 40-60%) in the deeper parts of the middle to lower estuary, particularly in autumn, but also in spring for all scenarios.

Modelled annual mean near-surface chlorophyll concentrations, show that the estuary under the current River Derwent flow regime and without any anthropogenic loads (i.e. near-pristine scenario) would be predominantly mesotrophic (54%) and partially eutrophic (46%). In 2003 eutrophic conditions occurred over 82% of the region and this increases to 87% in the 2015 business-as-usual scenario. In the 2015 active management scenario the eutrophic area of the estuary was reduced to 72% of the region with the remaining area classified as mesotrophic. See **Figure 5.8** for details.

The active management scenario simulation had lower dissolved inorganic nitrogen (DIN), DIP and chlorophyll

Figure 5.8: Regional chlorophyll derived classification for three scenarios and the 2003 Derwent estuary calibrated model simulation (summarized in table as % area) based on annual mean chlorophyll in near surface (0-11m) layer after Smith (1998). In the figure legend 1 is oligotrophic (purple) 2 is mesotrophic (green) 3 is eutrophic (dark red)



	Near pristine scenario	**2003 simulation**	**2015 active management scenario**	**2015 business-as-usual scenario**
Oligatrophic (<1mg Chl /m3)	0.0	0.0	0.0	0.0
Mesotrophic (1-3mg Chl /m3)	54.1	18.3	27.9	12.7
Eutrophic (>1mg Chl /m3)	45.9	81.7	72.1	87.3

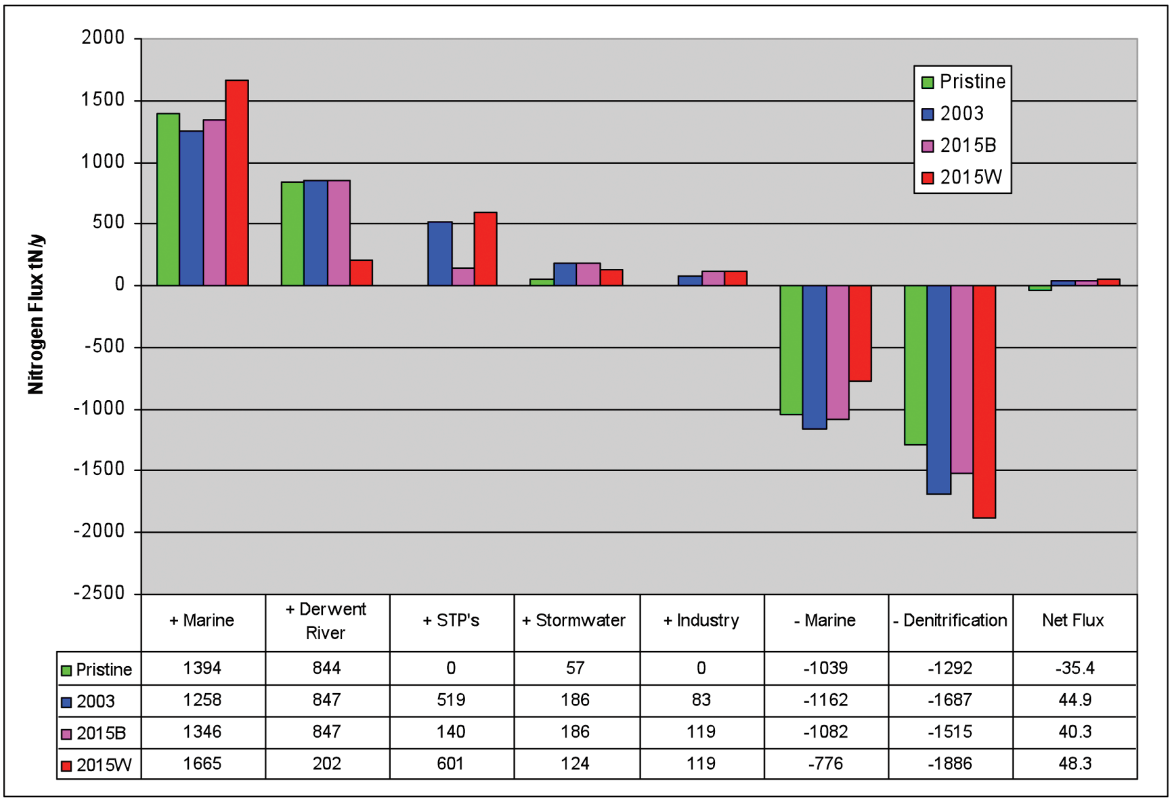
Source: Wild-Allen et al. (2009).

concentrations, and higher DO levels in bottom water and surface sediment, than the 2003 calibrated model. The active management scenario simulation demonstrated the greatest water quality improvement in the middle reaches of the estuary compared to the 2015 business-as-usual scenario and the 2003 calibrated model.

The business-as-usual scenario had higher DIN, DIP and chlorophyll concentrations and lower DO levels in bottom water and sediment than the 2003 calibrated model. The lower River Derwent flow in the 2015 business-as-usual scenario allowed excursion of the marine salt-wedge upstream into the estuary and there was also an enhanced influx of nutrients across the marine boundary. In the business-as-usual scenario the model favoured seagrass and macroalgae growth in shallow parts of the upper and middle reaches of the estuary and Ralphs Bay due to a combination of low attenuation (and increased propagation of light) and elevated sediment nutrient concentrations.

Nitrogen budgets for all scenarios showed contrasting nitrogen inputs from marine, river and point source loads that were very nearly balanced by denitrification and marine export, as illustrated in **Figure 5.9**. Modelled denitrification was found to be a key process in

Figure 5.9: Annual nitrogen flux into and out of the estuary, including total denitrification and net flux, for the three model scenarios and the 2003 Derwent Estuary calibrated model simulation



	+ Marine	+ Derwent River	+ STP's	+ Stormwater	+ Industry	- Marine	- Denitrification	Net Flux
🟩 Pristine	1394	844	0	57	0	-1039	-1292	-35.4
🟦 2003	1258	847	519	186	83	-1162	-1687	44.9
🟪 2015B	1346	847	140	186	119	-1082	-1515	40.3
🟥 2015W	1665	202	601	124	119	-776	-1886	48.3

Source: Wild-Allen et al. (2009b).

maintaining the health of the estuary and whilst this component of the model is consistent with sparse data, improved observation and validation of the modelled algorithms is a priority for future work. The modelled budgets suggest that a decline in denitrification efficiency could result in a rapid accumulation of nitrogen, and an associated decline in water quality, in the estuary.

This study has shown that interactions between river flow, nutrient sources and water quality are complex but well-simulated by the biogeochemical model. Low sediment DO levels were found to vary with total nitrogen load into the estuary, provisionally, by an exponential relationship. To achieve sediment DO oxygen concentrations in excess of 40% saturation over 95% of the region for 98% of the year, nutrient loads to the estuary should be constrained to levels proposed in the 2015 active management scenario (under average River Derwent flow conditions). Under low River Derwent flow conditions, nutrient loads to the estuary would need to be reduced further to avoid low DO in estuary sediments. This analysis could be improved by excluding the large refractory dissolved organic nitrogen component of total nitrogen and repeating each scenario simulation for a range of river flows (Wild-Allen *et al.* 2009b).

5.5 Nutrients: sources, transformation and fate of carbon and nitrogen in the Derwent estuary

In 2006, scientists at the Tasmanian Aquaculture and Fisheries Institute of the University of Tasmania were awarded an ARC-Linkage grant to investigate how nutrients are processed in the Derwent estuary. This four-year project is focusing on the role of sediments in nutrient processing and using stable isotopes to trace how nitrogen and carbon are cycled through the system. The project will document how conditions in the upper estuary have changed in response to a major reduction in organic loading from the Boyer paper mill – a unique opportunity to study ecosystem recovery. The project also includes scientists from the University of Melbourne and Southern Cross University, and is supported by the DEP and Norske Skog Boyer (J. Ross *pers. comm.*).

6.0 WATER QUALITY

The Derwent Estuary Program (DEP) coordinates two whole-of-estuary estuarine water quality monitoring programs: a monthly ambient water quality monitoring and a recreational water quality monitoring program. The ambient water quality monitoring program is a cooperative initiative between the State Government and two industries (see **Section 6.1** for details), while the recreational water quality program is a cooperative initiative between the State Government and six councils (see **Section 6.2** for details). A number of other localised or issue-specific monitoring programs have also been carried out, such as the DEP rivulet and stormwater monitoring program described in **Section 4.3.1**, and the localised or process-focused initiatives described in **Section 5**.

6.1 Ambient water quality monitoring

Ambient water quality monitoring in the Derwent estuary commenced in 1972, but has evolved and changed considerably over the years in terms of the number and location of sampling sites, the parameters measured and the frequency of monitoring. This report focuses on water quality data collected between January 2003 and December 2008. See previous *State of the Derwent Estuary* reports for a review of water quality data collected prior to 2003 (Coughanowr 1997, Green and Coughanowr 2003).

Since 2003, ambient water quality monitoring has been carried out on a monthly basis at up to 28 sites throughout the Derwent estuary by Norske Skog Boyer, Nyrstar Hobart and the State Government. Monitoring locations are shown in **Figure 6.1**. Monitoring is carried out by three different boat-based sampling parties, but is co-ordinated to occur on the same day each month. At each site, *in-situ* field measurements are taken using calibrated sensors for temperature, salinity, pH, dissolved oxygen and turbidity. Water clarity is also measured using a secchi disk. Surface and bottom water samples are collected for analysis of true colour, total suspended solids (TSS), total and dissolved nutrients, organic carbon and zinc. At most sites, depth integrated samples are also collected for chlorophyll a using a plastic tube. All water samples are analysed at Analytical Services Tasmania (AST), a NATA-accredited laboratory.

There have been several changes in the design of the ambient monitoring program between 2003 and 2008, as described below (see **Table 6.1** for details):

Phase 1: Jan 2003 – June 2005 (30 months)

- Full range of parameters.
- Sampling at 2 to 3 depths.
- Data set was used to develop and calibrate estuarine models, as described in **Section 5**.

Phase 2: Oct 2006 – Sept 2008 (24 months)

- Slight reduction in parameter set (omitted nitrite).
- Sampling at 2 depths.
- Data set used to provide pre- and post- water quality conditions associated with the new wastewater treatment plant at Norske Skog (see **Section 4.2.2**) and to support ARC-Linkage nutrient process studies (see **Section 5.5**).

Phase 3: October 2008 – Sept 2010 (current program – 24 months)

- Slight reduction in parameter set (omitted dissolved zinc and DOC).
- Sampling at 2 depths.
- Reduction in number of sampling sites to a 'skeleton set' focusing on mid-channel and boundary sites. This will provide continuity until full monitoring recommences in October 2010.

While the majority of sites have been monitored for most parameters over the full 2003 to 2008 time period, there was a three-month gap between Phase 1 and Phase 2 (July – Sept 2006), which could result in a slight bias in the interpretation of results for parameters that have strong seasonal patterns. See **Section 6.1.2** and **6.1.9** for further discussion.

For discussion purposes, the estuary is separated into three geographical areas. The *upper estuary* is the region from New Norfolk to the Bridgewater Bridge and includes monitoring sites NN, U19, U16/17, U14 and U12. The influence of freshwater inflows is strongest in this section of the estuary, and bottom waters are dominated by marine sources as far as New Norfolk. This is a 'salt wedge' feature, whereby the estuary is stratified with a freshwater layer overlying denser saltwater. At times of high River Derwent flow the salt wedge is pushed downstream, and freshwater conditions can extend to the seafloor. The *middle estuary* is the area between Bridgewater and the Tasman Bridge (including sites U7, U5, U4, U3 and U2). The middle estuary features many small bays and coves (sites PWB, NTB5, NTB9, NTB13, GB, CB, and LB), and is the most industrialised and urbanised section of the estuary. In the middle estuary stratification between fresher surface water and saltier marine waters is also frequently observed, particularly during periods of high river flow. When there is a strong difference in salinity between these water masses, this feature is called a halocline and results in poor vertical mixing between these waters. The *lower estuary* is the area between the Tasman Bridge and the mouth of the estuary between Iron Pot and Tinderbox (including sites G2, E, C, B1, B3, and B5). This part of the estuary is marine dominated, but is still subject to the influence

Figure 6.1: Ambient water quality monitoring sites in the Derwent Estuary (2003-2008)

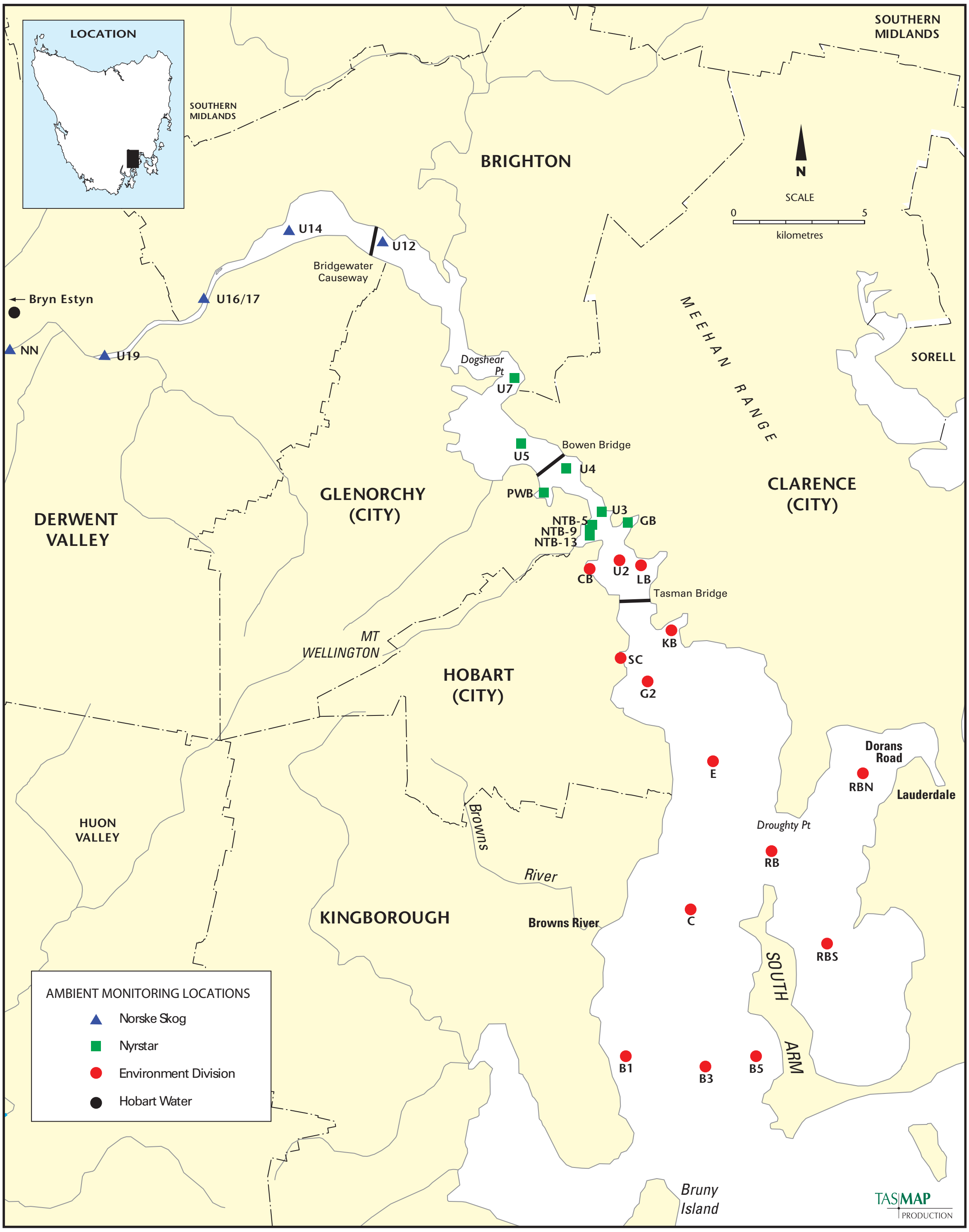


Table 6.1: Parameters measured at different ambient water quality monitoring sites in the Derwent estuary

Partner/Site	# sites depths	Water temperature	Salinity conductivity	pH	Dissolved Oxygen	Secchi Disc Depth	True colour	TSS (0.45)	Chl *a* †	Nitrate + nitrite	Filtered Reactive P	Ammonia + Ammonium	Total N	Total P	Total Zn	Dissolved Zn	Total Organic Carbon	Dissolved Organic Carbon	Nitrite
Norske Skog Boyer	5, 2																		
NN		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
U19		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
U16/17		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
U14		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
U12		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
Nyrstar Hobart Smelter	9, 3*																		
NTB 5		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3,	1,2	1,2	1,2	1,2	1,2	1,2	1,2,3	1,2	1,2	1,2	1
NTB 9		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3,	1,2	1,2	1,2	1,2	1,2	1,2	1,2,3	1,2	1,2	1,2	1
NTB 13		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3,	1,2	1,2	1,2	1,2	1,2	1,2	1,2,3	1,2	1,2	1,2	1
PWB		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3,	1,2	1,2	1,2	1,2	1,2	1,2	1,2,3	1,2	1,2	1,2	1,2
U3		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3,	1,2	1,2	1,2	1,2	1,2	1,2	1,2,3	1,2	1,2	1,2	1
U4		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
U5		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3,	1,2	1,2	1,2	1,2	1,2	1,2	1,2,3	1,2	1,2	1,2	1
U7		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
GB		1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1
Derwent Estuary Program /Env. Div.	14, 3*																		
B1		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
B3		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
B5		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1
C		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1
RB		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1
RBN		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
RBS		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1
E		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
G2		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1
SC		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1
KB		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1
U2		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1
CB		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1
LB		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1

† Surface sample only

* Surface, middle and bottom where halocline detected. Surface and bottom only where halocline is absent

MONITORING PHASES: 1= Phase 1 (Jan 2003 – June 2005); **2 = Phase 2** (Oct 2006 – Sept 2008); **3 = Phase 3** (Oct 2008 – Dec 2008 (current)) of freshwater flows in the upper 10 m of the water column. The water column below 10 m is very stable and typically well mixed. The lower estuary also includes several bays and coves (sites KB, SC), including Ralphs Bay (sites RBN, RBS, and RB).

6.1.1 Quality Assurance and Quality Control (QA/QC)

Quality assurance (QA) is the process whereby field sampling and laboratory activities are carried out in a way that ensures the generation of accurate and reliable results. The DEP monitoring program achieves this through the use of standard operating procedures that are used by the three different sampling operators. These procedures have been reviewed, revised and recirculated on a regular basis throughout the history of the program. The majority of collected water samples are analysed by Analytical Services Tasmania (AST), a NATA-accredited laboratory, to ensure that consistent analytical methods are used. For those parameters measured using field-based equipment (salinity, temperature, dissolved oxygen, pH and chlorophyll-a), regular inter-calibration exercises have been carried out between operators.

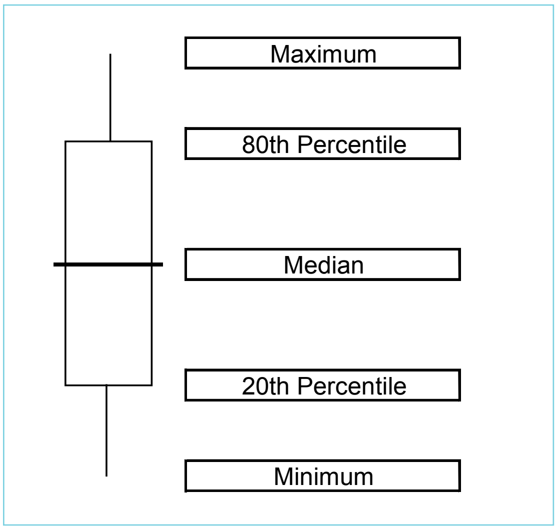
Quality control (QC) is a set of activities or techniques used to ensure that all quality requirements are being met. Specific control samples are used to achieve this, including the use of an artificial seawater standard (prepared at AST) for use as 'nutrient field blanks' (treated like a collected sample and filtered in the field) and 'nutrient trip blanks' (sample bottles that are not opened, but are handled and stored in the same manner as other samples). 'Metal field blanks' and 'metal trip blanks' are also used, consisting of deionised water.

6.1.2 Review of ambient water quality data

Derwent estuary water quality data collected over the six-year period between January 2003 and December 2008 are reviewed in the following sections. For the purposes of general discussion, 'box and whisker' diagrams are provided for key parameters, providing a comparative summary of the key statistics for each site (i.e. median, maximum, minimum and 20th and 80th percentiles, as illustrated in **Figure 6.2**).

For each parameter, two box and whisker plots are provided, one summarising data in surface water samples and the other in bottom water samples. These reflect the differing water chemistry typically observed in the two water masses, particularly at middle and upper estuarine sites. Each box and whisker plot is divided into two sections by a dashed vertical line. Mid-channel monitoring sites are displayed on the left-hand side of the plot, starting at New Norfolk (NN) and ending at the estuary mouth (B1, B3 and B5). Monitoring data for estuary bays and coves, including Ralphs Bay, are provided on the right-hand side of the plot (PWB to RBS).

***Figure 6.2:* Box and whisker plot example, illustrating hypothetical maximum, minimum, median and 80th and 20th percentiles.**



Sections 6.1.3 through **6.1.9** provide a general discussion of the major water quality parameters, with an emphasis on the spatial distributions of median values, while **Section 6.1.10** attempts a trend analysis between three comparable monitoring periods from 2000 to 2008. In reviewing this data, it should be noted that due to changes in the sampling program over the six year period – as well as several runs missed on account of poor weather – there is slight seasonal bias in the data. In particular, there were approximately a quarter fewer sampling runs in winter as compared to other seasons.

Ambient water quality results for key physical and chemical parameters from the Derwent estuary are compared to National Water Quality guidelines (ANZECC 2000) in **Table 6.2** and in the relevant sections. It should be noted that the ANZECC guidelines were developed as default trigger values for slightly disturbed estuarine ecosystems in south east Australia, and may not be entirely relevant to Tasmanian ecosystems as they do not contain any Tasmanian data. As such a precautionary approach should be adopted when applying these default trigger values to the Derwent estuary.

6.1.3 Salinity, temperature, dissolved oxygen and pH

Salinity, temperature, dissolved oxygen and pH influence the types and rates of biogeochemical processes and affect the distribution, diversity and abundance of species. These parameters also provide important contextual information about estuarine circulation. Water column profiles of temperature, salinity, dissolved

Table 6.2: Summary of ANZECC trigger levels for slightly disturbed estuaries in south-eastern Australia (ANZECC, 2000) and detection limits for parameters analysed at AST.

	Chl-a ug/L	Ammonium (NH_4^+) ug/L	Nitrate + nitrite ug/L	FRP ug/L	Total N ug/L	Total P ug/L	Dissolved oxygen (% saturation)	pH
ANZECC trigger level*	4	15	15	5	300	30	80-110	7.0-8.5
Method detection limit		2	2	2	40	5	–	–

oxygen and pH are measured as part of Derwent estuary ambient water quality surveys, using *in-situ* probes deployed from boats.

Salinity

Most plant and animal species have specific salinity tolerances, and the distribution and variability in salinity dictate to a large degree the types and distribution of estuarine biota. Salinity also plays an important role in the flocculation and settling of fine-grained sediment particles. Where turbid river water enters an estuary, dispersed particles tend to flocculate at the interface between fresh and salt water.

Salinity levels in the Derwent estuary range from essentially freshwater (<0.5 parts per thousand) at New Norfolk increasing to near seawater (34 ppt) at the estuary entrance, as illustrated in **Figure 6.3**. Salinities in the upper estuary extend over a wide range, with strong differences between surface and bottom salinities due to the highly stratified nature of the estuary in this area. In contrast, salinities in the lower estuary are typically high, with little variation between surface and bottom observations. A persistent halocline is present in the upper estuary under most conditions, however, during high river flow this halocline may be displaced downstream a considerable distance. For example, during a flood event in June 2004, the toe of the salt wedge was pushed downstream to Bridgewater and a strong halocline was observed throughout most of the estuary, with salinities as low as 2 ppt observed in surface waters off Sullivans Cove.

Temperature

Temperature influences microbial, plant and animal growth, as well as the rates of many biogeochemical reactions. Temperature is also an important factor in the timing of fish and other animal migration and reproduction within the estuary. Both temperature and salinity provide important clues about water column structure and estuarine mixing, and are essential information for the development and calibration of hydrodynamic models.

A summary of water temperatures in the Derwent estuary is provided in **Figure 6.4**. Water temperatures vary seasonally, with a greater range observed in surface waters of the upper estuary (from 5.4°C in winter to 22.1°C in summer), as compared to the more consistent temperatures observed at depth in the lower estuary (from 10°C in winter to 17.9°C in summer).

Dissolved oxygen

Oxygen is essential to nearly all forms of life and influences most chemical and biological processes in water bodies. Reduced dissolved oxygen (DO) levels can be stressful to fish and other marine organisms, particularly those living at the sediment-water interface where low DO events tend to be most pronounced. Chronic or intermittently low DO levels can eliminate more sensitive organisms and significantly alter benthic community structure. At low oxygen levels the types and rates of bacterial processes in sediments are altered, and consequences may include the release of sediment-bound nutrients and toxic metals, and the production of methane and hydrogen sulphide gases. Saturated levels of DO in a healthy estuarine environment generally lie between 6.5 and 9 mg/L, as measured over at least one daily cycle (ANZECC 1992). It is recommended that dissolved oxygen levels should generally not fall below 6 mg/L, or 80% DO saturation (ANZECC 1992, 2000).

Most organisms can grow and reproduce unimpaired when DO levels exceed 5 mg/L. When levels drop to 3 to 5 mg/L, however, they become stressed, and below 3 mg/L (hypoxia) many species will move elsewhere and immobile species may die. Where anoxia occurs (<0.5 mg/L), organisms that require oxygen for survival will die (USEPA 2002).

Figure 6.3: Salinity levels in a) surface waters and b) bottom waters (Jan 2003 – Dec 2008)

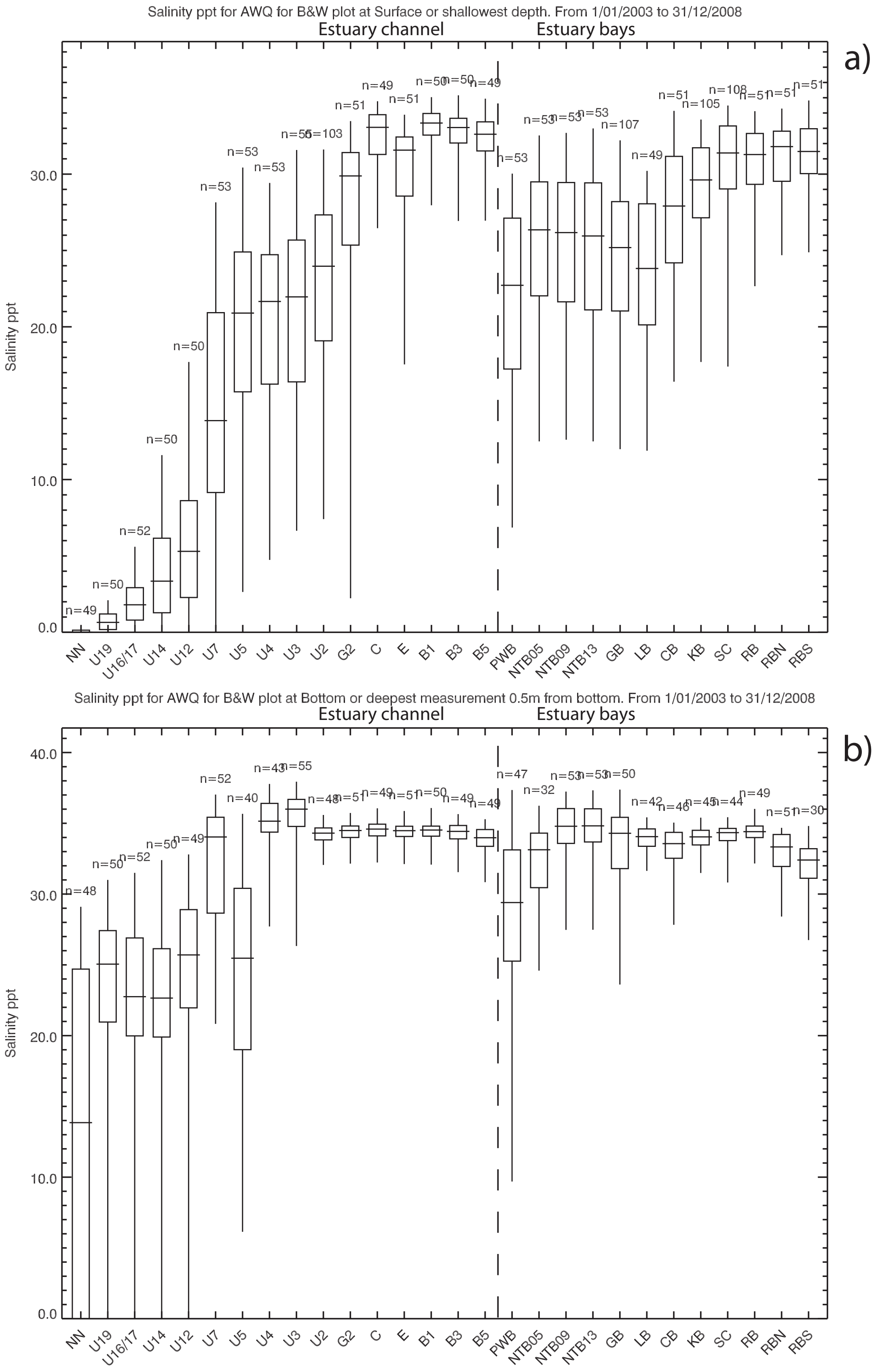
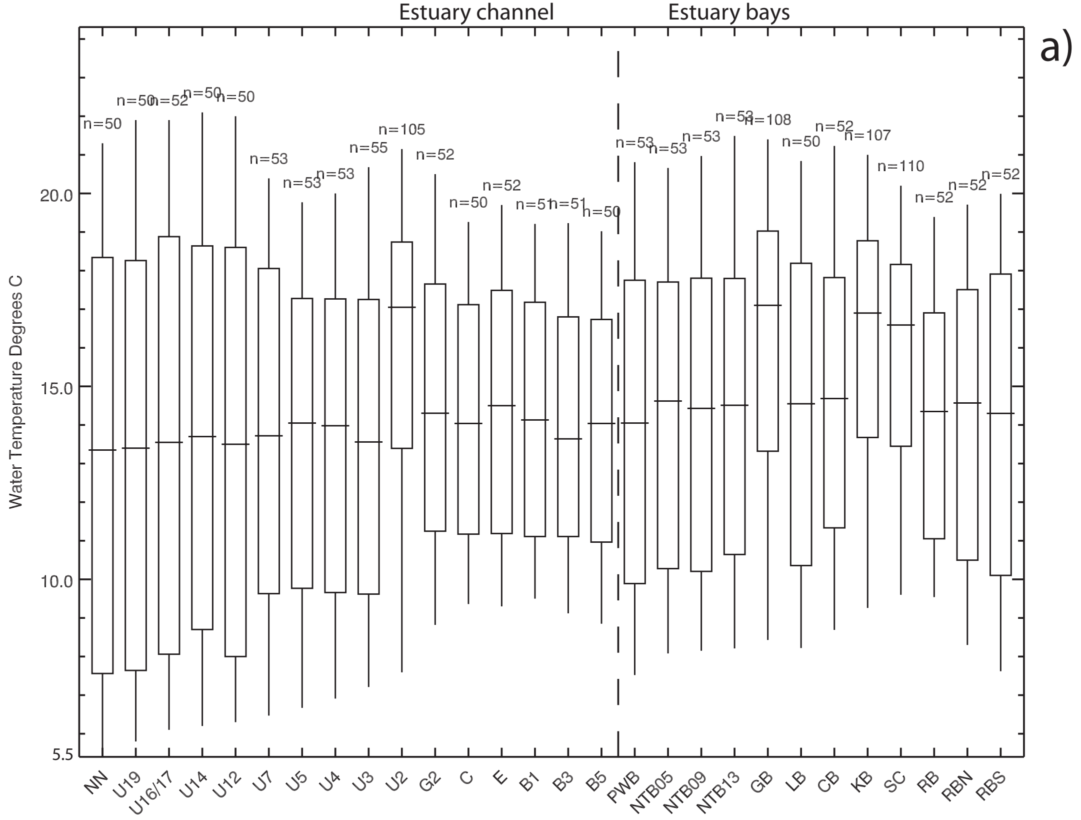


Figure 6.4: Water temperatures in a) surface waters and b) bottom waters (Jan 2003 – Dec 2008)

Water Temperature Degrees C for AWQ for B&W plot at Surface or shallowest depth. From 1/01/2003 to 31/12/2008



Water Temperature Degrees C for AWQ for B&W plot at Bottom or deepest measurement 0.5m from bottom. From 1/01/2003 to 31/12/2008

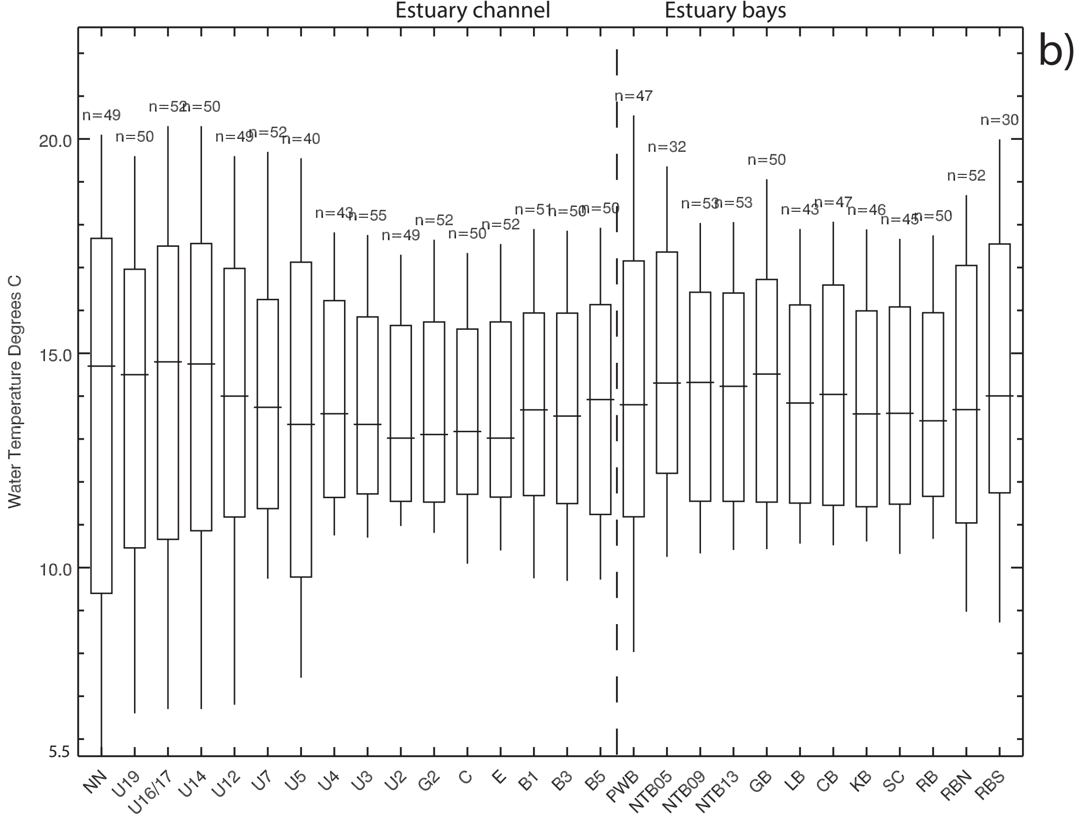
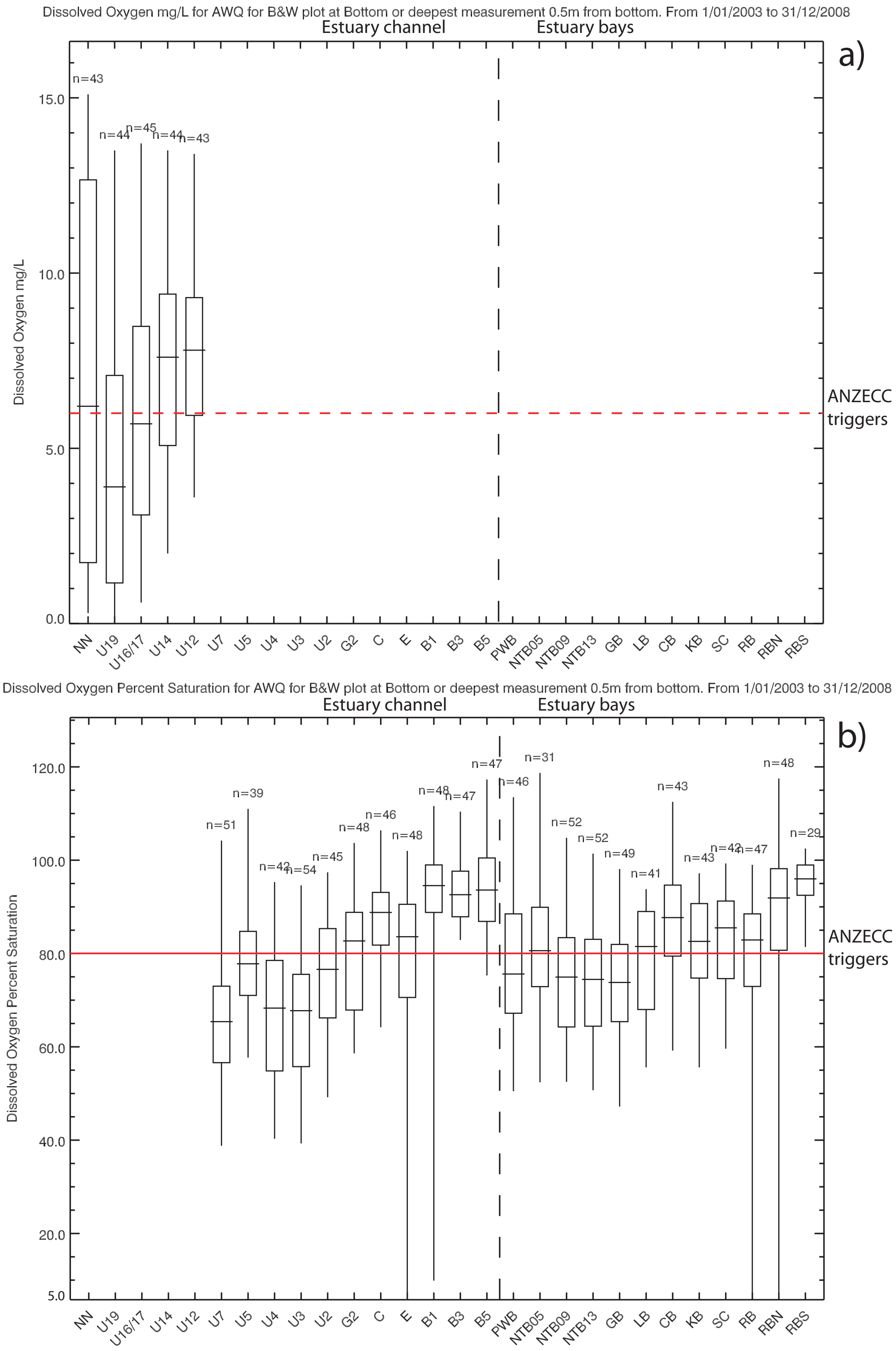
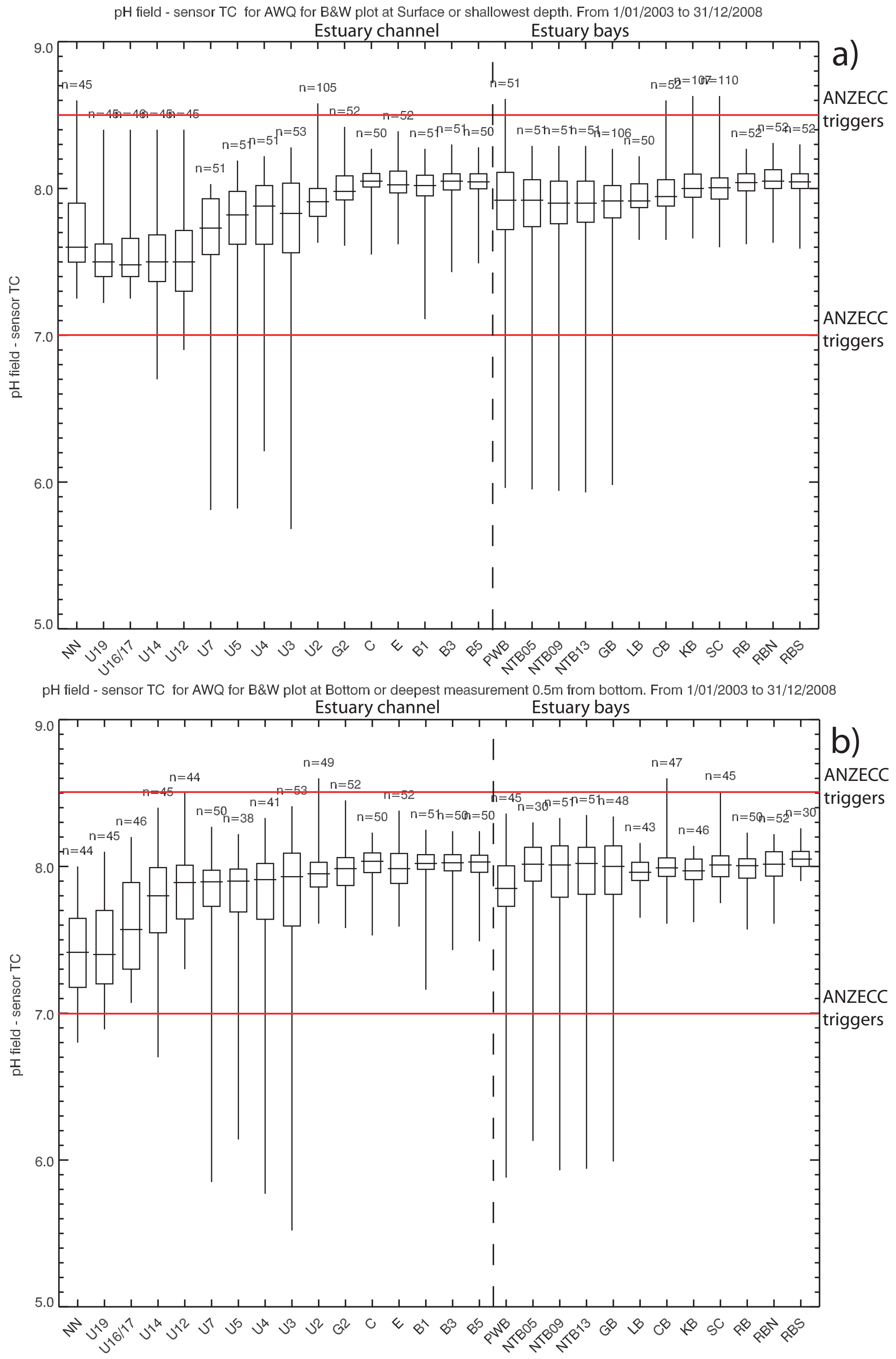


Figure 6.5: Dissolved oxygen levels in bottom waters (Jan 2003 – Dec 2008)



NOTE: due to differences in monitoring equipment, DO is measured in mg/L in the upper estuary a) and % in the middle and lower estuary b). The solid red line indicates the lower ANZECC trigger level (80 % saturation) while the dashed line in a) indicates approximate DO concentration equivalent to 80% in the upper estuary.

Figure 6.6: pH levels in a) surface waters and b) bottom waters (Jan 2003 – Dec 2008)



Dissolved oxygen levels in estuarine waters are dependent on a number of factors, including temperature, salinity, biological activity, turbulence and mixing, and may fluctuate widely over a period of hours, weeks or months. Oxygen dissolves more readily at low temperatures and low salinity; thus DO levels tend to be significantly higher in cold freshwater than in warm seawater. Aquatic plants are net producers of oxygen during daylight hours, but are net consumers at night. Therefore, DO levels also vary over a 24-hour period, with the lowest concentrations occurring around sunrise. DO levels in Derwent estuary bottom waters are plotted in **Figure 6.5** (note: different units are used in the upper estuary due to different monitoring equipment being used here).

The upper reaches of the Derwent estuary have a natural tendency towards oxygen depletion, particularly during summer months when river flows are low, water temperatures are elevated and there is strong thermal and salinity stratification. DO levels have been particularly low at sites U19 and U16/17, where the median DO at depth was <6 mg/L over the monitoring period, and considerably lower than this during summer months. This has been exacerbated in the past due to discharge of organic-rich pulp mill effluent from the Boyer mill, and the resultant oxygen consumption during degradation of this organic matter. In the middle estuary DO levels at depth were also low at a number of locations (median DO <80% saturation). A contributing factor in this area may be the organic loading associated with wastewater treatment plants (WWTPs). Several low DO events were also observed in the lower estuary, particularly at deeper monitoring sites and coinciding with very low levels occurring in the upper estuary. The lowest DO levels in the lower estuary were recorded in March 2005, and were detectable as far down river as site E, with a concentration of 4 mg/l DO at 21 m depth.

pH

pH – a measure of the acid balance of water – influences many biological and chemical processes and is an important control on the solubility of some metals, particularly iron and copper. Typical estuarine pH levels average between 7 and 7.5 in freshwater-dominated areas, and between 8 and 8.6, in more marine influenced areas (USEPA 2002). The ANZECC guidelines recommended that pH levels for slightly disturbed estuaries in south eastern Australia should lie between 7.0 and 8.5 (ANZECC 2000). Median pH levels in the Derwent estuary range from 7.5 to 8.1, as illustrated in **Figure 6.6**, however, if pH levels were to fluctuate widely, the metals bound to estuarine sediments could potentially be released to the water column.

6.1.4 Nutrients

Estuaries, nutrients and algal blooms

A number of water quality problems are caused by elevated nutrient levels in estuaries, particularly the excessive growth of algae. Excessive algal growth does occur at times in the Derwent estuary and can have a number of adverse effects including the following:

- loss of seagrass and macrophyte habitats due to shading/overgrowth by filamentous or epiphytic algae. This has been identified as a possible cause for the loss of extensive seagrass beds that once occurred in Ralphs Bay, as discussed in **Section 9.1.3**;
- excessive macroalgal growth (notably *Ulva sp.*) in intertidal areas such as Prince of Wales Bay, which can alter native habitat structure and may also contribute to seagrass decline in these areas;
- gradual and often undesirable changes in the species and numbers of aquatic flora and fauna in an estuary. For example excessive filamentous algal growth within Ralphs Bay may create an unfavorable habitat for endangered spotted handfish (see **Section 9.5.1**);
- fluctuating oxygen levels (i.e. high oxygen levels during the day, but low levels at night), which can cause physiological stress to fish and other organisms;
- blooms of introduced toxic species of microscopic algae (notably the dinoflagellate *Gymnodinium cantenatum*), which may result in periodic toxin buildup in shellfish and human health risks due to paralytic shellfish poisoning;
- diminished aesthetic appeal due to foul odours, dead fish and rotting algae, surface scum and discolouration of the water column (e.g. occasional *Noctiluca scintillans* dinoflagellate blooms in some areas of the Derwent).

Algal growth in estuaries is broadly dependent upon four factors: light, temperature, salinity and nutrient supply. Strategies to control algal problems usually focus on the major nutrients (nitrogen and phosphorus), in particular by reducing the loads entering the estuary. Nitrogen is considered to be the limiting nutrient for plant growth in most marine and estuarine systems, including the Derwent, although phosphorus may be limiting in the upper estuary where freshwater is more prevalent. The most biologically available form of nitrogen is ammonium (NH^4) followed by nitrate (NO^3), while orthophosphate (PO^4) is the most bioavailable form of phosphorus. Silicon is also been identified as a limiting nutrient for some types of phytoplankton (diatoms).

Nutrient sources and dynamics

Nutrients are derived from a variety of natural and anthropogenic sources and may be discharged directly to the estuary from wastewater treatment plants (WWTPs) and industries or transported via rainfall, rivers and streams, stormwater drains and groundwater. In addition, significant quantities of nutrients may be derived from internal sources within the estuary (e.g. sediments) and from adjacent coastal waters. Anthropogenic sources of nutrients include sewage, fertilisers, livestock wastes, industrial discharges, urban runoff, air pollution, landfills and numerous lesser sources. These are commonly categorised as either point or diffuse sources. Point sources, such as WWTPs or industrial discharges are readily identified, and as such can often be mitigated through capital improvements. Diffuse sources, such as agricultural or urban runoff, typically require a catchment management approach for effective control.

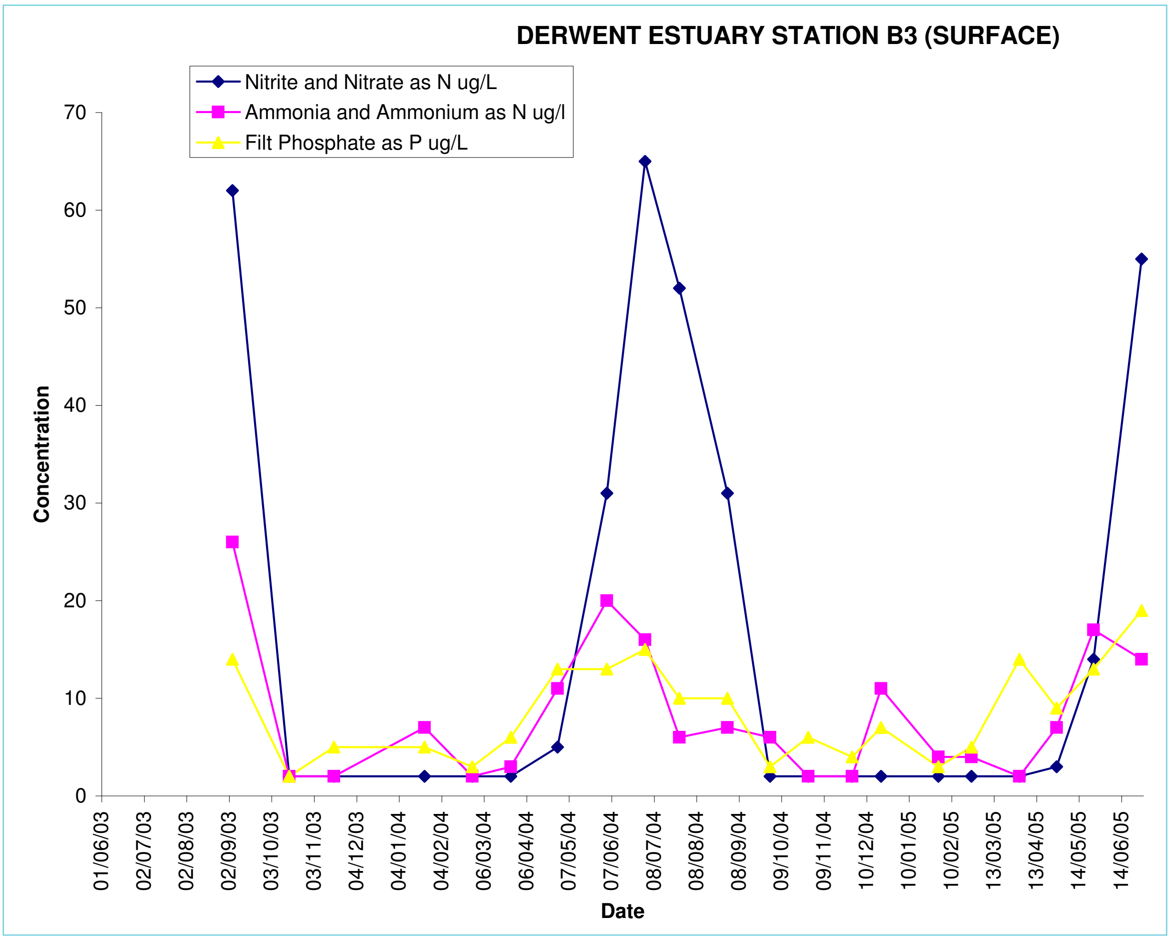
Nutrients are constantly cycling in the estuarine environment between the water column, biota, sediments and the atmosphere. In order to fully understand the cycling and availability of nutrients in the Derwent estuary, a complete nutrient 'budget' is required, which accounts for inputs, exports and 'fluxes' (or rates of transfer) between the various components. The cycling of phosphorus, and particularly nitrogen, in estuarine systems is complex and linked to many other variables, including the type and distribution of biota and sediments, dissolved oxygen and pH levels, water temperatures, and interactions with organic matter. To improve our understanding of the nutrient cycling within the Derwent estuary, a biogeochemical model has recently been completed, linked to hydrodynamic modeling, and incorporating water quality data from the estuary, point and diffuse sources (Wild-Allen *et al*. 2009). This model has enabled a nitrogen budget to be created for the estuary, as discussed in **Section 5.4**.

Nutrient monitoring in the Derwent estuary

The following sections review ambient nutrient data collected in the Derwent estuary between January 2003 and December 2008. Observations are compared with the relevant National Water Quality Guidelines (ANZECC 2000), keeping in mind the limitations of these guidelines with respect to Tasmanian systems.

A strong seasonality in nutrient concentrations occurs in the Derwent, particularly with respect to nitrate plus

Figure 6.7: Seasonal variability in nitrate and nitrite, ammonia and ammonium, and filtered reactive phosphate (ug/L) in the Derwent estuary at the estuary entrance site (site B3), June 2003 – June 2005



nitrite (NO_x), and filtered reactive phosphate (FRP, which is largely orthophosphate). This is linked both to seasonal changes in marine conditions and catchment inputs, as illustrated in **Figure 6.7**, with the highest levels measured during the months of May to September. The seasonally high oceanic inputs are a natural phenomenon, caused by the intrusion of nutrient-rich Southern Ocean waters into the estuary during winter and spring.

Total phosphorus

Total phosphorus (TP) is a measure of all the forms of dissolved and particulate phosphorus found in water. Particulate phosphorus primarily consists of plants and animals in the water column, precipitates of phosphorus, and phosphates in and adsorbed to mineral surfaces. Dissolved phosphorus consists of inorganic orthophosphates and organic compounds (OzCoast and OzEstuaries 2007).

Median TP concentrations in the Derwent estuary ranged from about 8 to 40 ug/L at most sites, as illustrated in **Figure 6.8**. TP concentrations increased progressively downstream from New Norfolk, with the highest values observed at mid-estuary sites and embayments and at depth in the middle and upper estuary. This probably reflects a combination of WWTP inputs as well as sediment inputs, particularly in the upper estuary where seasonally low DO levels may cause the release of sediment-bound phosphorus. TP concentrations were particularly high in the surface waters of Prince of Wales Bay (median 61 ug/L), probably as a result of WWTPs discharges plus occasional fertiliser plant run-off entering this poorly-flushed bay. As shown in **Figure 6.8**, median TP concentrations at most Derwent estuary sites were above the ANZECC trigger level of 30 ug/L, with the exception of surface waters upstream of Dogshear Point (site U7).

Filterable reactive phosphate

Filterable reactive phosphate (FRP) consists of inorganic phosphate, largely made up of orthophosphate (PO_4^{3-}). Median FRP concentrations in the Derwent estuary ranged from <2 to 18 ug/L at most sites, as illustrated in **Figure 6.9**. FRP distributions followed a similar pattern to TP, with very low concentrations observed in the upper estuary increasing progressively downstream. The highest FRP values were also observed at mid-estuary sites and embayments and at depth in the middle and upper estuary. As with TP, this probably reflects a combination of WWTP inputs as well as sediment inputs. FRP concentrations were also very high in the surface waters of Prince of Wales Bay (median 28 ug/L). Marked seasonal variations in DRP levels are typically observed in the Derwent estuary as a result of Southern Ocean influences, as shown in **Figure 6.7**. As shown in **Figure 6.9**, median FRP concentrations at most Derwent estuary sites were above the ANZECC trigger level of 5 ug/L, with the exception of surface waters upstream of Dogshear Point (site U7).

Total nitrogen

Total nitrogen (TN) is the sum of nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), ammonium (NH_4^+), as well as organic nitrogen in both dissolved (e.g. urea) and particulate forms (e.g. phytoplankton) (Swan-Canning Cleanup Program 2005).

Median TN concentrations in the Derwent estuary range from 160 to 280 ug/L at most sites, as illustrated in **Figure 6.10**. Median concentrations generally increase downstream from New Norfolk, with the highest median TN values observed at lower estuary sites and in estuary bays. TN values at depth tend to be slightly higher than surface water values, with the highest observed TN in Prince of Wales Bay (369 ug/L).

Median TN concentrations at most sites were below the ANZECC trigger level of 300 ug/L, with the exception of Prince of Wales Bay (PWB) and several of the mid-estuary channel sites and embayments (at depth only). There is a strong correlation between TN at New Norfolk (NN) and River Derwent flow ($R^2 = 0.8$) (Eriksen *et al*. 2006), and monitoring results show TN values are highest in winter months when river inputs are typically greater. Winter is also the time when TN increases in marine waters entering at the estuary entrance due to increased Southern Ocean influences.

Ammonia plus ammonium

Ammonia (NH_3) is a soluble gas in water, whilst ammonium (NH_4^+) occurs as dissolved inorganic ions in water. The majority of ammonia in seawater changes into ammonium (through protonation), however this is strongly regulated by pH. Ammonium is an important nutrient for aquatic algae and bacteria and elevated levels may cause algal blooms. Ammonium is rapidly oxidised to nitrate and nitrite by bacteria in the presence of oxygen through a process called nitrification. This process is inhibited at low temperatures and seasonal variations in ammonium and nitrate concentrations can therefore be linked to the degree of biological activity. Nitrification consumes oxygen, causing a decline in DO concentrations in the water column. This effect is most noticeable in the bottom waters of the estuary in summer, where increased temperature, decreased flow, and the oxygen demand from the breakdown of organic matter combine to form hypoxic zones near the sediment-water interface. Ammonium can also be a significant factor in sediment toxicity, primarily through porewater exposure routes.

Median ammonia + ammonium concentrations at most Derwent estuary monitoring sites ranged from 2 to 30

Figure 6.8: Total Phosphorus levels in a) surface waters and b) bottom waters (Jan 2003 to Dec 2008)

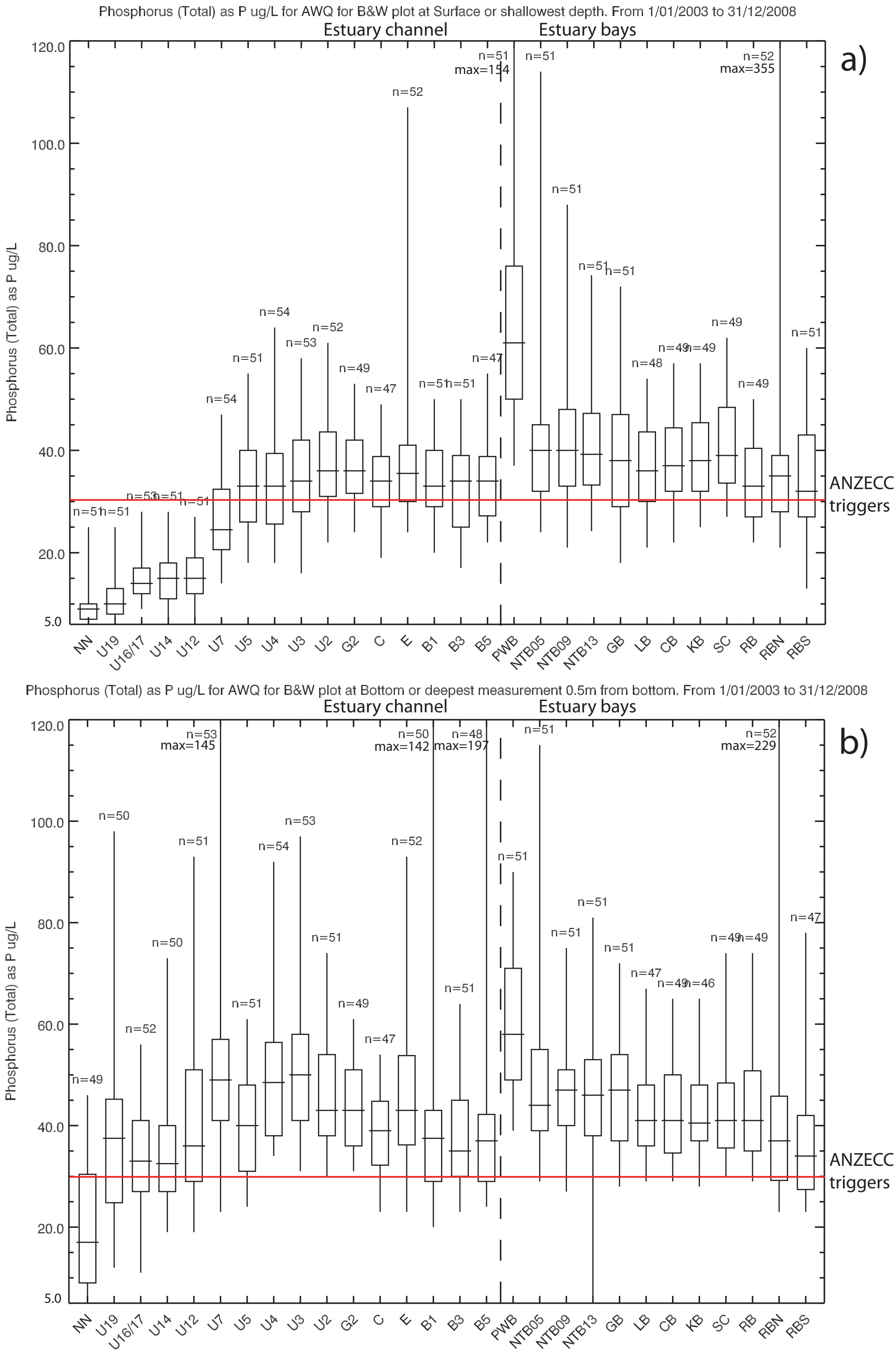
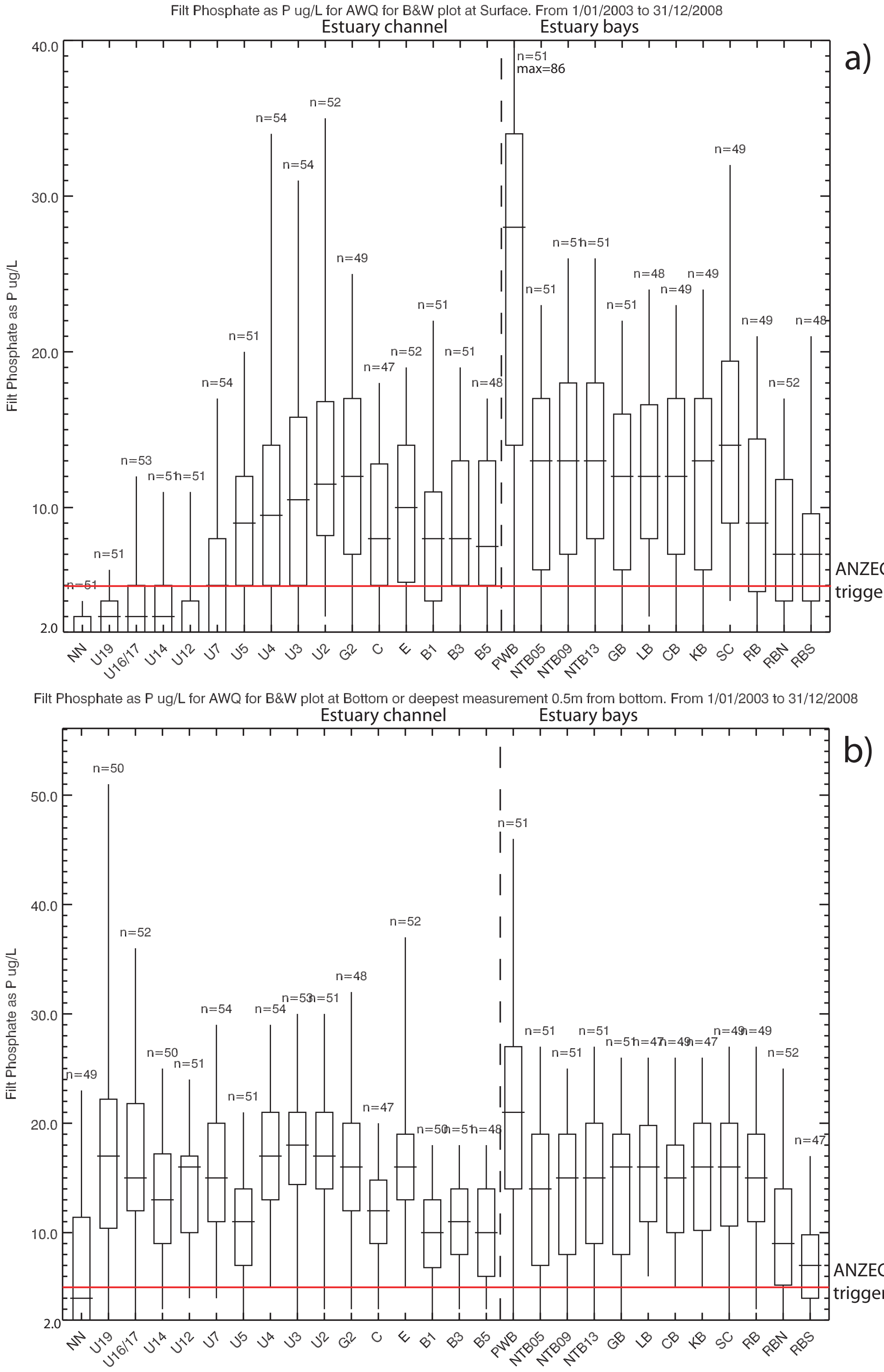


Figure 6.9: Filtered reactive phosphate levels in a) surface waters and b) bottom waters (Jan 2003 to Dec 2008)



ug/L, as illustrated in **Figure 6.11**, with generally higher levels in mid-estuary embayments and at depth in the middle and upper estuary. The highest ammonia + ammonium levels were observed in bottom water samples collected at two upper estuary sites U19 and U16/17 (median values of 75 ug/L and 45 ug/L, respectively). Studies conducted as part of the Norske Skog Environmental Risk Assessment (NSR 2001) attributed high bottom water ammonia concentrations in this area to the release of nutrients from sediments, particularly during summer months when DO levels are low. Recent research in the upper estuary suggests that low DO conditions may inhibit the conversion of ammonium to nitrite and nitrate, such that ammonium is fluxed back into the water column rather than being nitrified in the sediments (J. Ross 2009, *pers. comm*.). High ammonia + ammonium levels were also observed in Prince of Wales Bay (median 65 ug/L), probably associated with WWTP discharges to this poorly flushed bay.

In contrast, some surface sites had lower median ammonia + ammonium concentration than either New Norfolk or the estuary entrance, suggesting a possible drawdown of nutrients at sites U14, U12, and U7 that could potentially be attributed to high primary productivity in this area of extensive wetlands and macrophtyes. Ammonia + ammonium levels in the estuary are also influenced by seasonal influxes of Southern Ocean water, as illustrated in **Figure 6.7**.

As indicated in **Figure 6.11**, median ammonia + ammonium concentrations were below the ANZECC trigger level of 15 ug/L in most surface waters throughout the Derwent estuary, with the exception of several mid-estuary bays. However, the trigger level was exceeded at the majority of bottom water sites.

Nitrate plus nitrite

In marine waters, the majority of nitrate + nitrite (NO_x) is present as nitrate, as nitrite (NO_2) is rapid conversion to nitrate (NO_3) during the nitrification process. Median NO_x concentrations at most Derwent estuary monitoring sites ranged from 3 to 40 ug/L, as illustrated in **Figure 6.12**. In general, median NO_x levels were highest in the upper estuary, decreasing with distance downstream from New Norfolk. Elevated NO_x concentrations in the upper estuary probably reflect catchment contributions transported by the River Derwent. NO_x levels were also high in Prince of Wales Bay (35 ug/L), reflecting WWTP inputs to this bay. Median NO_x levels were typically lower in surface waters than in bottom waters, probably reflecting nitrate uptake in the photic zone and the release of NO_x at depth following the breakdown of organic matter in sediments. There was a notable drawdown of NO_x levels in the vicinity of Bridgewater and Dogshear Point (U12 and U7), which may again be related to nutrient uptake by the extensive macrophyte beds and wetlands in this area. Seasonal increases in NO_x are typically observed during winter months (May to August), entering the estuary from both the river and ocean ends (**Figure 6.7**).

As shown in **Figure 6.12**, median NO_x concentrations were below the ANZECC trigger level of 15 ug/L in most surface waters throughout the Derwent estuary, with the exception of several upper estuary sites and mid-estuary embayments. However, the trigger level was exceeded at depth for the majority of the estuary channel sites.

6.1.5 Phytoplankton, chlorophyll a *and algal blooms*

As discussed in **Section 6.1.4**, nutrient enrichment in many estuaries leads to phytoplankton blooms and other excessive plant growth, including rapid growth of nuisance macroalgae and epiphytic algae which can shade out or overgrow productive seagrass beds. Seasonal stratification of the water column during periods of low winds may also promote toxic algal blooms in the Derwent estuary, as occurs in the nearby Huon estuary (Hallegraeff *et al*. 1995).

Phytoplankton are very small single-celled algae that live in the water column and are an important component of aquatic flora in estuaries, in many cases forming the base of the food chain. The Derwent estuary is characterised by high phytoplankton species diversity (>180 taxa), including approximately 83 species of diatoms, 73 dinoflagellates and 30-40 nanoplankton taxa (Hallegraeff and Westwood 1994). Several studies by Clementson *et al*. (1989), Harris *et al*. (1987, 1991) and Lane (2005) have investigated phytoplankton populations and processes in Storm Bay and on a more regional scale.

The amount, or biomass, of algae in the estuary is typically represented by the amount of the photosynthetic pigment chlorophyll *a* (chl *a*) (Chapman 1992). Chl *a* concentrations are routinely monitored in the Derwent estuary as part of the ambient water quality monitoring program using a Lund tube (which collects integrated water column samples) or an *in-situ* fluorometer. Results for the six year period – summarised in **Figure 6.13** – show that median chl a levels ranged from about 1.0 to 2.5 ug/L, with the highest values observed at mid-estuary sites (U2 and G2) and adjacent embayments. All medians were below the ANZECC trigger level for chl *a* of 4 ug/L.

Dissolved nitrogen-to-phosphorus ratios suggest that nitrogen could potentially be limiting phytoplankton growth in the lower and middle estuary, while phosphorus may be limiting in the upper estuary (Coughanowr 1995). This is supported by the Norske

Figure 6.10: Total nitrogen levels in a) surface waters and b) bottom waters (Jan 2003 – Dec 2008)

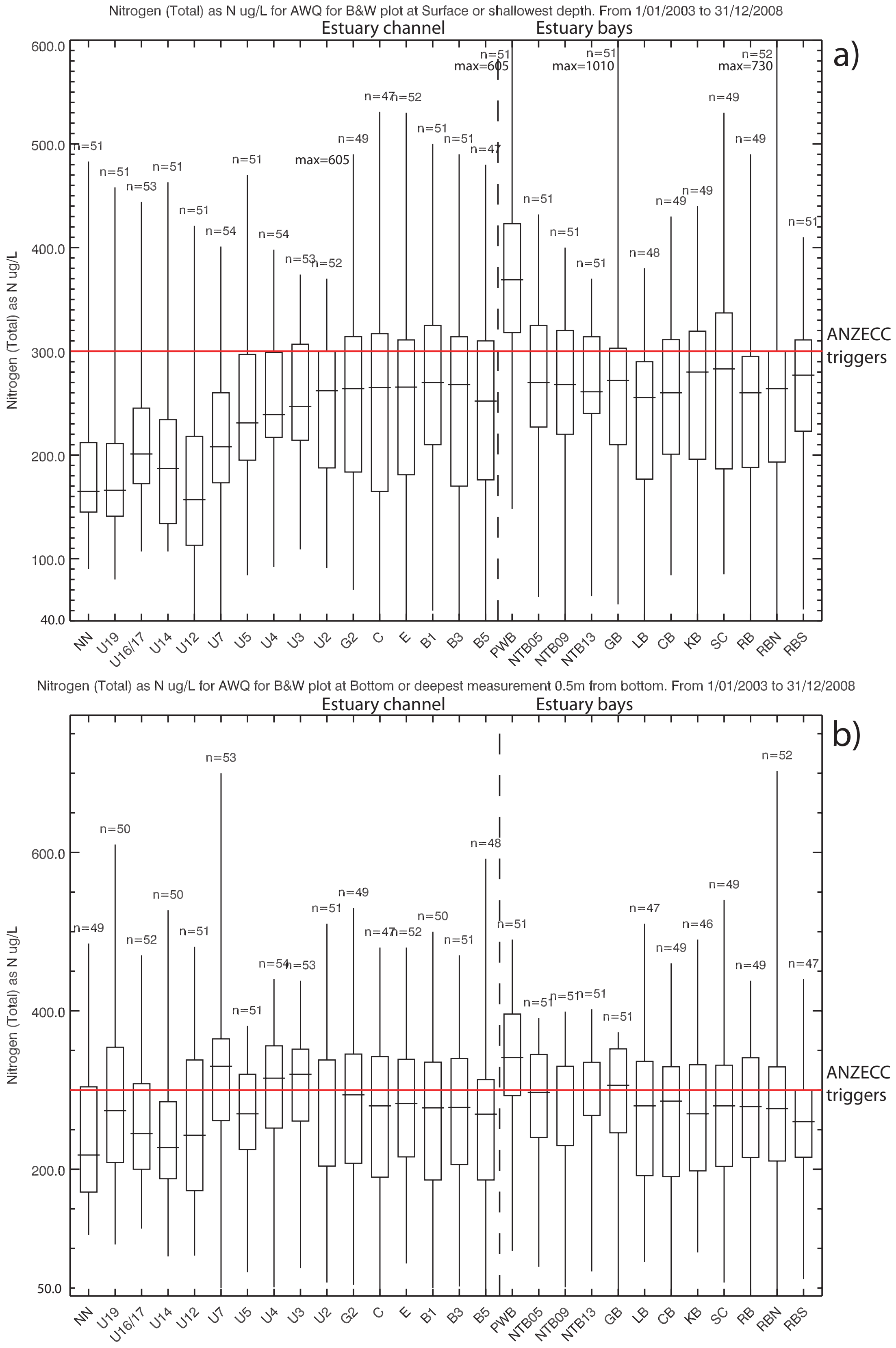
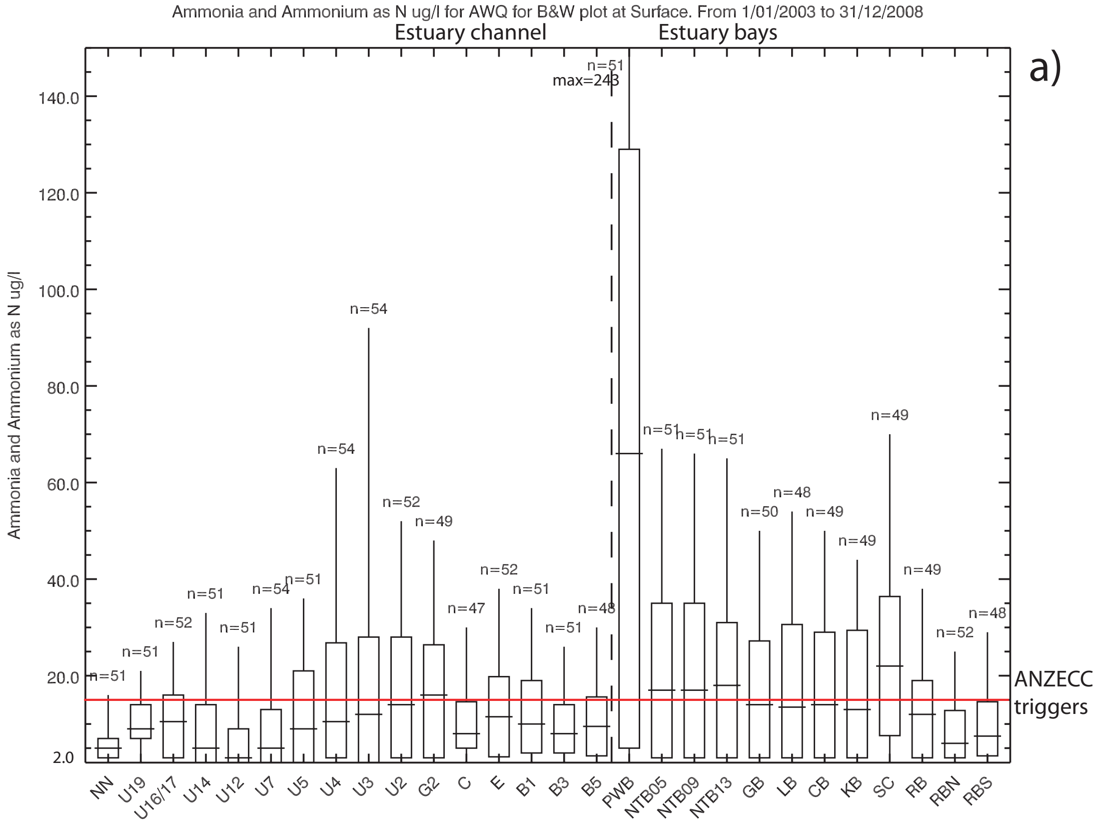


Figure 6.11: Ammonia and ammonium levels in a) surface waters and b) bottom waters (Jan 2003 – Dec 2008)



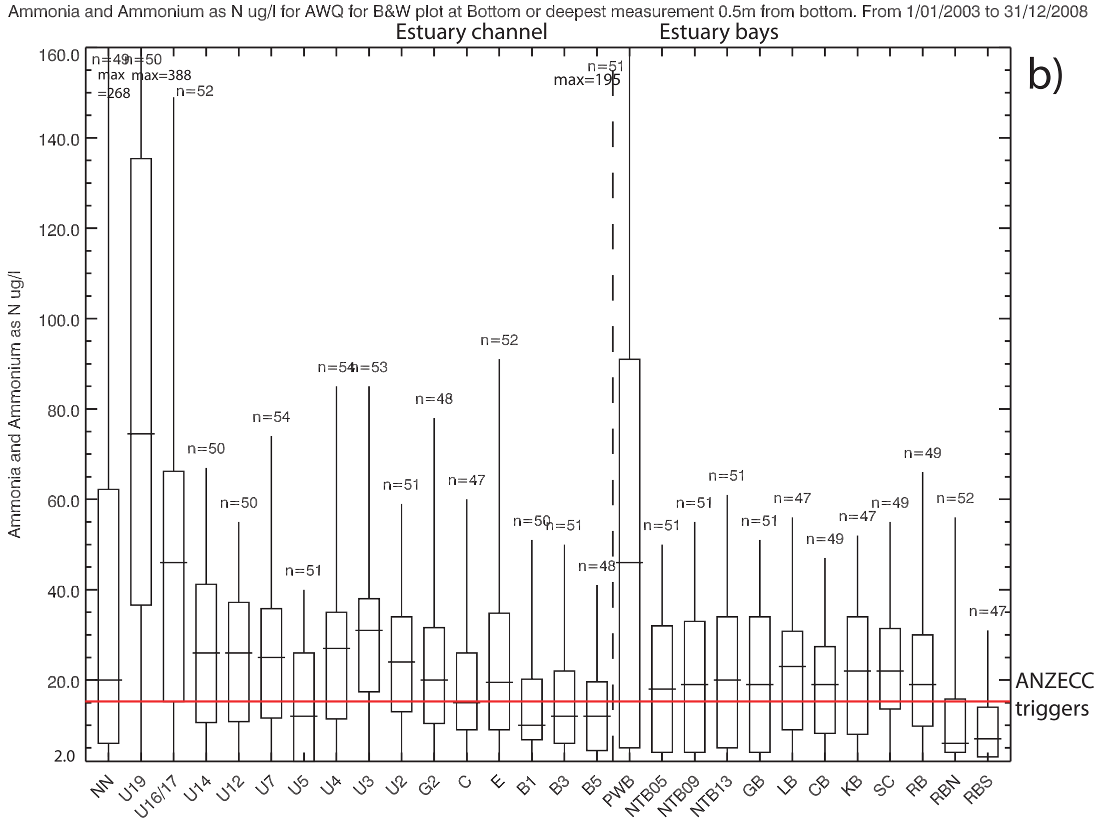


Figure 6.12: Nitrate and nitrate levels in a) surface waters and b) bottom waters (Jan 2003 – Dec 2008)
Note: GB maximum = 445 ug/L)

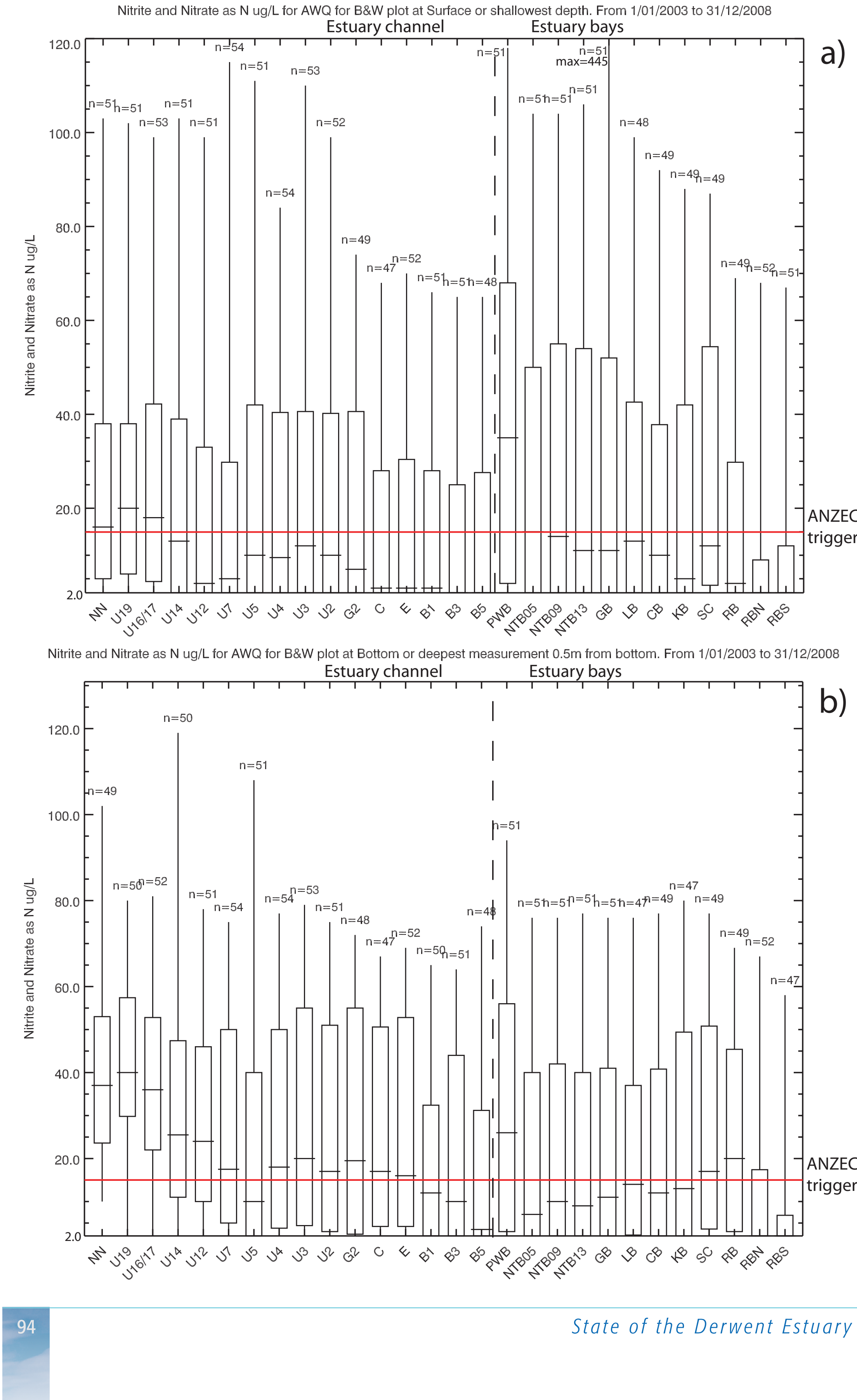
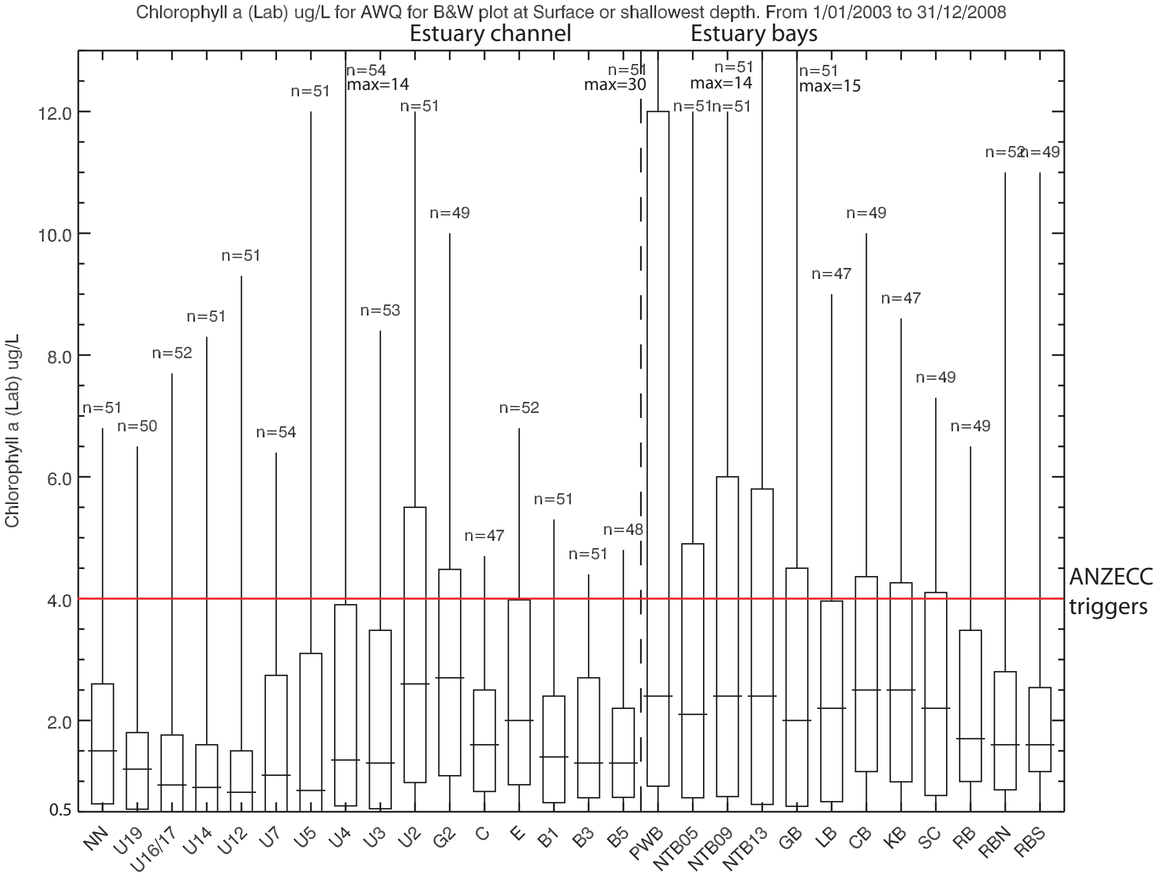


Figure 6.13: ***Chl-a data from Lund tube (integrated water column) samples (Jan 2003 – Dec 2008)***



Skog ERA investigation in the upper estuary that found phytoplankton growth is at times strongly limited by the amount of phosphorus available in the water, particularly during late spring to early autumn (NSR 2001). However, the relatively low median chl *a* values observed in the Derwent estuary as a whole (1.6 µg/L) – despite the presence of bioavailable nutrients – suggest that environmental factors other than nutrients also play a role. Hallegraeff and Westwood (1994) conducted a series of *in-situ* bioassays in the middle and lower estuary to investigate the causes of phytoplankton limitation and found that growth may be limited at times by light availability due to humic substances in the water column. Temperature and rapid flushing rates may also play a role.

A more detailed analysis of the chl a data – illustrated in **Table 6.3** – demonstrates the occurrence of periodic algal blooms (defined as chl a levels ≥4 µg/L) that typically occur in autumn (March-May) and spring (Sept-Nov) in the middle estuary and associated embayments, and to a lesser degree in the outer estuary. Algal blooms in the upper esuary were rare, with only a single event observed across multiple sites in April 2008. The highest chl-a levels were observed in mid-estuary bays, notably at Cornelian, Geilston, Lindisfarne, Newtown and Prince of Wales bays. Chl a levels in excess of 10 µg/L are uncommon, except in Prince of Wales Bay, where levels as high as 30 µg/L have been observed.

Routine algal identification to assess the species composition of algal blooms is not presently undertaken in the Derwent estuary, however a general understanding of regional phytoplankton dynamics is available based on previous studies .The spring algal blooms often consist of diatoms, which are stimulated by the annual intrusion of nitrate-rich oceanic water into the estuary from the Southern Ocean. The algal composition of the autumn blooms has been little studied, however the Derwent estuary is somewhat unusual in that dinoflagellates are relatively abundant throughout most of the year (Hallegraeff and Westwood 1994).

Dinoflagellate algal blooms in the Derwent estuary are considered to be largely a natural phenomenon, however, there are some introduced species – particularly the toxic dinoflagellate *Gymnodinium catenatum* – which can dominate the dinoflagellate algal blooms. Blooms of toxic dinoflagellates are usually short lived (several weeks), but occasionally can persist for

Table 6.3: Monthly chlorophyll a observations at Derwent estuary monitoring sites (Jan 2003 – Dec 2008)

		Upper estuary					Middle estuary					Lower estuary						Estuary Bays (middle and lower)									Ralphs Bay		
		NN	U19	U16/17	U14	U12	U7	U5	U4	U3	U2	G2	C	E	B1	B3	B5	PWB	NTB05	NTB09	NTB13	GB	LB	CB	KB	SC	RB	RBN	RBS
Summer	Jan-03						4.4	3.5	4	3				0.9	0.5		0.7	17.6	3.8	3.1	3.8	2.7					1	1.2	0.9
Summer	Feb-03	1.9	1.2		0.8	1.3	2.6	4.8	7.7	4.2	3.8	2.4	1	1.9	0.9	0.8	1	24.1	4.6	6	5.8	5.2	4	4	2.1	2.1	1.2	0.9	3.1
Autumn	Mar-03	2.9	2.6	1.6	0.9	1.5	5.5	7.8	5.3	3	3	2	1.5	2	0.9	0.8	0.9	21.1	7.5	7.8	7.7	6.6	3.7	6.4	2.5	2.1	1.6	0.9	2.4
Autumn	Apr-03	4.9	3.2	2	1.6	1.3	1.4	1.4	1.3	0.7	1.6	3.3	2.8	5.3	2	3	3	1.8	1.5	2.4	2.8	1.9	1.6	2.7	2.6	1.4	3.8	2.5	2.6
Autumn	May-03	3.9	2.4	2.2	1.8	1.1	0.9	1.1	1.4	3.6	3.8	6.4	4	5.6	5	4.4	2.6	1.1	1.5	2	1.8	2.8	2.3	3.9	5	5.3	3.9	2.8	4
Winter	Jun-03			0.9						0.85				2															
Winter	Jul-03																												
Winter	Aug-03	0.85	0.65	0.55	0.5	0.5	0.75	0.85	0.8	1.4	1.4	1.5	0.83					0.95	1.1	1.4	1.2	1.1	0.9	1.1	1.5	1.4			
Spring	Sep-03						0.64	0.64	0.6	0.55	0.5	0.64		0.73	0.78	0.83	1.2	0.92	0.73	0.55	0.55	0.5	0.5	0.5	0.55	0.6	1.4	3.7	7.9
Spring	Oct-03	1.1	0.95	0.9	0.8	0.75	3.4	1.6	5.3	7	12	8.3		6.8	2.1	4.3		6	9.3	12	13	15	8.6	10		7.3	6.5	4.3	3
Spring	Nov-03	2.4	1.6	0.91	0.64	0.55	6.4	12	14	8.4	5.5	3.1	2	1.4		2.3	1.9	17	11	8.6	7.9	6.7	4.5	4.1	4.8	3.9	1.3	1.4	1.3
Summer	Dec-03			1.3						2.1																			
Summer	Jan-04	0.5	0.5	0.5	0.5	0.5	0.52	0.53	0.68	1.2	0.53	0.88	0.5	0.96	0.5	0.5	0.55	1.3	0.84	1.5	0.5	1.1	0.77	1.8	0.63	0.59	0.5	0.6	1.4
Summer	Feb-04	0.63	0.67	0.5	0.5	0.5	0.59	0.63	1.1	1	3.8	2.9	1	0.94	0.88	1.1	0.7	1.3	1.8	3	3.6	3.5	4.5	3.3	4.4	4.1	1.7	0.5	0.5
Autumn	Mar-04	0.74	0.5	0.5	0.5	0.5	0.65	0.74	2.1	2	0.85	1.5	1.5	1.5	0.89	1.2	1.3	5.8	3.1	4.6	3.1	3.7	0.64	4.2	1.2	2.2	1.3	0.76	1.4
Autumn	Apr-04	1.6	1.3	1.5	0.77	0.59	0.5	0.5	0.5	0.5		2.7	1.3	2.6	1.5	2.5	2	0.9	0.68	0.75	0.5	1.4		1.3		0.5	2	1.6	1.8
Autumn	May-04																												
Winter	Jun-04						0.5	0.5	0.95	0.5	1	0.93	0.65	1.6	0.72	0.5	0.5	0.5	0.85	1.3	0.98	0.59	0.62	1.3	1.1	0.5	1	0.5	1.3
Winter	Jul-04	0.68	0.8	1.1	1.1	0.82	0.5	0.63	0.5	0.5	1.1	4.4	0.69	0.7	0.65	0.57	0.5	0.5	0.5	0.5	0.62	0.5	0.5	0.65	0.99	0.5	0.77	1.2	1.2
Winter	Jul-04	0.61	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.65	0.5	1.2	4.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.6	11	9.5
Winter	Aug-04	0.61	0.55	0.5	0.5	0.5	0.5	0.5	0.7	0.56	0.98	4.4	3.3	4.1	2.7	2	1.3	1.4	0.73	0.75	0.55	0.6	1.1	1.5	2	3.1	3.4	7.2	8
Spring	Sep-04	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.55	1	3.8	2.2	4.7	1.4	1.2	1	3.2	2.4	1.4	1.1	1.9	2.2	5.2	2.5	1.5	3	1.1	0.72
Spring	Oct-04	0.71	0.51	0.5	0.5	0.5	2.8	3	6.8	5.7	6.5	4.4	2.4	3.8	1.7	1.8	1.1	18	5.7	10	11	4.5	3	4.6	4.4	5.9	2.6	1.6	2
Spring	Nov-04	1.4	0.95	0.5	0.5	0.5	1.2	3.3	1.1	2.3	1.9	3	2	3.9	1.2	1.8	1.6	30	6.9	6.5	7.9	7.3	4.4	5.2	2.6	3	2.9	2.1	1.9
Summer	Dec-04	0.6	0.6	0.5	0.5	0.5	0.66	0.5	1.3	0.93	1.5	0.63	1		2.4	0.53	0.6	7.7	1.5	3.5	2.4	0.5	1.8	2.5	2.1	2.3	0.5	0.83	1.5
Summer	Jan-05	4.2	2.4	2	1.5	1	2.2	5.6	2.8	1.3	4.2	1.4	2	2.8	0.55	1.2	2.7	28	7.3	5	4.7	6.4	2.9	3.4	2.2	2.3	3.6	2.5	1.3
Summer	Feb-05	1.8	1.5	0.95	1.1	0.95	1.1	2.8	1.4	1.1	3.4	1.7	0.75	0.9	0.85	0.5	0.55	8.4	2.2	2.6	2.4	2.2	3	2.8	2.5	2.2	0.7	0.5	0.5
Autumn	Mar-05	2	1.6	0.8	0.7	0.7	0.55	0.7	0.5	0.5	1.5	3.4	0.85	1.9	0.5	0.55	0.65	10	1.4	1.3	1.1	1.8	2.2	1.6	2.3	3.2	1.1	1.1	1.6
Autumn	Apr-05	2.6	1.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.7	5.6	4.6	4.1	4.5	2.7	2	0.5	0.5	0.5	0.5	0.5	1.4	1.2	2.7	4.4	3.7	2.1	1.9
Autumn	May-05	2.3	1.6	1.2	1.3	1.2	0.5	0.7	0.6	0.8	1.1	1.2	1.3	1.8	1.3	1.3	1.6	1.6	1.5	1.1	0.8	1.1	0.55	0.95	0.7	1.6	1.6	2.8	2.1
Winter	Jun-05	1.5	0.9	0.93	0.67	0.6	0.64	0.5	0.55	0.5	0.55	0.6	0.65	0.55	0.6	0.75	0.9	0.64	0.5	0.5	0.82	0.5		0.5	0.5	0.6	0.8	3.2	11
Spring	Oct-06	1.2	1.2	0.61	0.55	0.5	2.6	2.3	3.8	5	7.2	4.8	2.5	4.3	2.3	1.3	2.5	2.4	2.6	6.5	3.9	3	6.9	3.4	5.3	5.9	4.6	0.79	0.78
Spring	Nov-06	2.1	1.3	1	1.1	1.2	0.5	0.68	0.79	0.86	0.81	6.3	2.3	3	0.51	0.66	1.3	8	2.1	1.2	1.2	2	1.7	1.9	2.3	1.2	2.2	0.65	0.66
Summer	Dec-06	1.5	1.2	1	0.93	0.9	1.8	2.4	5.1	4.7	3.4	4	1.3	3.4	0.99	0.9	0.91	4.2	4.9	5.8	6.7	4.1	3.3	5.8	4	4.1	1.2	0.85	1.2
Summer	Jan-07	1.2	1.1	0.85	0.67	0.5	0.5	2.8	3.2	3.3	3.6	3.1	1.1	1.6	1.6	1.6	1.1	4.4	2.7	2.6	2.5	2	3.2	1.6	2.6	2.7	1.3	0.98	1.3
Summer	Feb-07	2.6	0.5	0.9	0.69	1.5	1.8	3.6	3	3.1	4.2	2.6	2.2	1.7	2	1.7	2.2	8.9	5.2	5.3	5.5	5.4	4	3.4	3.4	2.5	2.5	1	1.8
Autumn	Mar-07	1.6	1.4	1.1	1.1	1.7	1.4	2.2	2.1	2.4	5	4.4	2	1.8	2	1.9	1.6	17	4.9	4.2	3.9	3.3	3.4	5	4.7	4.1	2.1	1.6	1.5
Autumn	Apr-07	2.9	2.2	2.7	2	1.2	2.3	2.3	4.6	6	9.7	4.6	2.3	2.9	2.3	1.7	2.2	13	12	10	14	8.3	9	10	8.6	6	3.9	2.6	2.3
Autumn	May-07	3.8	2.9	2.4	1.6	1.5	1.1	0.62	0.59	0.73	1.5	1.4	1.9	2.3	1.3	2.1	2.1	1.2	0.97	1.8	1.4	1.8	1.3	1.4	1	1	2.3	1.9	2.1
Winter	Jun-07	2.4	2.3	1.3	0.91	0.65	0.87	0.82	0.69	0.55	0.62	0.87	1.2	1.2	0.81	0.73	0.95	0.61	0.5	0.55	0.6	0.5	0.5	0.71	0.67	0.88	0.99	5	0.91
Winter	Jul-07	1.2	1.3	1.1	1	0.63	0.76	0.6	0.5	0.55	0.5	0.66	0.51	0.8	1.5	0.56	0.79	0.6	0.5	0.5	0.5	0.5	0.5	0.51	0.61	0.5	0.55	4.9	2.1
Winter	Aug-07	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	2.5
Spring	Sep-07	0.57	0.5	0.5	0.69	0.5	1	0.5	1.1	2.2	9.4	4.7	3.2	3.5	2.4	3.5	1.9	3.1	3.7	6.6	6.3	3.2	3.8	4	4.8	2.4	5.8	2.7	1.1
Spring	Oct-07	0.5	0.5	0.84	0.8	0.5	0.5	0.5	2.9	5.4	9.8	1.9	2.2	3.2	2.6	0.85	0.8	1.1	2.4	5.6	3.4	2.3	1.5	2.7	4.1	3.2	4.1	3.4	1.6
Spring	Nov-07	2.2		1.8	3.5	3.3	5.3	5	7.7	4.1	8.4	5.3	2.3	3.1	2.3	1.7	2.2	17	5.9	9.8	9.7	5.6	6.9	7.5	4.3	6.1	2.5	2.1	3.8
Summer	Dec-07	0.55	0.8	1.1	1.1	0.85	2.7	2.6	3.4	1.8	2.9	1.4	0.8	0.75	0.5	0.95	1.1	12	2.2	1.4	2	1.5	1.5	1.2	1.8	1.3	0.85	0.6	0.95
Summer	Jan-08	1.3	1.2	1.4	2	1.6	2.9	3.8	3.9	3.1	4.1	2.4	1.6	1.2	0.65	1.1	0.9	10	2.6	3.2	4.4	2.3	3	2.5	3	3	1.9	1.4	1.3
Summer	Feb-08	2.6	1.7	2	2.5	2.9	3.5	3.1	1.7	1.4	2.6	2.2	1.5	1.9	0.9	1.5	1.4	3.5	2.8	2.4	3.4	2.7	2.7	2.8	2.6	2.2	1.6	1.3	2.4
Autumn	Mar-08	1.5	1.3	1.6	3.2	3.9	5.1	5.4	7.1	4.7	7.6	5.5	2.5	3.2	1.9	1.9	2.2	8.8	9.2	9.1	9.7	7.8	7.9	6.5	5	5.7	2	1.5	1.6
Autumn	Apr-08	6.8	6.5	7.7	8.3	9.3	3.3	1.8	1.8	1.6	2.3	10	3.9	4	3.8	2.3	1.7	2.3	1.7	2.1	2.2	1.6	1.1	1.8	3.9	7.1	2.6	2.8	1.5
Autumn	May-08	4.7	3.6	2.8	1.7	1.2	1.1	0.7	0.9	0.9	4.5	4	2.9	1.3	2.1	3.4	2	1.5	2.1	1.2	1.1	1.8	1.4	1.5	1.6	1.4	1.6	1.6	1.4
Winter	Jun-08	4.8	3.8	2.8	2	2.3	1.6	1.2	0.9	0.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1.6	1.4	2	1.1	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Winter	Jul-08	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.3	3.8	4.7	4.6	2.6	3.6	4.1	0.5	0.5	0.5	0.5	0.5	2.3	2.8	3.5	3.7	4.7	2.7	2
Winter	Aug-08	1.9	1.6	1.6	1.3	0.9	1.1	0.9	1.5	1.9	1.6	2.5	3.8	2.8	3.1	3.5	3.4	1.3	3.3	3.2	3.4	2.2	1.3	1.2	1.8	2.1	3.3	3.5	2.6
Spring	Sep-08	1.4	1.5	0.8	0.8	1.4	0.9	0.8	0.9	0.8	6.4			6.3	5.3	4.2		1.8	0.9	0.9	1	0.9						2.5	
Spring	Oct-08	0.9	0.8	0.7	1.4	1.3	1.7		1.9	1.9	8.8			2.2	3.7	3.6												1	
Spring	Nov-08	2.1	1.6	1.9	1.8	2	2.4		3.9	3.9	4.4			4.4	2.3	3.5												1.9	
Summer	Dec-08	1.2	1	0.6	0.9	1.6	2.8		2.6	2.6	5.9			2.1	0.9	0.8												1.7	

▨ = blooms >4 micrograms/L (ANZECC, 2000) a few months. Reported blooms for *G. catenatum* have occurred from October to May, but there is evidence (from 2008) that the growing season may be extending through the winter months (G. Hallegraeff, 2008, University of Tasmania *pers. comm*.).

A recent arrival to the Derwent estuary is the dinoflagellate *Noctiluca scintillans*, which had previously only occurred along the coast of the Australian mainland. This species causes a conspicuous pink-red discolouration of surface waters when in bloom, and was first observed in Tasmanian coastal waters in 1994 having been transported here by the East Australian Current. Following major blooms in 2001 it has become permanently established in the State, and since 2003 can be found year round in the water column in eastern and southern Tasmania (Ajani *et al*. 2001, Albinsson *et al*. 2006). When in bloom *Noctiluca* can cause fish deaths and skin irritations in humans .(Source: University of Tasmania, harmful algal species website: http://www.utas.edu.au/docs/plant_science/hab).

Nutrient and chl a concentrations may not always be representative indicators of ecosystem health, particularly in parts of the Derwent estuary where algae may experience light limitation and a relatively rapid rate of tidal and freshwater flushing. Other indicators of nutrient enrichment, such as dense macroalgae beds in intertidal areas, filamentous or epiphytic algae overgrowth of seagrass beds or losses of seagrass and macrophyte habitat may be more appropriate. There is little quantitative data on the distribution or biomass of nuisance macroalgae within the Derwent estuary. In spring to early summer, a line of bright green lettuce-leaf-like macroalgae (*Ulva sp.*) can often be observed growing along the rocky intertidal shorelines of the middle estuary, suggesting some degree of response to nutrient enrichment. At times this macroalgal growth smothers the intertidal habitat, for example in Prince of Wales Bay during the summer of 2008-09 (J. Whitehead, 2009, DEP *pers. obs.*). Epiphytic algal overgrowth has also been observed on seagrass beds in the middle estuary and on macrophyte beds in the upper estuary. Information on seagrass and macrophyte distributions and trends is provided in **Section 9**.

6.1.6 Organic matter

Large inputs of organic matter into an estuary may stimulate bacterial production, resulting in low DO levels. At higher loading rates, organic matter may accumulate as organic-enriched sediments, characterised by low DO and impoverished benthic fauna and flora. In extreme cases, organic matter may accumulate as sludge deposits, accompanied by anoxia, death of benthic organisms and production of unpleasant or toxic gases such as hydrogen sulphide and methane. Organic matter also has a strong affinity for metals, hydrocarbons, pesticides, and many other contaminants, and may adsorb these substances if present in the water column, and then transfer them through the food chain or sequester them in sediments. Major sources of organic matter to the Derwent estuary include catchment inputs of decaying vegetation, chemical leaching of organic-rich soils, *in-situ* production (particularly by phytoplankton, marine algae and seagrasses) and anthropogenic sources – including the Boyer paper mill, WWTPs and urban runoff.

Organic matter within the Derwent estuary water column has been monitored both as total organic carbon (TOC) and as dissolved organic carbon (DOC). Comparison of mean TOC and DOC data indicate that the vast majority of organic carbon measured in the estuary is in the dissolved form. This relationship holds true throughout the estuary, both at the surface (97% DOC) and at depth (98% DOC).

Results for the six year period – summarised in **Figure 6.14** – show that median TOC levels ranged from <1.0 to 4.5 ug/L, with the highest values observed in surface waters of the upper estuary. The median TOC concentration at New Norfolk was 3.1 mg/L in surface waters (2.6 mg/L in bottom waters), increasing to a maximum of 4.5 mg/L in the vicinity of the Norske Skog effluent outfall (site U16/17) – reflecting the high organic load discharged at this point until October 2007 (see **Section 4.2.2**). From this point, median TOC concentrations decreased with distance downstream, and were generally higher in surface waters influenced by freshwater flows than in more marine-influenced bottom waters. Embayments in the middle estuary had higher median TOC levels than those from the lower estuary, suggesting additional sources and/or retention of organic carbon in these areas.

6.1.7 Water clarity, colour and total suspended sediments

The optical quality of water, particularly its clarity and colour, is determined by the attenuation of light as it passes through the water column. Optical properties in water bodies are important because:

- many predatory fish (and some predatory birds) rely on clear water to see their prey;
- changes in water colour can alter the spectral distribution of underwater light available for photosynthesis and illumination;
- attenuation of light through the water column can limit the growth of plants reliant on photosynthesis such as plankton, seagrasses and macrophytes, and benthic microalgae;
- decreased light penetration and high total suspended solids (TSS) can reduce DO levels due to decreased photosynthesis, greater heat absorption and increased decomposition of organic matter; and

Figure 6.14: Total organic carbon carbon levels in a) surface waters and b) bottom waters (Jan 2003 – Dec 2008)

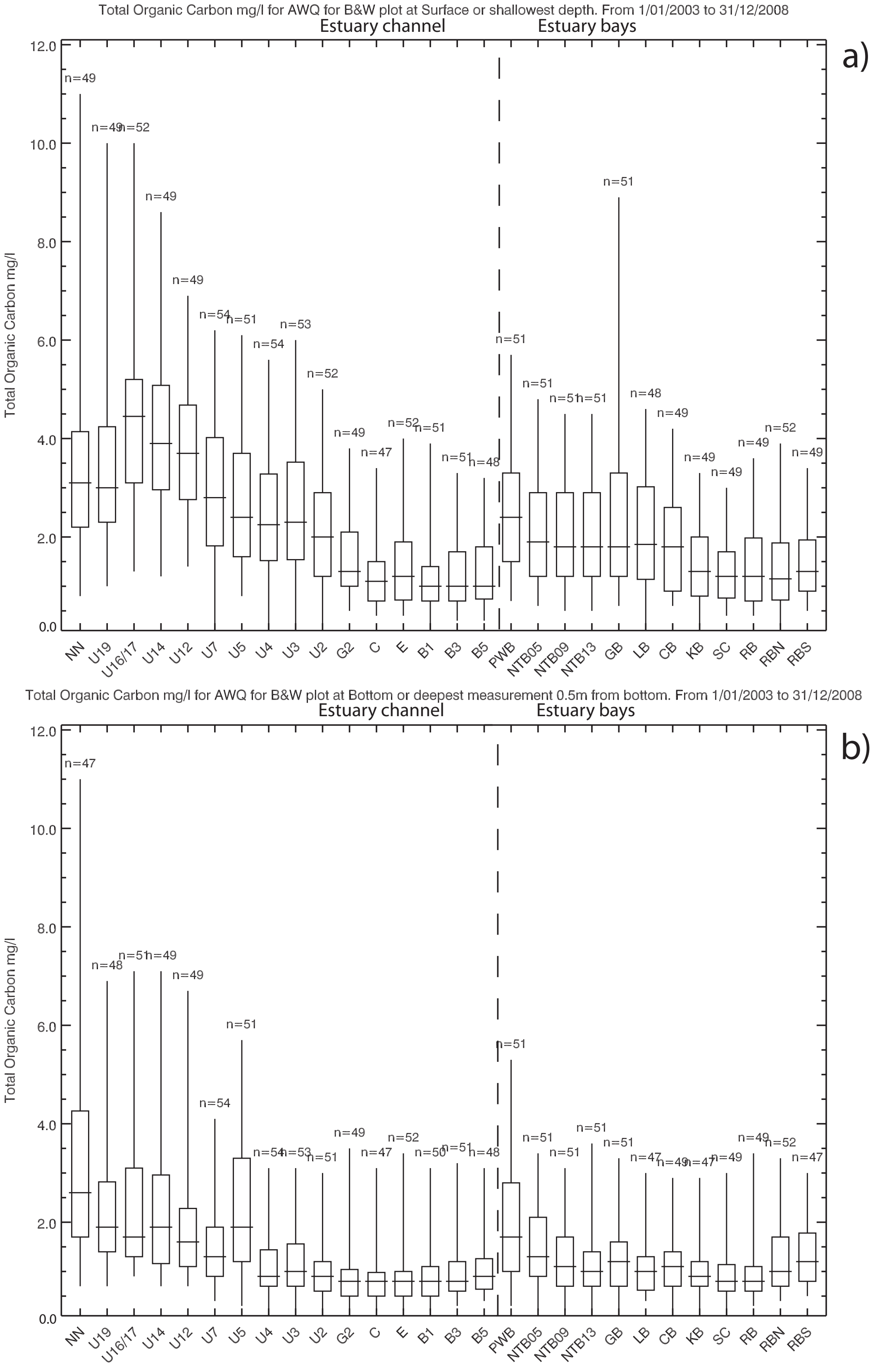
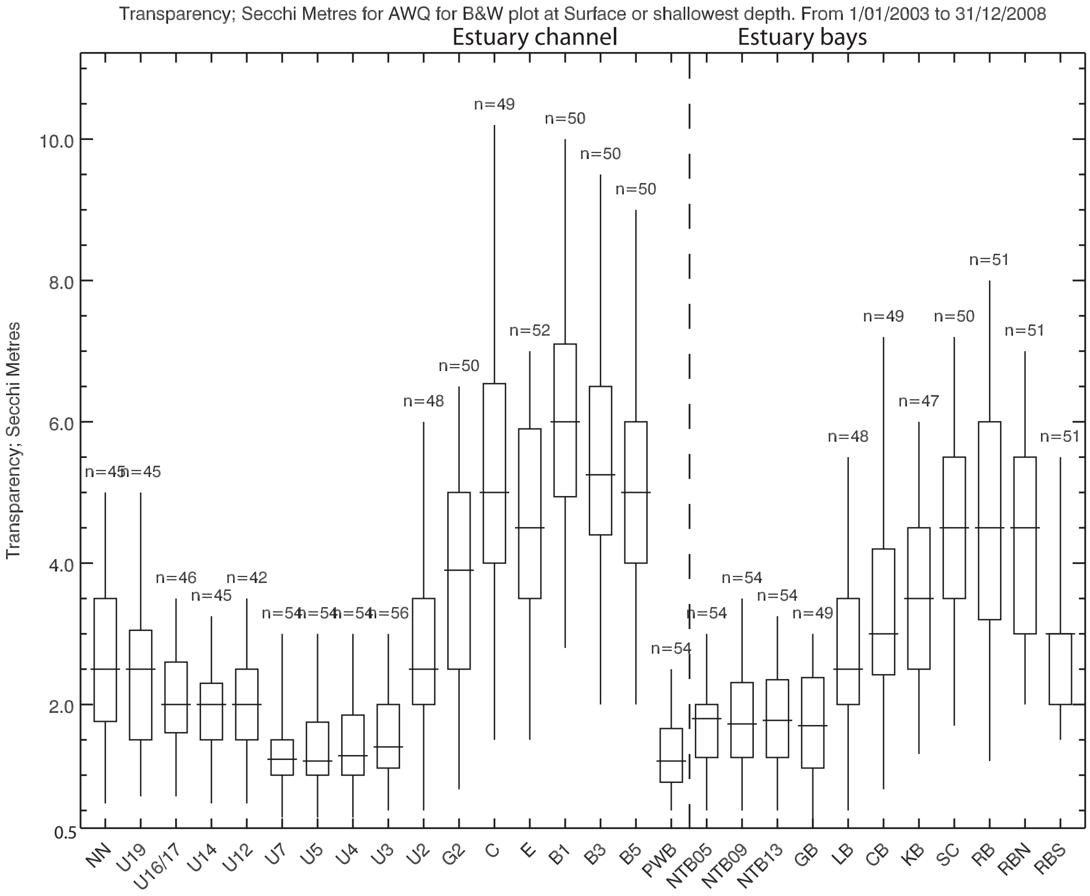


Figure 6.15: Secchi disc depth (Jan 2003 – Dec 2008)



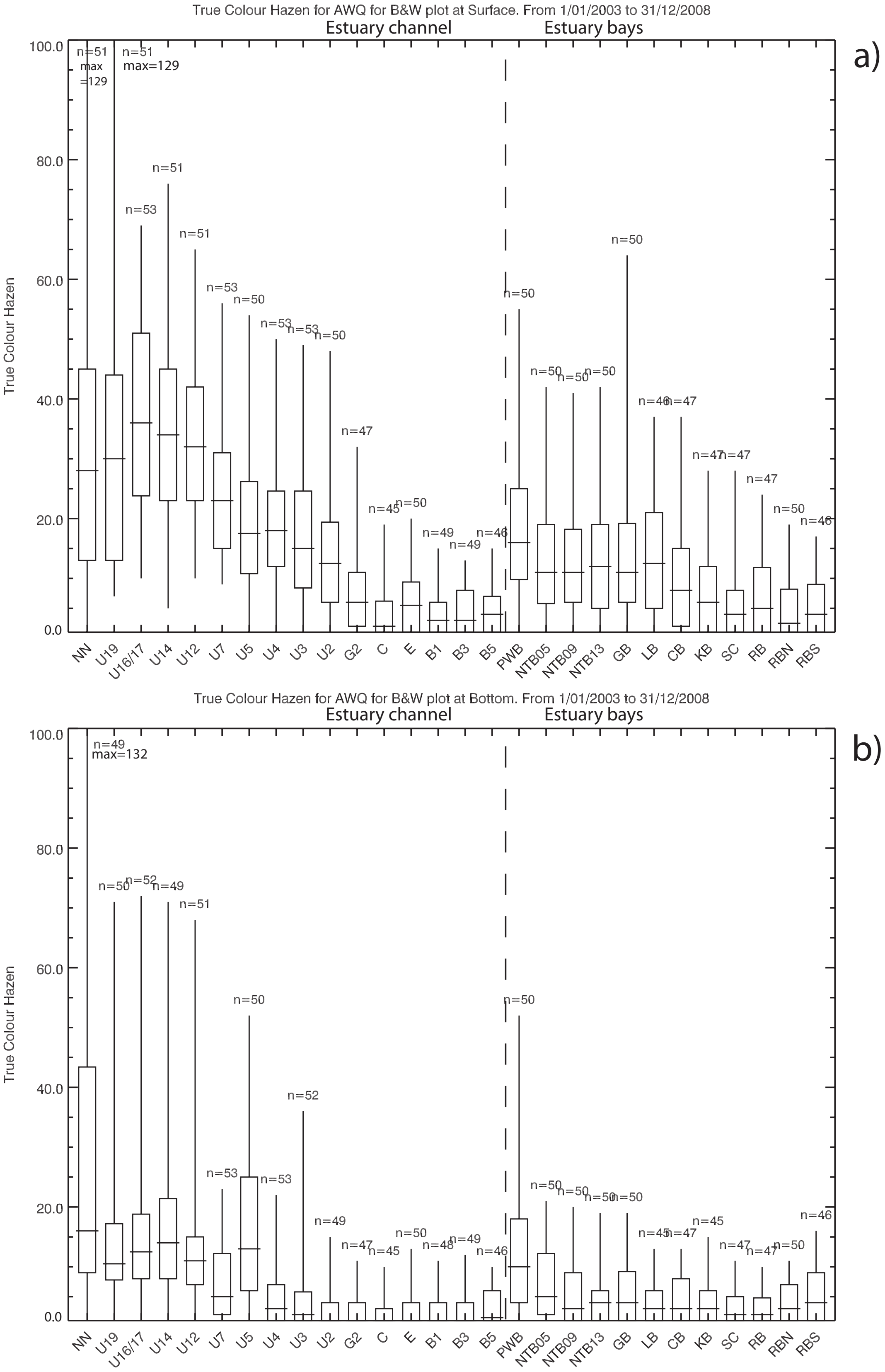
- high levels of TSS and colloidal materials can clog fish gills and foul filter-feeding organisms, smother fish eggs and bottom dwelling organisms and alter substrate conditions required by estuarine species (ANZECC 1992, USEPA 2002).

Water clarity or transparency is the distance that objects can be viewed through the water column. Water clarity in the Derwent is measured using a black and white 'Secchi disc', which is lowered over the side of the boat. The water depth at which the disc is no longer visible is recorded as the Secchi depth (SD) and can be used to calculate the euphotic depth (Z_e). This is the depth at which photosynthetically active radiation (PAR) is reduced to 1% of the level at the waters surface, whereby $Z_e = 2 \times SD$ (Aarup 2002). Aquatic plants cannot grow at depths greater than the euphotic depth due to light limitation, unless they are mobile and can move vertically through the water column (e.g. dinoflagellates).

Secchi depth observations for the period Jan 2003 to Dec 2008 – summarised in **Figure 6.15** – indicate that median SD ranged from 1.0 to 6.0 m, with the lowest values observed at mid-estuary sites and adjacent embayments and the highest values observed at lower estuary sites and in Ralphs Bay. The median SD was also relatively lower in the shallow waters of Ralphs Bay South (RBS) where wind disturbance of sediments may reduce water clarity. In the upper estuary, the SD was greatest in summer and early autumn, probably as a result of lower rainfall and runoff in the catchment, resulting in lower river flow.

Turbidity is another measure of water clarity or murkiness. It is an optical property that expresses the degree to which light is scattered and absorbed by molecules and particles, and is influenced by both coloured dissolved organic matter as well as suspended particulate matter in the water column (OzCoasts website). Turbidity is measured using a nephelometer as Nephelometric Turbidity Units (NTUs). In the Derwent estuary, turbidity measurements have only been collected for middle-to-lower estuary sites over the monitoring period. Median surface water turbidity levels averaged over this area were very low at 1.2 NTU. Turbidity values from slightly disturbed estuarine

Figure 6.16: True colour levels in a) surface waters and b) bottom waters (Jan 2003 – Dec 2008)



True Colour Hazen for AWQ for B&W plot at Surface. From 1/01/2003 to 31/12/2008

True Colour Hazen for AWQ for B&W plot at Bottom. From 1/01/2003 to 31/12/2008 to coastal marine ecosystems throughout southeastern Australian typically range between 0.5 to 10 NTU (ANZECC 2000).

The visible colour of water is the result of different light wavelengths absorbed by the water itself or by dissolved and particulate substances present. Colour can be measured as both true and apparent colour in water. Apparent color is the color of the whole water sample, and is influenced by both dissolved and suspended components. Apparent colour is thus partially caused by the reflection and refraction of light on suspended particulates, including some species of plankton which are highly coloured. True colour is measured using water samples which have been filtered to remove all particles, such that the colour reflects the optical effects from dissolved substances in the water. Dissolved natural minerals such as ferric hydroxide and organic substances such as humic acids give true colour to water.

True colour observations for the six-year monitoring period are presented in **Figure 6.16**. Median values range from <1 to a maximum of 36 Hazen units, with the highest values observed in surface waters of the upper estuary and in the vicinity of the highly-coloured Norske Skog paper mill outfall. It has been observed that in the upper Derwent estuary the true colour of the water co-varies with DOC. A notable DOC component is humic acid (derived largely from microbiological breakdown of plant material), which tends to vary within the estuary depending upon relative inputs from the River Derwent. Total suspended solids (TSS) (also called suspended particulate matter) consists of silt and clay, phytoplankton, decaying organic matter and other particles derived from both natural and anthropogenic sources. Light availability is reduced during periods of high TSS, and particulate material can also acts as a sponge, adsorbing nutrients, heavy metals and hydrocarbons. TSS is a measure of the particulate load carried by the water column in the estuary, which varies in response to river discharges, wind and tidal mixing, phytoplankton blooms and other factors. The largest external source of TSS to the estuary is the River Derwent, whilst more localised sources include stormwater runoff, industrial and WWTPs. TSS concentrations are typically higher during periods of high river flow or in shallow areas where wind-driven resuspension of sediments occurs. TSS concentrations are also affected by river flow rates (influencing particle sinking time), salinity levels (enabling clay flocculation) and wind speeds (estuary bed scouring).

Median TSS concentrations in the Derwent estuary – illustrated in **Figure 6.17** – are relatively low, ranging from 2 to 6 mg/L. TSS levels are typically somewhat higher at depth than in surface waters, with the highest values observed in bottom waters of the upper-middle estuary, in the area between the Bridgewater Bridge (site U12) and Dogshear Point (site U7). This may reflect an important zone of sediment deposition (clay flocculation), where colloidal clay carried in fresh river water interacts with saltier marine waters at depth.

6.1.8 Heavy metals

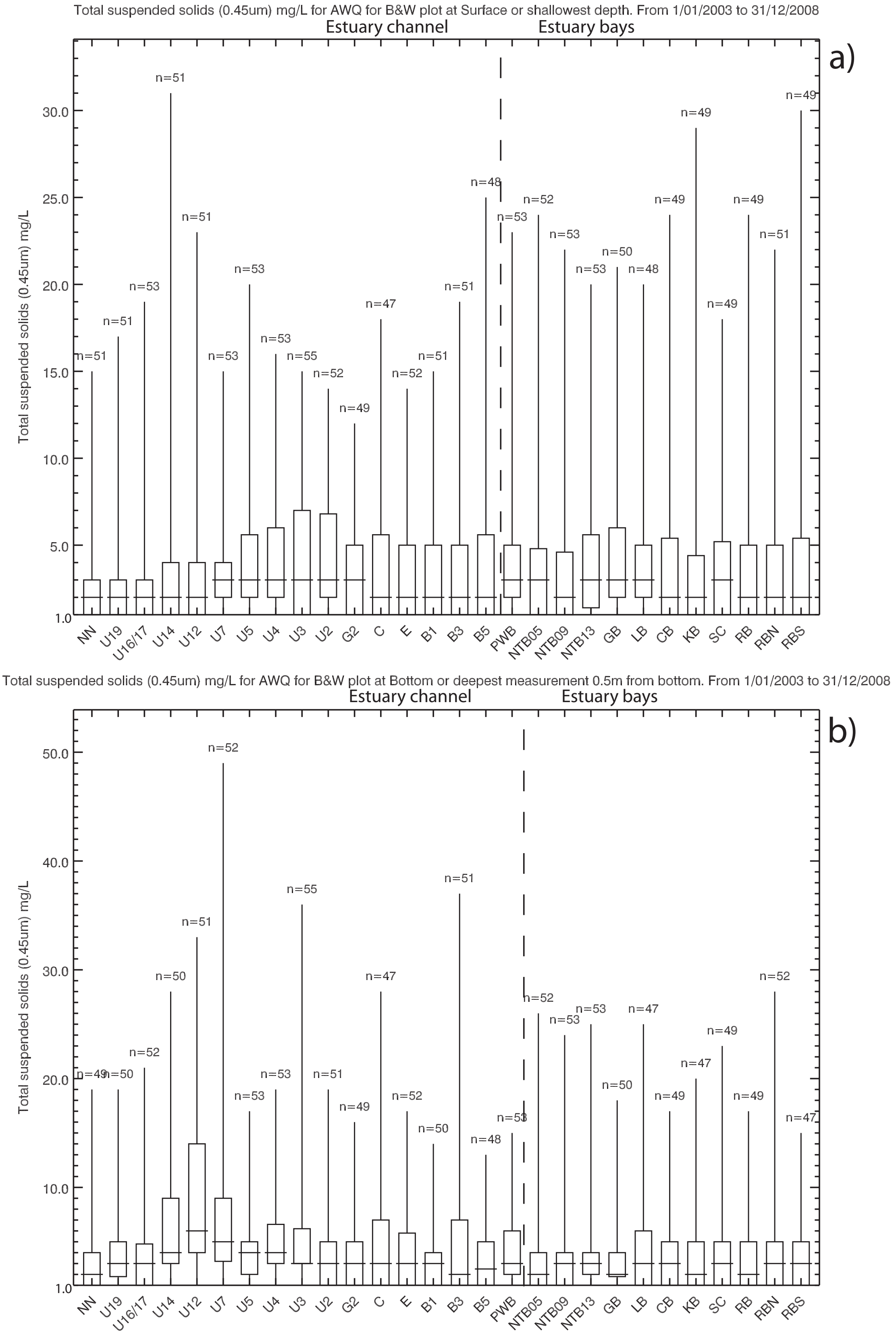
Heavy metals in aquatic systems are derived from both natural and human sources. Natural sources include the weathering of rocks and leaching from soils, while anthropogenic sources include automobile emissions, power plants, mining and industrial wastes (particularly smelting, refining and electroplating). As heavy metals rapidly sorb to particulate matter, they tend to accumulate in bottom sediments of estuaries and other aquatic ecosystems. Estuarine organisms can accumulate heavy metals from seawater, bottom sediments, interstitial waters or their food supply. The accumulation of heavy metals by marine organisms is a function of many factors, such as temperature, salinity, diet and spawning (Kennish 1996).

Heavy metals are persistent in the environment, where if they are present above a threshold availability, they pose potentially hazardous conditions due to their toxicity to estuarine and marine organisms. Heavy metals may be subdivided into two categories: i) transitional metals (e.g. cobalt, copper, iron, manganese) which are essential to metabolism at low concentrations but may be toxic at high concentrations, and ii) metalloids (e.g. arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), selenium, tin) which are generally not required for metabolic function and are toxic at low concentrations (Kennish 1996). An approximate order of decreasing toxicity of common metals is: mercury, cadmium, copper, zinc, nickel, lead, chromium, aluminum and cobalt, however toxicity can vary significantly between different organisms (Kennish 1996).

Cadmium and mercury are highly toxic to aquatic organisms at very low concentrations, and also represent significant health hazards to humans. Inorganic forms of mercury have a relatively low toxicity to biota but are readily converted to more toxic organo-mercury forms. The most toxic form of mercury is methylmercury which is highly toxic, resistant to environmental degradation and is rapidly taken up by aquatic organisms.

Physico-chemical conditions in the water column and sediments influence the specific form or 'species' of metals, which in turn determines their potential to enter the ecosystem. Species in solution are generally more bio-available and potentially more toxic than metals bound to particulate material.

Figure 6.17: Total suspended solids levels in a) surface waters and b) bottom waters (Jan 2003 – Dec 2008)



The main sources of heavy metal contamination to the Derwent estuary have historically been the zinc smelter at Lutana and the paper mill at Boyer. The zinc smelter began discharging metallurgical liquid effluent containing heavy metals to the Derwent estuary when it was established in 1917. In recent years, the smelter's point source discharges have been greatly reduced, however diffuse sources still contribute significant heavy metal loads, particularly via groundwater (see **Section 4.2.1**). The newsprint mill also discharged heavy metals to the estuary in the past, including mercury which was historically used as a slimicide, and in association with the chlor-alkali plant (which closed in 1993). Zinc was also present in emissions from the paper mill due to the former use of zinc hydrosulphite as a brightening agent.

National heavy metal guidelines

The National Water Quality guidelines for toxicants (ANZECC 2000) specify trigger levels for the protection of aquatic ecosystems at four different protection levels: 99%, 95%, 90% and 80%, whereby the protection level signifies the percentage of species expected to be protected. The highest protection level (99%) is chosen as the default value for ecosystems with high conservation value and the 95% trigger value could apply to ecosystems classified as slightly-to-moderately disturbed (ANZECC 2000). For ecosystems that can be classified as highly disturbed it may be appropriate to apply a less stringent guideline trigger value, such as 90%, or perhaps even 80%, depending upon the management goals for the particular ecosystem. Trigger levels for selected heavy metals in marine waters are presented in **Table 6.4**.

Heavy metals in Derwent estuary waters

Heavy metals have been monitored periodically in Derwent estuary waters since the early 1970s. Data collected up until 1997 (reviewed in the 1997 *State of the Derwent Estuary* report) showed high values of some metals, particularly in the middle estuary, and noted that significant reductions had occurred over this 25-year time frame. Since 2000, heavy metals have been monitored as part of the DEP's ambient water quality monitoring program. Initially, a wide range of metals were monitored, however as most concentrations were found to be below detectable levels, monitoring has subsequently focused on zinc. The Nyrstar Hobart smelter has continued monitoring a broader suite of heavy metals within the water column at a number of Derwent estuary sites – primarily in New Town Bay – however concentrations of other heavy metals have rarely been above detectable levels (see Nyrstar EMPs for further details).

As discussed in **Section 5**, zinc is considered to be indicative of the behavior of most other heavy metals in the Derwent (with the exception of mercury) and has been used as the basis for toxicant modeling Comparison of total and dissolved zinc analyses indicates that dissolved zinc accounts for the majority of the observed concentrations. Typically 85% of total Zn in surface water samples is in dissolved form, and 77% of total Zn in bottom water samples is dissolved. This suggests that the majority of zinc in the water column may be fairly bioavailable.

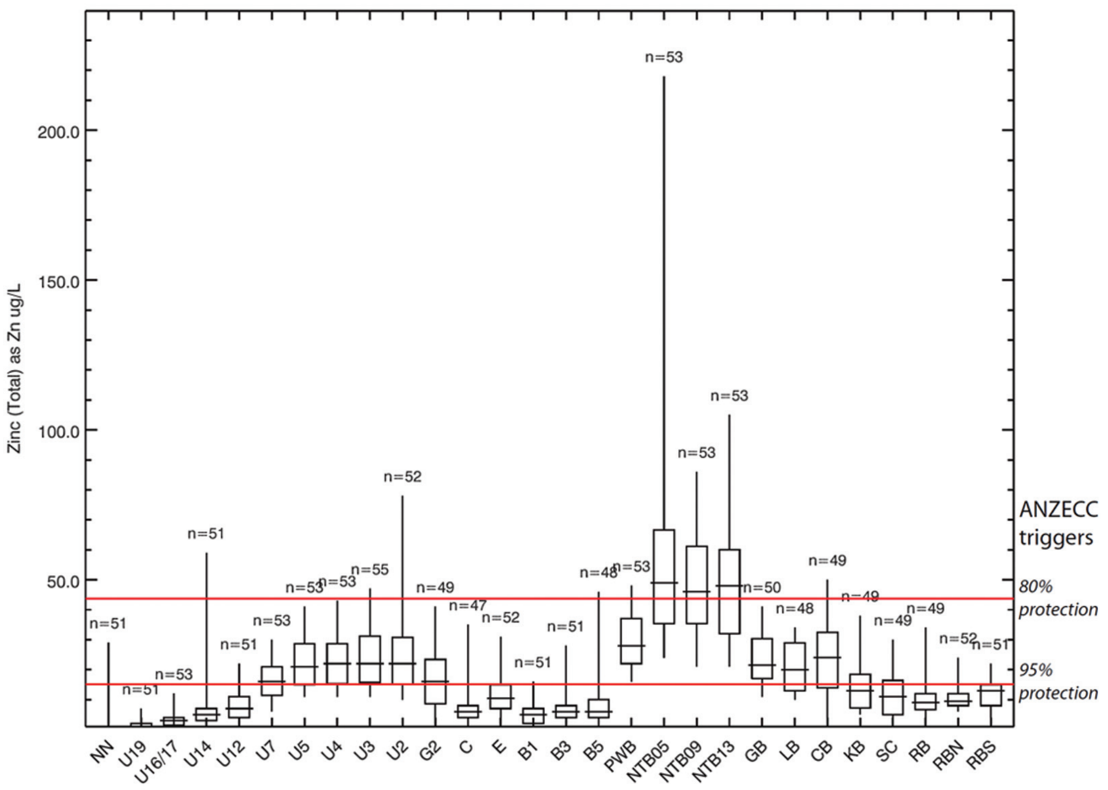
Monitoring data for the period Jan 2003 to Dec 2008 – summarised in **Figure 6.18** – indicate that median total

Table 6.4: ANZECC guidelines for heavy metals in marine waters

Metal (total) ug/L	**ANZECC Marine Guidelines (2000) (Trigger levels)**			
	99%	**95%**	**90%**	**80%**
Cadmium	0.7	5.5	14	36
Chromium	0.005	4.4	20	85
Cobalt	0.3	1	14	150
Copper	2.2	1.4	3	7
Lead	0.1	4.4	6.6	12
Mercury	0.14	0.4	0.7	1.4
Nickel	14	120	290	750
Zinc	7	15	23	43

Figure 6.18: Total zinc levels in a) surface waters and b) bottom waters (Jan 2003 – Dec 2009)

Zinc (Total) as Zn ug/L for AWQ for B&W plot at Surface or shallowest depth. From 1/01/2003 to 31/12/2008



Zinc (Total) as Zn ug/L for AWQ for B&W plot at Bottom or deepest measurement 0.5m from bottom. From 1/01/2003 to 31/12/2008

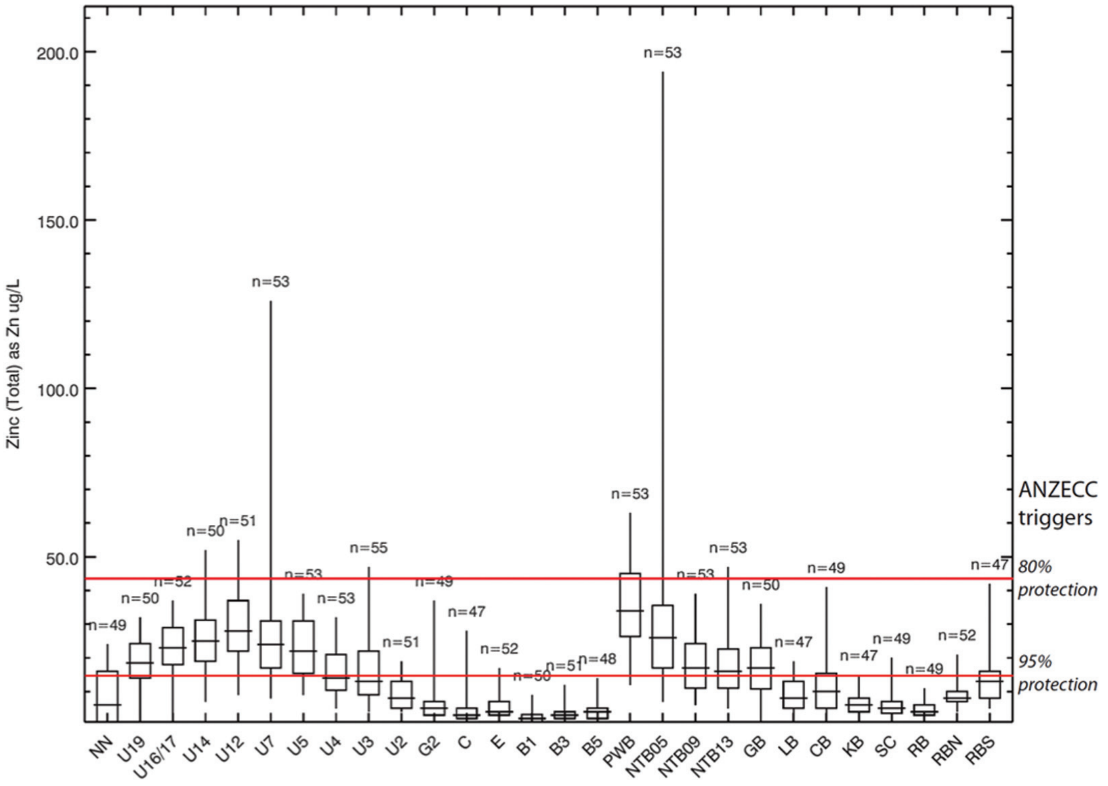


Figure 6.19: Mean DOC and TOC values in surface and bottom waters during 2003-05 (RED) and 2006-08 (BLUE) monitoring periods

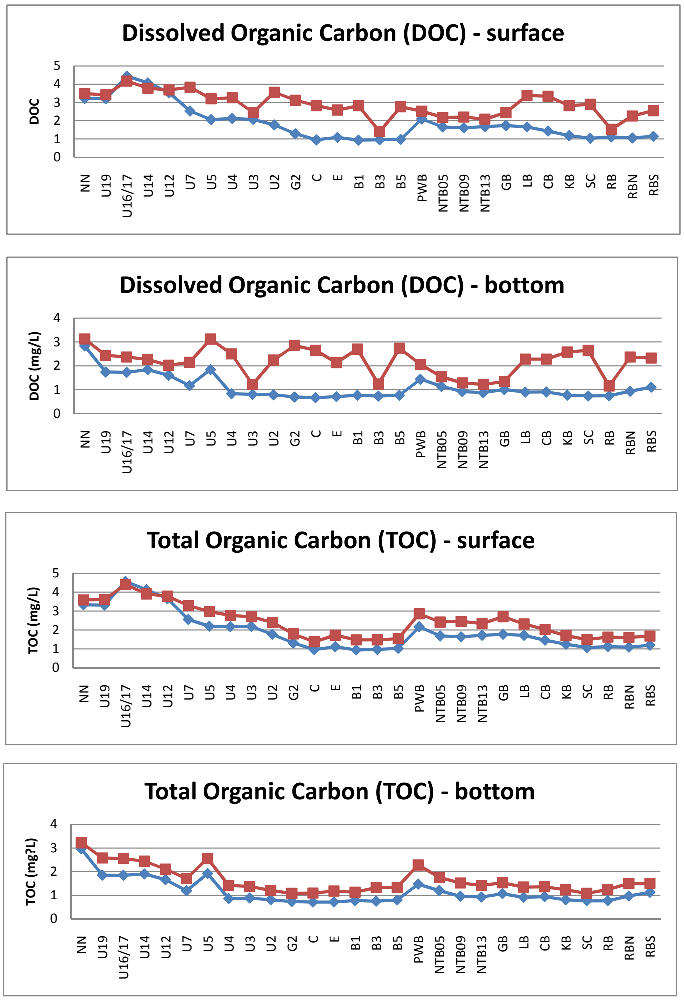
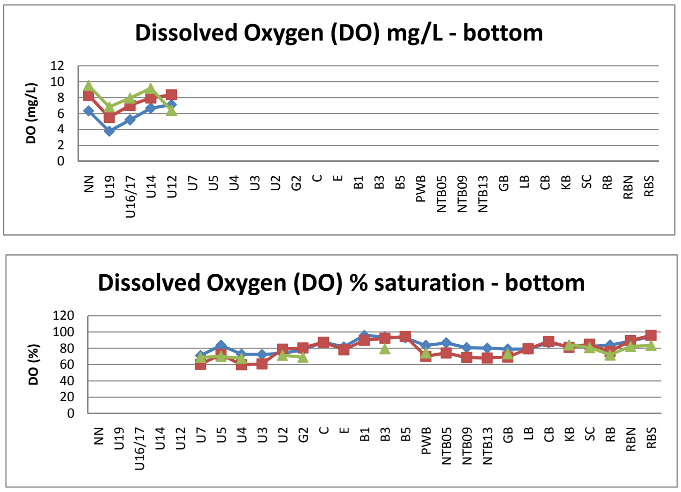


Figure 6.20: Mean dissolved oxygen values in bottom waters (in mg/L and % saturation) during 2000-02 (GREEN), 2003-05 (RED) and 2006-08 (BLUE) monitoring periods



zinc levels ranged from <2 to 50 ug/L, with the highest values observed in surface waters and embayments of the middle estuary (particularly in New Town Bay). Total zinc levels were also elevated at depth in the middle-to-upper estuary, with median zinc levels peaking at nearly 30 ug/L in the vicinity of the Bridgewater Causeway (U12). This distribution pattern of zinc in the estuary is related both to the location of the primary source at the zinc works, as well as the salt-wedge estuarine circulation system, whereby more saline bottom water travels slowly up-estuary carrying with it any entrained contaminants. The gradual increase in zinc levels in bottom waters between U3 and U12 also suggests that there may be some additional inputs from contaminated sediments in this region of the estuary. See **Section 5** for further discussion of the heavy metal geochemistry of Derwent sediments.

As illustrated in **Figure 6.18**, median zinc levels exceed the ANZECC (2000) trigger levels for the protection of 95% of marine species in surface waters and embayments of the middle estuary, with particularly high levels in Newtown Bay (where median levels exceed the 80% trigger level). The 95% trigger level is also exceeded in bottom waters of the middle-to-upper estuary.

6.1.9 Water quality trends through time

This section reviews longer-term water quality trends over the period 2000 to 2008. Mean values of number of key water quality parameters are compared over three monitoring periods, specifically:

- January 2000 through December 2002 (as reported in the 2003 *State of the Derwent Estuary* Report);
- January 2003 through June 2005 (monitoring phase 1 of the current report); and
- January 2006 through December 2008 (monitoring phases 2 and 3 of the current report).

As noted in the following sections, a number of significant changes over time were identified based on a one-way analysis of variance (ANOVA; a = 0.05 significance level). However, some caution is advised in the interpretation of these longer-term trends as differences in monitoring design over the three monitoring periods could slightly bias the findings. In particular, fewer samples were collected during the 2000 – 2002 period than in subsequent periods due to a lower monitoring frequency (quarterly vs monthly). Also, there were proportionally fewer winter observations in interval 2 (2003 – 2005) as compared to interval 3 (2006 – 2008), which could bias interpretation of those parameters that have a strong seasonal signal (e.g. TOC and TN).

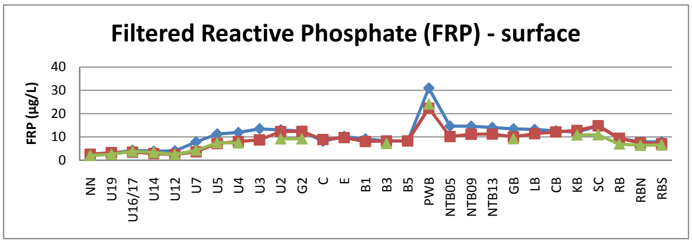
Mean values for dissolved oxygen, organic carbon, nutrients, chlorophyll a and zinc are plotted in **Figures 6.19** through **6.26** for the three monitoring intervals. In each figure, mean values for mid-channel estuarine sites are plotted on the left-hand side, while values for embayments are displayed on the right-hand side. See **Figure 6.1** for the location of sampling sites. In general, the mean values of many of the parameters have been relatively consistent over the three monitoring intervals, as have the estuarine-wide distribution patterns. However, there are some significant differences, as discussed in the sections below.

River Derwent flow has a direct influence on the observed concentrations of a number of parameters, particularly TSS, TN and organic carbon. As discussed in **Section 3.4.1**, annual flows have varied considerably over the 2003 to 2008 monitoring period. Mean monthly river flows during the 2003 – 2005 interval were relatively high, whereas the 2006 – 2008 interval was characterized by very low flows. The influence of river flow can be clearly seen in the trend diagrams for DOC and TOC (**Figure 6.19**) as well as TN (**Figure 6.23**), which show significantly higher DOC, TOC and TN levels during the 2003 – 3005 interval as compared to the 2006 – 2008 interval. For DOC and TOC, these differences were found to be statistically significant at two-thirds of the monitoring sites (surface and bottom), whereas for TN there were significant differences at about half of the surface sites and two-thirds of the bottom sites (based on one-way ANOVA analysis).

During sustained periods of low River Derwent flow, the upper estuary experiences strong stratification whereby the denser and deeper saltwater layer becomes relatively static – unable to mix with the well-oxygenated fresher water layer above and not replenished by DO richer marine waters. Under these conditions, dissolved oxygen can be rapidly depleted, particularly where sediments contain large amounts of organic material. **Figure 6.20** clearly shows this effect, with significantly lower DO levels observed in the upper estuary (sites NN, U19, U16/17 and U14) during a relatively persistent period of low River Derwent flow between 2006 – 2008. Low DO levels can influence sediment chemical processes on the estuary floor, resulting in the release of some nutrients and heavy metals, as discussed below.

Mean values of total phosphorus and filtered reactive phosphate have been relatively consistent between the monitoring intervals – particularly in surface waters – showing a gradual downstream increase from New Norfolk towards the estuary mouth (**Figures 6.20** and **6.21**). Australian soils are typically low in phosphates, explaining the relatively low concentrations in River Derwent water. However significant increases in the concentrations of TP – and particularly FRP – have occurred in several locations, particularly at depth in the upper estuary and in Prince of Wales Bay. The increase

Figure 6.21: Mean filtered reactive phosphate values in surface and bottom waters during 2000-02 (GREEN), 2003-05 (RED) and 2006-08 (BLUE) monitoring periods



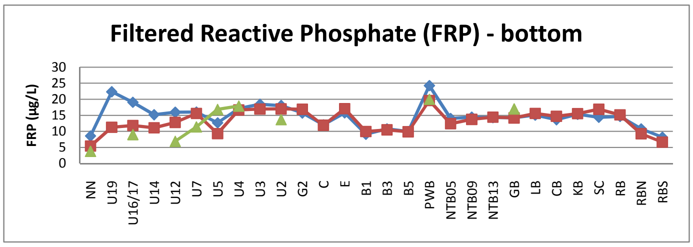


Figure 6.22: Mean total nitrogen and total phosphorus values in surface and bottom waters during 2000-02 (GREEN), 2003-05 (RED) and 2006-08 (BLUE) monitoring periods

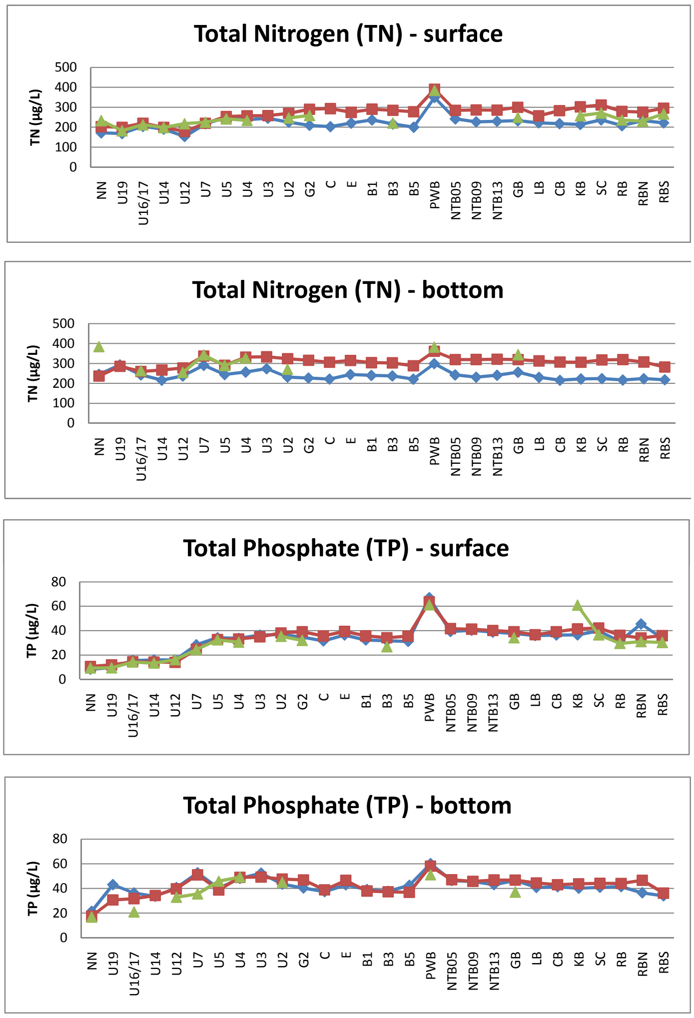


Figure 6.23: Mean nitrate + nitrite and ammonia + ammonium values in surface and bottom waters during 2000-02 (GREEN), 2003-05 (RED) and 2006-08 (BLUE) monitoring periods

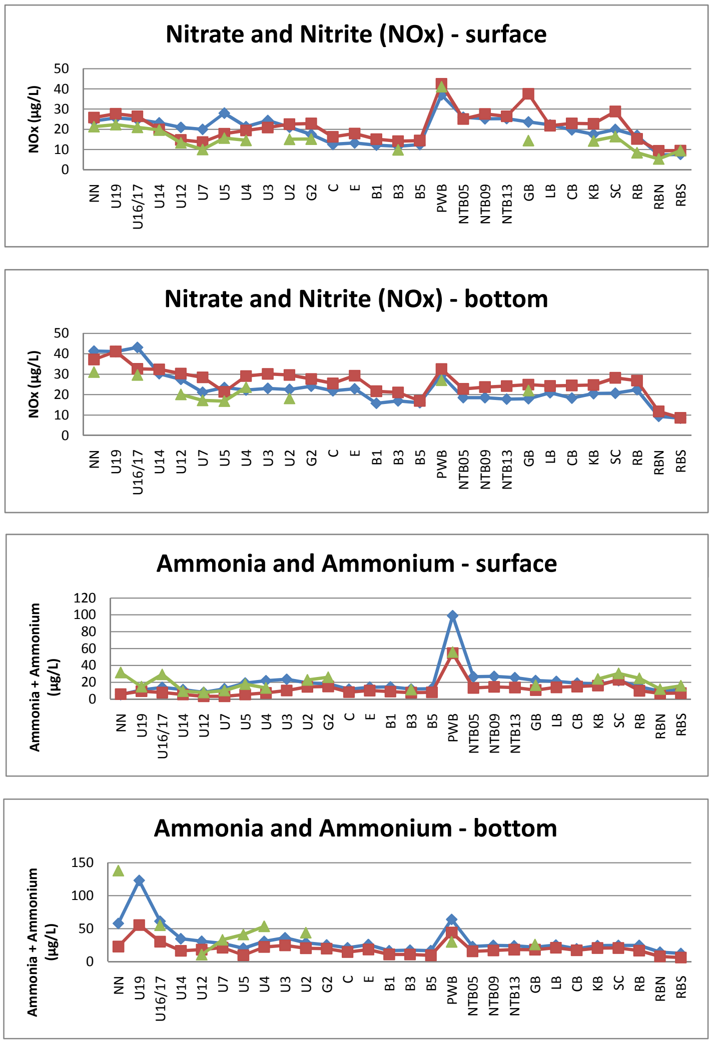
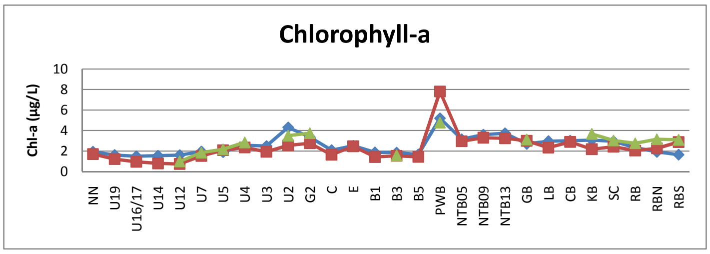


Figure 6.24: Mean chlorophyll a values in surface and bottom waters during 2000-02 (GREEN), 2003-05 (RED) and 2006-08 (BLUE) monitoring periods



in FRP levels in the bottom waters of the upper estuary are probably related to the low oxygen levels observed in this area during low river flows, resulting in a release of FRP from bottom sediments. In Prince of Wales Bay, the increased FRP levels could be related to WWTP discharges and/or to inputs from the nearby phosphate fertilizer plant.

The soluble forms of nitrogen, as nitrate + nitrite (NO_x) and ammonia + ammonium, do not appear to show significant trends associated with changes in River Derwent flow (**Figure 6.23**). NO_x levels did not show significant differences between the three sampling intervals. However significant increases in levels of ammonia + ammonium were observed in several locations, specifically at depth in the upper estuary and in Prince of Wales Bay. As was the case for FRP, the increase in ammonium levels in the bottom waters of the upper estuary are probably related to the low oxygen levels observed in this area during low river flows, resulting in a release of ammonium from bottom sediments. In Prince of Wales Bay, the increased levels may be related to changes in WWTP discharges. Interestingly, there was relatively less algal growth in PWB in 2006-08, compared to that in 2003-05, although more ammonia + ammonium was available.

Mean chlorophyll a levels (an indicator of algal production) observed over the three monitoring intervals are shown in **Figure 6.24** and were relatively consistent, with few significant changes. The exception to this was in Prince of Wales Bay, where chl a levels declined between the 2003-2005 and 2006-2008 monitoring periods.

Heavy metal emissions from the zinc refinery at Lutana have declined significantly in recent years, as discussed in **Section 4.2.1**. As part of the *Derwent Estuary Water Quality Improvement Plan for Heavy Metals* (DEP 2007), a review of all previous heavy metal monitoring data in Derwent estuary waters was carried out. **Figure 6.25** shows the levels of total zinc observed in surface waters between 1971 and 2006 at a site immediately downstream of the zinc works (Site U2). This figure confirms that there has been a substantial reduction in zinc concentrations in the Derwent estuary since the 1970s and 1980s when values exceeding 1,000 ug/L were occasionally recorded (Bloom 1975; Coughanowr 1997).

Total zinc concentrations in surface and bottom water samples over a shorter time period (2000 to 2008) are presented in **Figure 6.26**. This figure shows a remarkable consistency in the distribution of zinc concentrations throughout the estuary over the three sampling periods, with very few significant differences between the 2003-2005 and 2006-2008 intervals. However the data suggests a statistically significant increase in zinc concentrations at depth in the middle to upper estuary since the 2000-2002 interval. The cause of this is unclear, as there is no known source of increasing zinc emissions in this region. It is possible this could be an artefact of the monitoring design or related to a change in sediment geochemistry, allowing increased flux of zinc from the sediments to the water column.

Figure 6.25: Annual average zinc concentration (μg/L) at Site U2 from 1971 to 2004. Data gap indicates no routine monitoring conducted by DEPHA. (Source: DEP 2007).

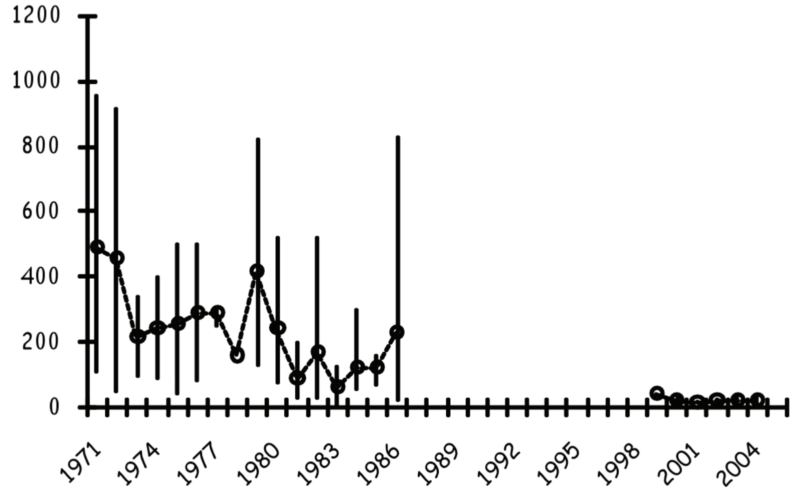
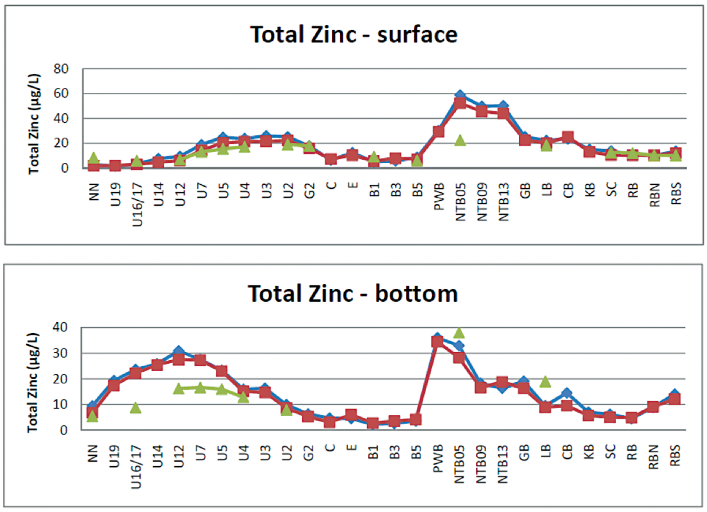


Figure 6.26: Mean total zinc values in surface and bottom waters during 2000-02 (GREEN), 2003-05 (RED) and 2006-08 (BLUE) monitoring period



6.2 Pathogens and faecal indicator bacteria

6.2.1 Pathogens and health risks

Water contaminated by sewage and animal faeces may contain pathogenic micro-organisms (bacteria, viruses, protozoa) which pose a health hazard when the water is used for recreational activities, particularly those involving total immersion. During these activities, there is a risk that water could be swallowed, inhaled or come into contact with ears, nasal passages, mucous membranes and cuts in the skin, allowing pathogens to enter the body (NZMFE 2002). The most common types of illness that have been associated with primary contact are gastrointestinal disorders, respiratory illnesses, eye, nose and throat infections and skin disorders.

6.2.2 Indicator organisms and recreational water quality guidelines

Direct detection of pathogens is not a feasible option for routine assessments, since they occur intermittently and are difficult to recover from water. For this reason, 'indicator' micro-organisms are generally used to assess the health risks associated with pathogens in recreational waters. Previously, Australia's recreational water quality guidelines (NH&MRC 1990) used thermotolerant coliforms as the primary indicator of health risks in recreational waters, and *enterococci* as a secondary indicator.

Thermotolerant coliforms are a sub-group of the total coliform population that are easy to measure and are present in virtually all warm blooded animals. However, not all thermotolerant coliforms are of faecal origin. In human faeces thermotolerant coliforms bacteria are made up of about 97% *E. coli*, around 2% Klebsiella, and a further 2% Enterobacter and Citrobacter together (ANZECC 1992). *Enterococci* are now considered to be a more representative indicator, particularly in marine waters. The enterococcus group is a sub-group of the faecal streptococci (found in the faeces of warm-blooded animals) that includes *Streptococcus faecalis, S. faecium, S. gallinarium* and *S. avium* (NZMFE 2002). The World Health Organisation (WHO), New Zealand, Canada and the United States recommend guidelines for recreational waters be based on either *enterococci* or *E. coli* (NZMFE 2002, USEPA 2002). Bacterial counts in water are not normally distributed and are highly skewed. Only after logarithmic transformation are the results normally distributed (Hunter 2002). The Hazen method of calculating the 95th percentile provides a parametric estimate of the theoretical 95th percentile and is the recommended method for bathing waters with microbial standards for classification purposes (Hunter 2002).

Australia's national guidelines for recreational water quality were revised in 2005. The new *Guidelines for Managing Risks in Recreational Water* (NH&MRC 2005) are based on the World Health Organisation guidelines (WHO 2003), which adopt a risk-based classification of recreational waters that relies on a combination of sanitary surveys and water quality monitoring. Under the new guidelines, *enterococci* is the recommended indicator in coastal waters and microbiological water quality risks are determined on the basis of the 95th Hazen percentile *enterococci* values. The national NH&MRC guidelines do not, however, incorporate triggers for resampling and/or poor water quality advisories when *enterococci* levels are high. To address this need, the DEP has used trigger levels set out in New Zealand's *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas* (2003). These guidelines prescribe a trigger level of 140 *enterococci* per 100 ml for resampling and two consecutive measurements of 280 *enterococci* per 100 ml as a trigger for advising the public of poor water quality.

In 2007, the DHHS issued new *Recreational Water Quality Guidelines for Tasmania* under the *Public Health Act 1997.* The state guidelines refer to the new NH&MRC guidelines as a benchmark document, but also incorporate the trigger levels set out in the New Zealand guidelines. The State guidelines have also adopted a three-tiered approach to long-term (5-year or 100 samples) water quality classification with colour codes for easier interpretation, as follows:

- Green (surveillance mode) – represents good water quality (95th Hazen percentile for *enterococci* of <200) and involves routine sampling to monitor contaminant levels.
- Yellow (alert mode) – reflects moderate water quality (95th Hazen percentile for *enterococci* of 200-500) and recommends investigation into the causes of the elevated contaminant levels. Increased frequency of sampling may be needed at this level to enable a more accurate assessment of the risks to recreational users.
- Red (action mode) – represents poor water quality (95th Hazen percentile for *enterococci* of >500). Where recreational water sites are considered to be a threat to public health, the controlling authority must advise the general public, including the placement of warning signs.

6.2.3 The Derwent estuary recreational water quality monitoring program

This monitoring program commenced in 1987 as a joint monitoring initiative between the DEP, local councils, DHHS and the Environment Division (DPIPWE). Over the past six years, up to 40 sites have been monitored around the Derwent estuary at the locations shown in **Figure 6.27**. These sites are categorised as either swimming sites or environmental sites, as described below.

- *Swimming sites* are designated beaches and other sites where significant number of people swim or engage in primary contact activities on a regular basis. These sites are monitored to provide a basis for public health information and advice.
- *Environmental sites* include bays, coves and other environmental sites that provide an overall picture of water quality in the Derwent estuary providing context and continuity on recreational water quality conditions and trends. These sites include:
  - Bays and coves that are frequently used for water based activities and/or have foreshore parks.
  - Areas with potentially significant sewage, stormwater or other pathogen sources.
  - Several clean sites in the upper and middle estuary to provide context.
  - Sites associated with major swimming events (e.g. Cross-Derwent Swim, International Triathlon).

Water samples are collected weekly during the months of December through to March and are analysed at the Public Health Laboratories for *enterococci* using the Enteralert method which provides 24-hour confirmed results.

6.2.4 Recreational water quality – 2003-2004 to 2008-2009

Monitoring results for the six most recent monitoring seasons are reviewed in the following sections. **Table 6.5** presents the numerical results and classifications

Figure 6.28: Recreational water quality classifications for Derwent beaches during 2003-2004 as compared to 2008-2009

Figure 6.27: Recreational water quality monitoring sites, including 2008-9 classification

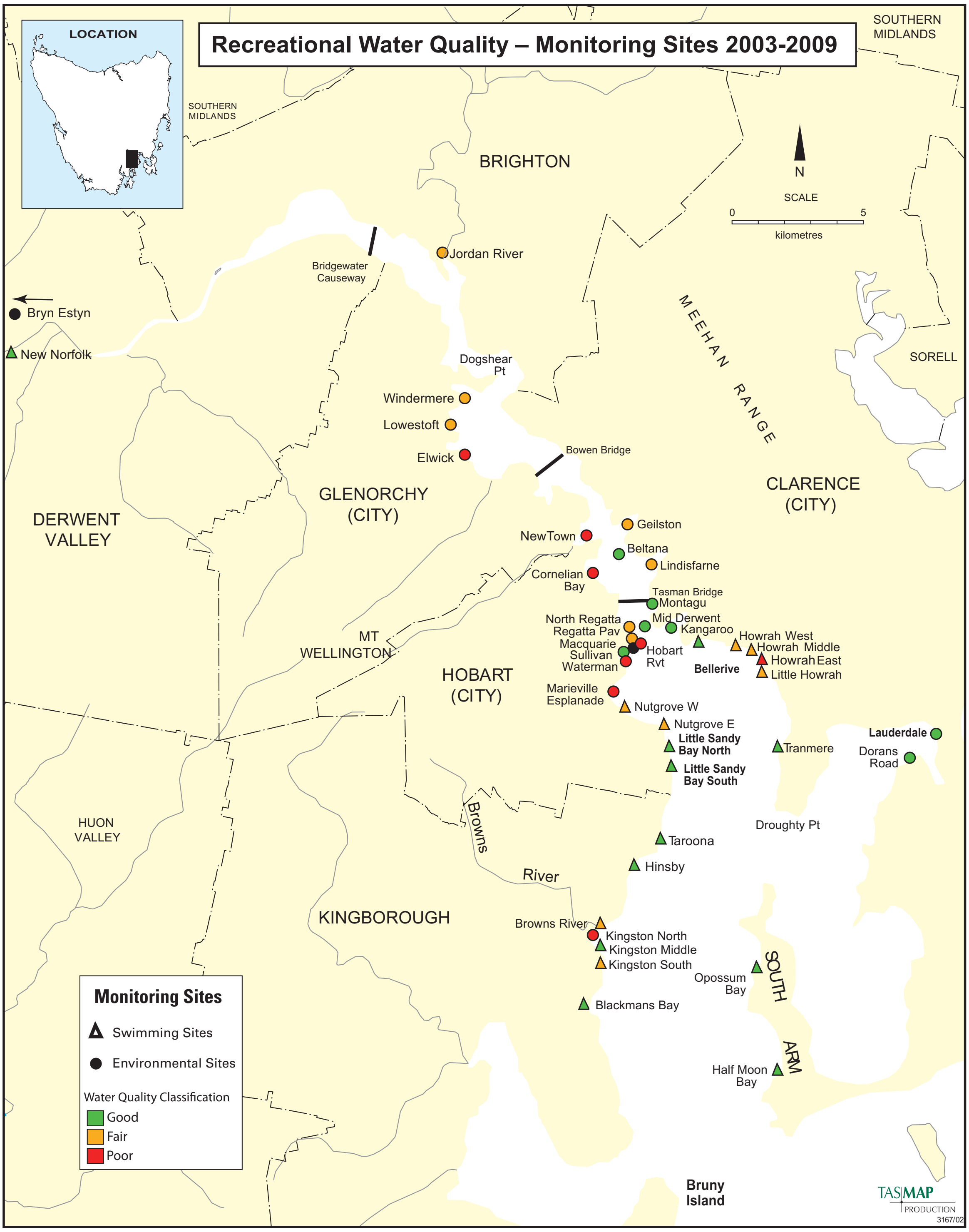


Table 6.5: Recreational water quality at Derwent beaches – classification of sites over the past 6 summers (green = good; yellow = fair; red = poor)

Site	**2003/2004**	**2004/2005**	**2005/2006**	**2006/2007**	**2007/2008**	**2008/2009**
New Norfolk Esplanade	74	65	125	151	149	140
Nutgrove Beach 1 (east)	591	591	591	591	324	317
Nutgrove Beach 2 (west)	348	781	924	924	229+	268#
Little Sandy Bay Beach 1 (south)	478	478	467	326	87	78
Little Sandy Bay Beach 2 (north)	98*	106*	111	111	81	-
Hinsby Beach	49	46	46	20	20	22
Taroona Beach	104	70	78	37	42	42
Kingston Beach (north)	274	215	176	124	132	268
Kingston Beach (middle)	398	235	388	148	192	184
Kingston Beach (south)	594	606	499	304	377	381
Blackmans Bay Beach	264	264	59	37	42	50
Bellerive Beach	382	233	204	178	197	175
Howrah Beach (east)	570	560	495	485	416	502
Howrah Beach (middle)	373*	373*	168*	365*	349	293
Howrah Beach (west)	706*	706*	200*	193*	197	200
Little Howrah Beach	-	-	-	138*	163*	232*
Opposum Bay	41	73	64	48	42	42
Half Moon Bay	10*	-	-	-	-	-

** Represents 5-year 95th Hazen percentiles for enterococci with less than 50 data points. + Indicates that a 3-year 95th Hazen Percentile for enterococci was used. #Indicates that a 4-year 95th Hazen Percentile for enterococci was used.*

Table 6.6: Recreational water quality as Derwent bays, coves and environmental sites – classifiaction of sites over the past 6 summers (green = good; yellow = fair; red = poor)

Site	**2003/2004**	**2004/2005**	**2005/2006**	**2006/2007**	**2007/2008**	**2008/2009**
Jordon River	401	342	677	303	288	-
Windemere Bay	298	259	258	293	298	298
Elwick Bay	397	557	560	582	560	552
Lowestoft Bay	-	-	948*	513*	478	-
New Town Bay	941	1007	890	711	729	885
Cornelian Bay	1900	2005	2005	2005	2005	2005
200 m N of Reg Pav	156*	124	184	159	308	-
Regatta Pavilion	1285	1270	1255	340	398	428
Mid-river Derwent Swim	-	26*	20*	27	20	41
50 m S of Reg Pav (mouth of Hobart Rivulet)	9805*	8134	8183	8471	3664	9747
Sullivans Cove	-	31*	32*	69	42	122
Watermans Dock	-	-	1837*	1350	1417	1210
Marieville Esplanade	1401	1445	1917	1917	2005	2005
Geilston Bay	945	843	828	448	407	418
Lindisfarne Bay	111	110	122	109	158	254
Beltana Point (U2)	20	20	37	20	31	-
Montagu Bay	41	53	50	53	53	-
Kangaroo Bay	158	42	42	42	44	138
Dorans Road	56	74	62	33	61	62
Browns River	1000	1120	1000	718	841	1590
Tranmere	28	28	28	31	53	-
Lauderdale Canal	109	178	197	-	-	-

** Represents 5-year 95th Hazen Percentile for enterococci with less than 50 data points.*

for the Derwent's main swimming sites, while **Table 6.6** presents the results and classifications for bays, coves and other environmental sites. It should be noted that the 2003 – 2004, 2007 – 2008 and 2008 – 2009 seasons were relatively dry in contrast to the 2004 – 2005, 2005 – 2006 and 2006 – 2007 seasons, which experienced a number of heavy rainfall events.

Nearly all of the Derwent's main swimming beaches have received good or fair water quality ratings over the past few summers, with the cleanest water found at Opossum Bay, Hinsby and Taroona beaches, Blackmans Bay beach and at Little Sandy Bay. Water quality at Nutgrove Beach has been variable, but with marked improvements over the past two summers. Water quality at Howrah beach has also been variable, with poorer water quality noted at the eastern end of the beach (probably associated with a large stormwater outfall). In 2008 – 2009 Howrah Beach West slightly exceeded the 'poor' water quality classification (i.e. a 5 year 95th Hazen percentile for *enterococci* of 502 as compared to the guideline of >500). Given the exceedance is very small (i.e. within the range of sample variability), the Council and DHHS do not at this point propose to close this section of the beach and have retained a yellow (fair) water quality classification, subject to further monitoring and investigations into potential sources of contamination.

As indicated in **Figure 6.28** and **Table 6.5**, water quality at Derwent swimming sites has shown a clear improvement over the past six years, and classifications for a number of beaches have been upgraded, in particular at: Nutgrove Beach (poor to fair), Kingston Beach South (poor to fair), Little Sandy Bay (fair to good), Blackmans Bay (fair to good) and Bellerive Beach (fair to good).

Recreational water quality of the Derwent's bays, coves and environmental sites is variable, as indicated in **Table 6.6**. Several sites including Tranmere, mid-Derwent swim, Sullivans Cove, Montagu Bay and Kangaroo Bay typically have excellent water quality. At other sites, water quality has been continually poor, e.g. at Cornelian Bay, Marieville Esplanade, Browns River, Watermans Dock, New Town Bay and Elwick Bay. Swimming is not recommended at any times at these sites. Hobart Rivulet – while not a recreational site – discharges in close proximity to the Regatta Pavilion, which is the starting point for the annual Cross-Derwent swim. Several sites have shown improving trends over the past six year period, in particular at the Regatta Pavilion (classification upgraded from poor to fair), Geilston Bay (classification upgrade from poor to fair) and Watermans Dock (still poor but improving). The only site that has shown a decline in water quality is Marieville Esplanade.

6.2.5 Public information

In 2006 the DEP released a *Swimming in the Derwent* brochure as a means of providing recreational water quality information to the general public, however, this information became rapidly dated and was also difficult to distrib ute to a wide audience. During the 2007 – 2008 season a new *Beach Watch* reporting system was designed, which not only provides the most recent weekly water quality results for Derwent estuary swimming sites (pass, retest or fail) but also displays the longer-term classification. This weekly *Beach Watch* snapshot is published in the Saturday *Mercury Newspaper* from December through to March as a public service.

During the 2008 – 2009 season the DEP introduced weekly recreational water quality reporting on the DEP website (www.derwentestuary.org.au), and expanded this to include both swimming sites (*Beach Watch* snapshot) as well as environmental sites (*Bay Watch* snapshot), as shown in **Figure 6.29**. The web-based *Beach Watch* and *Bay Watch* snapshots provide information on the long-term water quality classification at each site, the weekly test results and also include the numerical *enterococci/* values for the weekly test result. This feature is particularly useful for swimming event organisers and competitors. Weekly *Beach Watch* and *Bay Watch* snapshots are archived on the website.

6.2.6 Beach signage

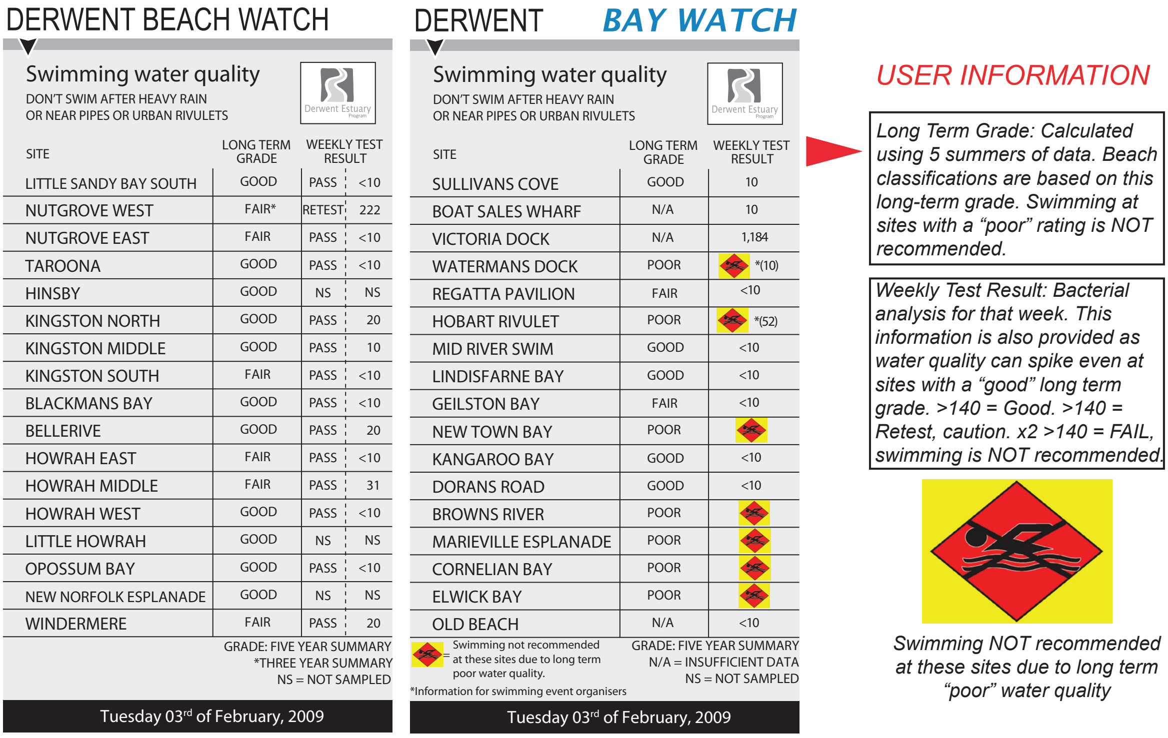
During the 2008 – 2009 season the DEP, in collaboration with DHHS, developed and implemented a new signage strategy for beaches and bays around the Derwent. Previously recreational water quality signage had only been installed at sites that had a 'poor' water quality classification. The overall objective of the new signage strategy was to:

- communicate information about the long-term water quality classification at a given location;
- raise awarness about the potential for poor water quality associated with stormwater drains and heavy rainfall; and
- allow for advisories to be posted in the event of poor water quality incidents.

A flip-down sign was agreed on as the best way to present this information for sites with a 'fair' or 'good' classification (**Figure 6.30**), while a single plated sign was recommended for sites with a 'poor' water quality classification (**Figure 6.31**). Under normal conditions, the sign reflects the long-term classification of the site in accordance with Tasmania's three tiered classification system: 'good' (green), 'fair' (yellow) and 'poor' (red).

The classification is based on *enterococci* data collected over a five-year period, in accordance with state and national guidelines. The sign also advises the community against swimming after heavy rainfall or near stormwater pipes, and indicates the time period over which monitoring is carried out. In the event of poor water quality (i.e. two consecutive samples of greater than 280 *enterococci*/100 mL), the sign can then be flipped down to display an advisory warning. When the water quality improves to acceptable levels (i.e. less than 140 *enterococci*/100 mL), the sign can be folded back up, again displaying the long-term classification. The sign also provides a Council contact number for further information.

Figure 6.29: Examples of Beach Watch and Bay Watch snapshots that appear weekly on the DEP website (December through March)



DERWENT BEACH WATCH

Swimming water quality

DON'T SWIM AFTER HEAVY RAIN
OR NEAR PIPES OR URBAN RIVULETS

SITE	LONG TERM GRADE	WEEKLY TEST RESULT	
LITTLE SANDY BAY SOUTH	GOOD	PASS	<10
NUTGROVE WEST	FAIR*	RETEST	222
NUTGROVE EAST	FAIR	PASS	<10
TAROONA	GOOD	PASS	<10
HINSBY	GOOD	NS	NS
KINGSTON NORTH	GOOD	PASS	20
KINGSTON MIDDLE	GOOD	PASS	10
KINGSTON SOUTH	FAIR	PASS	<10
BLACKMANS BAY	GOOD	PASS	<10
BELLERIVE	GOOD	PASS	20
HOWRAH EAST	FAIR	PASS	<10
HOWRAH MIDDLE	FAIR	PASS	31
HOWRAH WEST	GOOD	PASS	<10
LITTLE HOWRAH	GOOD	NS	NS
OPOSSUM BAY	GOOD	PASS	<10
NEW NORFOLK ESPLANADE	GOOD	NS	NS
WINDERMERE	FAIR	PASS	20

GRADE: FIVE YEAR SUMMARY
*THREE YEAR SUMMARY
NS = NOT SAMPLED

Tuesday 03rd of February, 2009

DERWENT BAY WATCH

Swimming water quality

DON'T SWIM AFTER HEAVY RAIN
OR NEAR PIPES OR URBAN RIVULETS

SITE	LONG TERM GRADE	WEEKLY TEST RESULT
SULLIVANS COVE	GOOD	10
BOAT SALES WHARF	N/A	10
VICTORIA DOCK	N/A	1,184
WATERMANS DOCK	POOR	◆ *(10)
REGATTA PAVILION	FAIR	<10
HOBART RIVULET	POOR	◆ *(52)
MID RIVER SWIM	GOOD	<10
LINDISFARNE BAY	GOOD	<10
GEILSTON BAY	FAIR	<10
NEW TOWN BAY	POOR	◆
KANGAROO BAY	GOOD	<10
DORANS ROAD	GOOD	<10
BROWNS RIVER	POOR	◆
MARIEVILLE ESPLANADE	POOR	◆
CORNELIAN BAY	POOR	◆
ELWICK BAY	POOR	◆
OLD BEACH	N/A	<10

◆ = Swimming not recommended at these sites due to long term poor water quality.

GRADE: FIVE YEAR SUMMARY
N/A = INSUFFICIENT DATA
NS = NOT SAMPLED

*Information for swimming event organisers

Tuesday 03rd of February, 2009

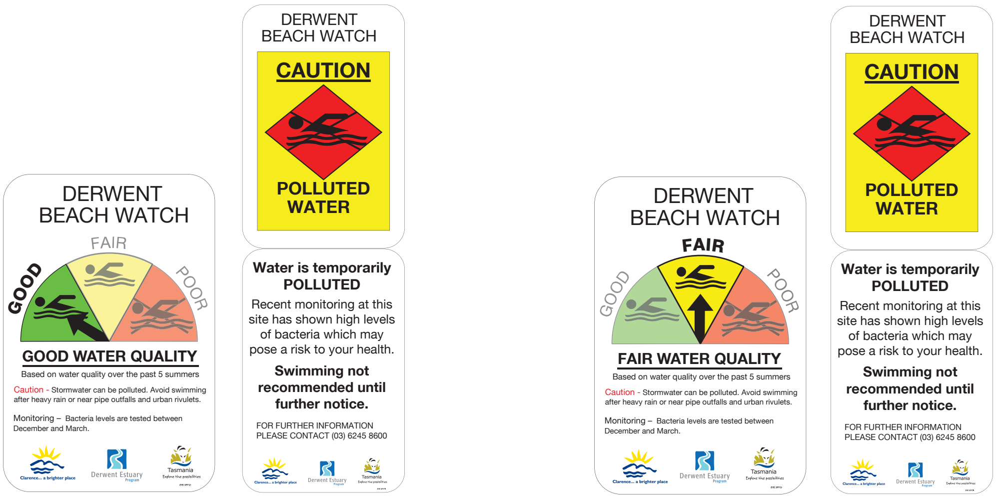
USER INFORMATION

Long Term Grade: Calculated using 5 summers of data. Beach classifications are based on this long-term grade. Swimming at sites with a "poor" rating is NOT recommended.

Weekly Test Result: Bacterial analysis for that week. This information is also provided as water quality can spike even at sites with a "good" long term grade. >140 = Good. >140 = Retest, caution. x2 >140 = FAIL, swimming is NOT recommended.

Swimming NOT recommended at these sites due to long term "poor" water quality

Figure 6.30: Good and Fair flip-down recreational water quality signs. Under normal conditions, the signs would display the long-term 'good' or 'fair' water quality information. In the event of a poor water quality incident, the signs could be flipped down for the duration of the event



DERWENT BEACH WATCH

CAUTION

POLLUTED WATER

Water is temporarily POLLUTED

Recent monitoring at this site has shown high levels of bacteria which may pose a risk to your health.

Swimming not recommended until further notice.

FOR FURTHER INFORMATION PLEASE CONTACT (03) 6245 8600

DERWENT BEACH WATCH

GOOD WATER QUALITY

Based on water quality over the past 5 summers

Caution - Stormwater can be polluted. Avoid swimming after heavy rain or near pipe outfalls and urban rivulets.

Monitoring – Bacteria levels are tested between December and March.

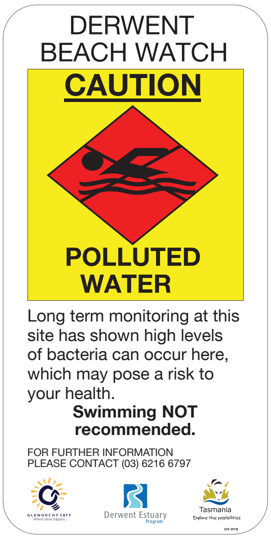
FAIR WATER QUALITY

Based on water quality over the past 5 summers

Caution - Stormwater can be polluted. Avoid swimming after heavy rain or near pipe outfalls and urban rivulets.

Monitoring – Bacteria levels are tested between December and March.

Figure 6.31: Permanent sign for sites with a 'poor' water quality classification Swimming at these sites is not recommended



DERWENT BEACH WATCH

CAUTION

POLLUTED WATER

Long term monitoring at this site has shown high levels of bacteria can occur here, which may pose a risk to your health.

Swimming NOT recommended.

FOR FURTHER INFORMATION PLEASE CONTACT (03) 6216 6797

7.0 DERWENT ESTUARY SEDIMENTS

Most estuaries act as depositional areas, trapping and retaining sediments and organic matter from their catchments, along with associated contaminants such as heavy metals, nutrients, hydrocarbons and other organic contaminants. These sediments may be transported and redistributed by floods, tides and currents, eventually settling out in lower energy environments. The contaminants associated with estuarine sediments may be re-processed through chemical or biological processes or buried, forming part of the sedimentary record.

The Derwent estuary has a long history of sediment contamination, particularly by heavy metals and organic matter discharged as a result of past industrial practices. Historical and contemporary land uses within the catchment also influence sediment inputs, grain size and chemistry. Previous *State of the Derwent Estuary* reports have summarised sediment surveys and investigations carried out up until 2003. These have included extensive surveys of heavy metals and pulp fibre in surface sediments (Bloom and Ayling 1977), sediment biomarkers, resin acids and hydrocarbons (Leeming and Nichols 1998, Volkman *et al.* 1988), and studies of sediment history and deposition based on cores (Samson 2002).

During the past five years, the main focus has been on heavy metal sediment process studies, sediment toxicity and effects on benthic invertebrate communities. Much of this work has been carried out in the context of the *Derwent Estuary Water Quality Improvement Plan for Heavy Metals* (WQIP). The WQIP reviewed heavy metal sources and loads, set environmental targets and recommended actions to reduce and manage heavy metals in the Derwent. Detailed estuarine models – including a sediment transport model – were developed to support the WQIP and extensive sediment investigations were carried out. These investigations have been reviewed in **Section 5.0** and will not be repeated here.

The following sections provide an overview of our current knowledge concerning heavy metal impacts on sediment quality in the Derwent estuary.

7.1 Sediment Quality Guidelines

The *National Water Quality Management Strategy* (NWQMS) has identified interim sediment quality guidelines (ISQG) for heavy metals, based on a literature review of sediment toxicity testing. The guidelines define ISQG-high and ISQG-low values (**Table 7.1**), which represent the lower 10th percentile and 50th percentile of chemical concentrations associated with adverse biological effects. The guideline levels were obtained from studies undertaken on North American biota, with some minor alterations for Australian applications including, numerical rounding and inclusion of several additional chemicals [Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000)].

An evaluation of the ISQG applicability to Australian biota undertaken in New South Wales estuaries concluded that the ISQG-low guidelines are appropriate for compliance and protection of biota (McCready *et al*. 2006). However, a national review of Australian sediment quality guidelines recommended that an alternative approach be used in assessing sediment contamination, based on Multiple Lines of Evidence (MLE) (Simpson *et al*. 2005). The MLE approach assesses sediment

Table 7.1: National sediment quality guidelines for heavy metals

Contaminant	ISQG low	ISQG high
Metals (mg/kg dry weight)		
Arsenic	20	70
Cadmium	1.5	10
Chromium	80	370
Copper	65	270
Lead	50	220
Mercury	0.15	1
Nickel	21	52
Silver	1	3.7
Zinc	200	410
Metalloids (mg/kg dry weight)		
Arsenic	20	70

Source: Interim sediment quality guidelibnes adopted by ANZECC, 2000 contamination on the basis of geochemistry, toxicity and biological communities. This approach is being developed to assess Derwent estuary sediment quality, as described in the *Derwent Estuary Water Quality Improvement Plan for Heavy Metals* described in **Section 5**. However, for the purposes of this discussion, the Derwent estuary sediments will be compared to the ISQG values in **Table 7.1**.

7.2 Heavy metals

Heavy metal contamination – particularly by zinc, cadmium, lead, copper and mercury – is one of the Derwent estuarys most severe and persistent problems, with metal concentrations in sediments among the highest in Australia and indeed the world. Past heavy metal contamination of the Derwent estuary had been primarily associated with the Lutana zinc smelter (established in 1917) and the Boyer newsprint mill (established 1941). Other potential sources of heavy metals include urban run-off, sewage treatment plants, refuse disposal sites, old tips and contaminated sites, air pollution and internal cycling from contaminated sediments within the estuary. There have been significant reductions in emissions over the last few decades, but levels of zinc, mercury, cadmium, lead, copper and arsenic still greatly exceed the ANZECC (2000) sediment quality guidelines over most of the estuary.

7.2.1 Surface sediment heavy metal concentrations

A summary of the major sediment surveys carried out in the Derwent since the 1970s is provided in **Table 7.2**, with an emphasis on the larger, whole-of-estuary surveys. The first comprehensive study of heavy metals in Derwent sediments was carried out in 1975 by Bloom and Ayling (1977) in the middle estuary. More widespread heavy metal surveys were undertaken on surface sediments throughout the Derwent estuary in 1996 by Pirzl (1996), 1996-97 by Jones *et al*. (2003), and in 2000 by the Derwent Estuary Program (DEP) and Tasmanian Aquaculture and Fisheries Research Institute (TAFI). Further details about these surveys, as well as more localised studies undertaken prior to 2003 are available in the previous *State of the Derwent Estuary* reports (Coughanowr 1997, Green and Coughanowr 2003). Further analyses and surveys have been undertaken on surface sediments from the estuary (DEP 2007), including several intertidal areas within the estuary (Koehnken and Eriksen 2004, Geocoastal 2009). See **Section 5.1** for details.

Figures 7.1 to 7.8 illustrate the distribution of heavy metals in Derwent estuary surface sediments based on the most recent survey, which was carried out as a joint project between the DEP and TAFI in 2000. Distribution maps for sediment texture and percentage organic matter are also provided.

Table 7.2: Ranges of heavy metal concentrations in Derwent estuary surface sediments (mg/g)

STUDY	Bloom & Ayling 1977	Garland and Statham	Pirzl 1996	Jones et al. 2003	DEP & TAFI	Green	Pascminco Hobart Smelter	Geocoastal 2009	**Guidelines***	
Sampling	1975	1990	1996	1996	2000	1999	1999/2002			
Location	Entire Estuary	ANM to Green Island	Entire Estuary	Entire Estuary	Entire Estuary	Prince of Wales Bay	New Town Bay	Ralphs Bay	ISQG low	ISQG high
No. of Sites	*102 sites*	*30 sites*	*40 sites*	*69 sites*	*123 sites*	*105 sites*	*10 sites*	*47 sites*		
Metals (mg/Kg)										
Arsenic			0.001-20.9	1-657	1-1,400			<0.1-10.8	**20**	**70**
Cadmium	0.3-1,400	<0.5-3.8	0-134	<10-180	1-477	1-40	27-290	<0.1-1.5	**1.5**	**10**
Chromium	1.1-258			<5-183		1-122		1.2-40.6	**80**	**370**
Cobalt	0.4-137			34912		31107		0.4-18		
Copper	1.5-10,050		7-530	<2-1,182	1-1,490	14-2,940		0.8-28.4	**65**	**270**
Lead	0.7-41,700		10.5-2,078	4-3,866	8-8,120	11-1,840		1.9-44.8	**50**	**220**
Manganese	0.8-8,900		6.5-781		2-7,740	40-2,300		2.1-43.2		
Mercury	0.01-111	<0.02-11	0.023-55.7	<5-36	0.02-130	0.05-45	13-76	<0.1-0.53	**0.15**	**1**
Nickel	0.05-36			<2-35		1-197		0.7-16.4	**21**	**52**
Zinc	22-104,000	23-1,590	26.8-19,201	<2-22,593	24-59,000	19-6,790	1,000-40,000	0.2-140	**200**	**410**

ISQG low effects range low – adverse effects 10% of the time

ISQG high effects range median – adverse effects 50% of the time

(Note: in studies where cores have been collected, the concentration ranges are for surface sediments only.)

Figure 7.1: Distribution of particle size in Derwent estuary surface sediments (2000-01)

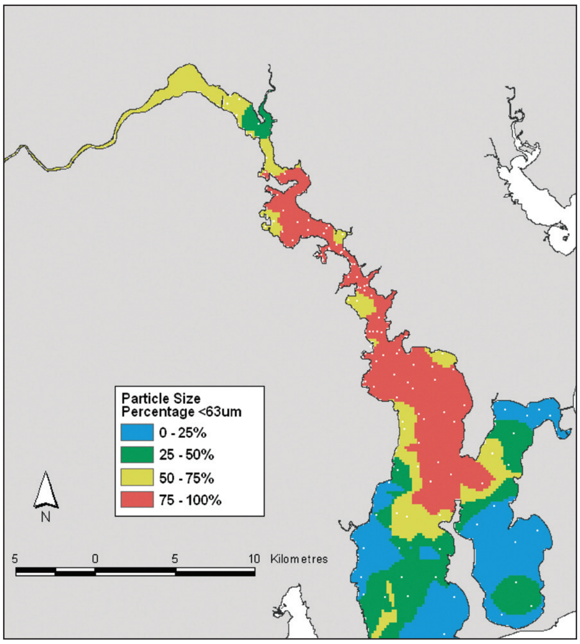


Figure 7.2: Percentage organic carbon in Derwent estuary surface sediments (2000-01)

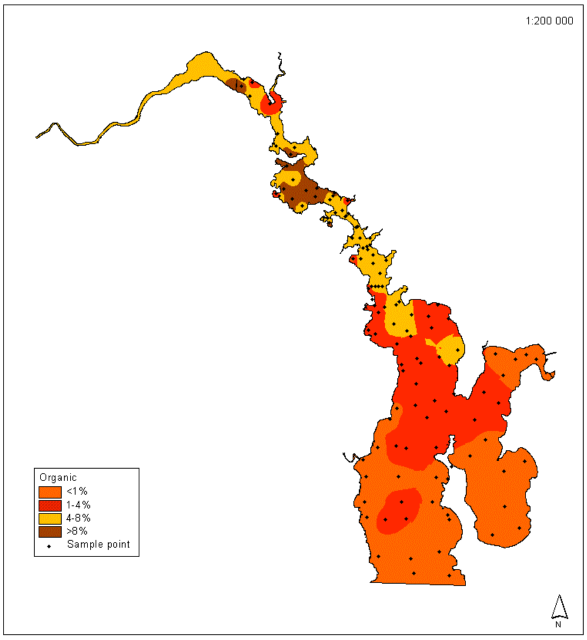


Figure 7.3: Distribution of arsenic in Derwent estuary surface sediments (2000-01)

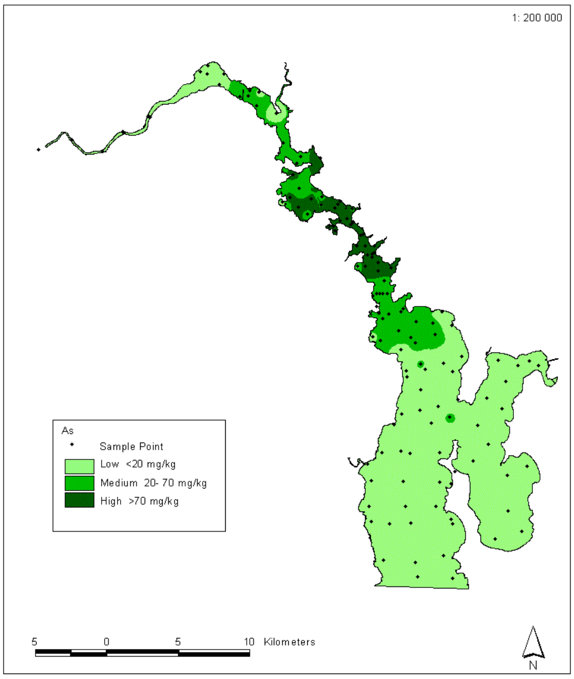


Figure 7.4: Distribution of cadmium in Derwent estuary surface sediments (2000-01)

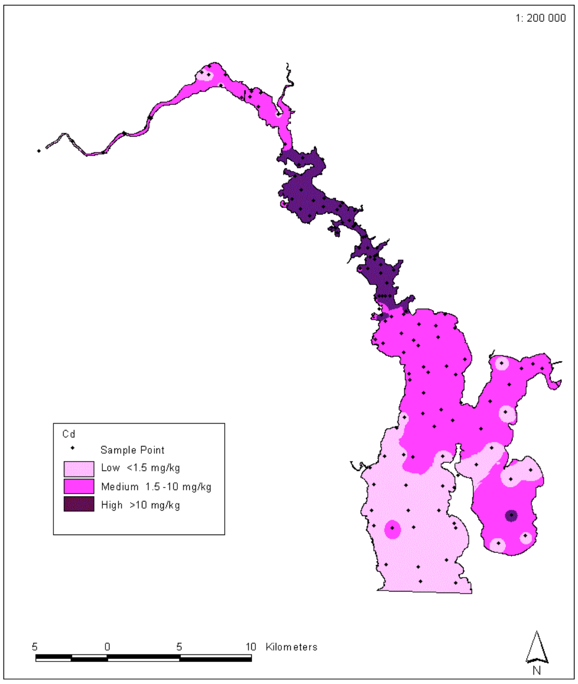


Figure 7.5: Distribution of copper in Derwent estuary surface sediments (2000-01)

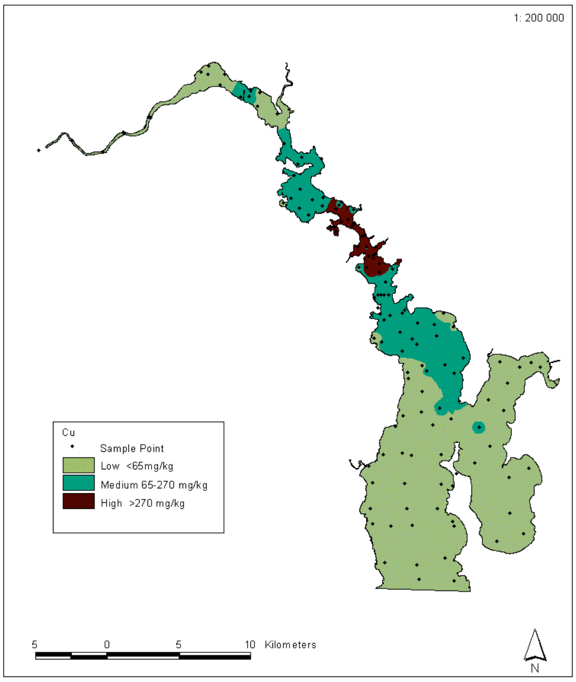


Figure 7.6: Distribution of mercury in Derwent estuary surface sediments (2000-01)

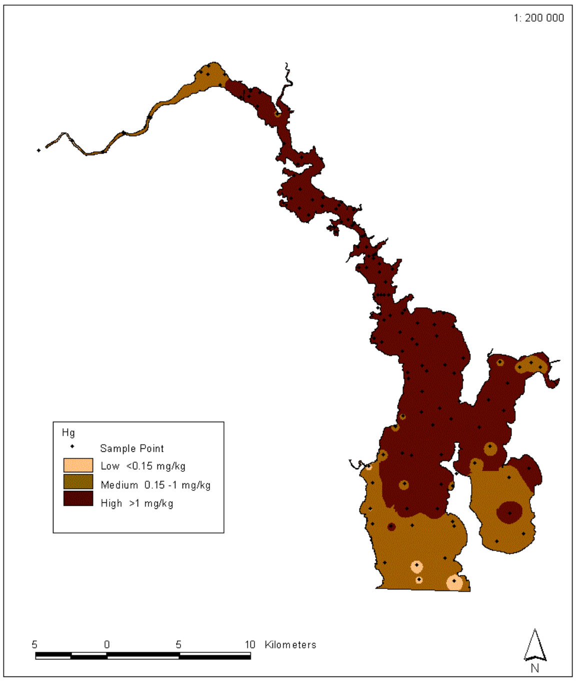


Figure 7.7: Distribution of lead in Derwent estuary surface sediments (2000-01)

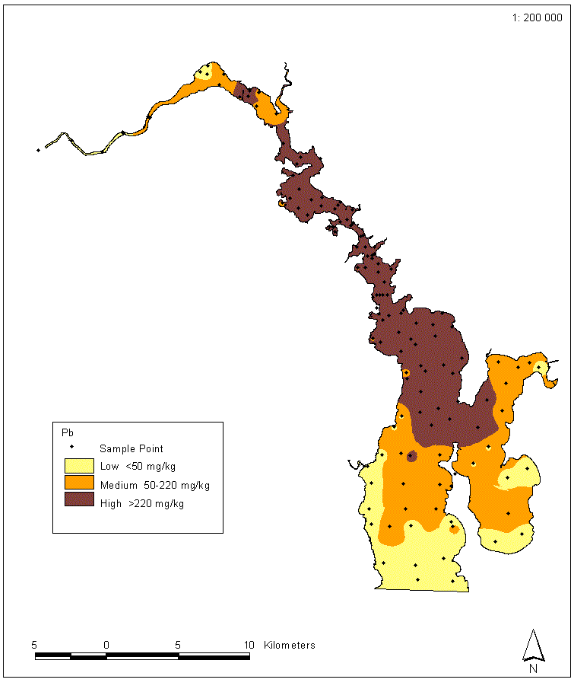
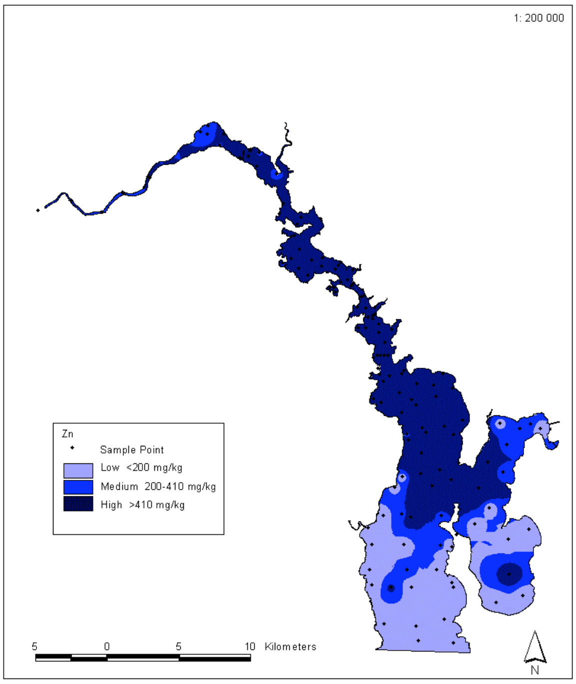


Figure 7.8: Distribution of zinc in Derwent estuary surface sediments (2000-01)



These maps indicate that the majority of estuarine surface sediments do not meet national interim sediment quality guidelines (ISQGs), particularly for mercury, lead, zinc and cadmium (DEP 2007). As indicated in **Table 7.3**, over 95% of surface sediments in the estuary exceed the low ecological risk sediment quality guidelines for at least one metal, while over 65% exceed the median ecological risk guidelines.

Heavy metal concentrations decrease gradually towards the marine and riverine extremities of the estuary. Three major factors influence the distribution of metals in the estuary:

- the location of the zinc refining plant in the middle estuary;
- sediment transport and depositional patterns controlled by the Derwent estuary's salt-wedge circulation; and
- the sediment types in the estuary (i.e. grain size and organic content).

The middle reaches of the estuary are particularly contaminated with heavy metals and in this area can be ten times the (ISQG high) guidelines or more, particularly for mercury and zinc. Heavy metal concentrations tend to be higher in areas with higher mud content and thus the shallow sandier intertidal areas around the perimeter of the estuary tend to have relatively low metal concentrations compared with the deeper central estuary (Koehnken and Eriksen 2004). However, heavy metals in some intertidal regions may still exceed national interim sediment quality guidelines. See **Section 5.1.2** for details.

Multivariate statistical analysis of the DEP and TAFI 2000 survey data was used to broadly classify the Derwent into six zones based on significant differences in the heavy metals zinc and mercury, organic content and grain size (Koehnken and Eriksen 2004) (See **Figure 5.2**).

7.2.2 Past heavy metal concentration in Derwent estuary sediments

Several attempts have been made to assess trends in heavy metal concentrations in Derwent estuary sediments through the use of comparative surveys and analysis of sediment cores. As discussed in the 2003 *State of the Derwent Estuary* report, concentrations of lead, zinc, copper and cadmium and mercury surveyed in1996 and 2000 were generally lower than those of the 1975 survey (Pirzl 1996). Similarly, sediment core studies suggest that heavy metal concentrations have declined, particularly in the middle reaches of the estuary. This implies that relatively cleaner sediments have been accumulating in parts of the Derwent estuary and are burying the older more contaminated sediments. See **Section 5.1.2** for further details.

7.2.3 Heavy metal ecotoxicity and bioavailability

Estuarine sediments act as a sink for anthropogenic heavy metal contamination (Fan *et al.* 2002, Forstner and Wittman 1981). A conceptual model illustrating heavy metal behaviour in relation to sediment redox condition (oxic or anoxic) and resuspension has been created for zinc (**Figure 7.9**). Zinc has been chosen in the Derwent as a model for the behaviour of most other heavy metals also found in the estuary (with the exception of mercury) (DEP 2007).

Geochemical conditions of the sediments often determine if heavy metals are partitioned between aqueous (pore water, overlying water) and solid phases (sediment, suspended particulate mater and biota) (Cantwell *et al.* 2002, van Ryssen *et al.* 1999). Heavy metal concentrations in aqueous form (in this instance within pore water between sediment grains) is more closely related to toxicity to organisms than total sediment heavy metal concentration (Eggleton and Thomas 2004).

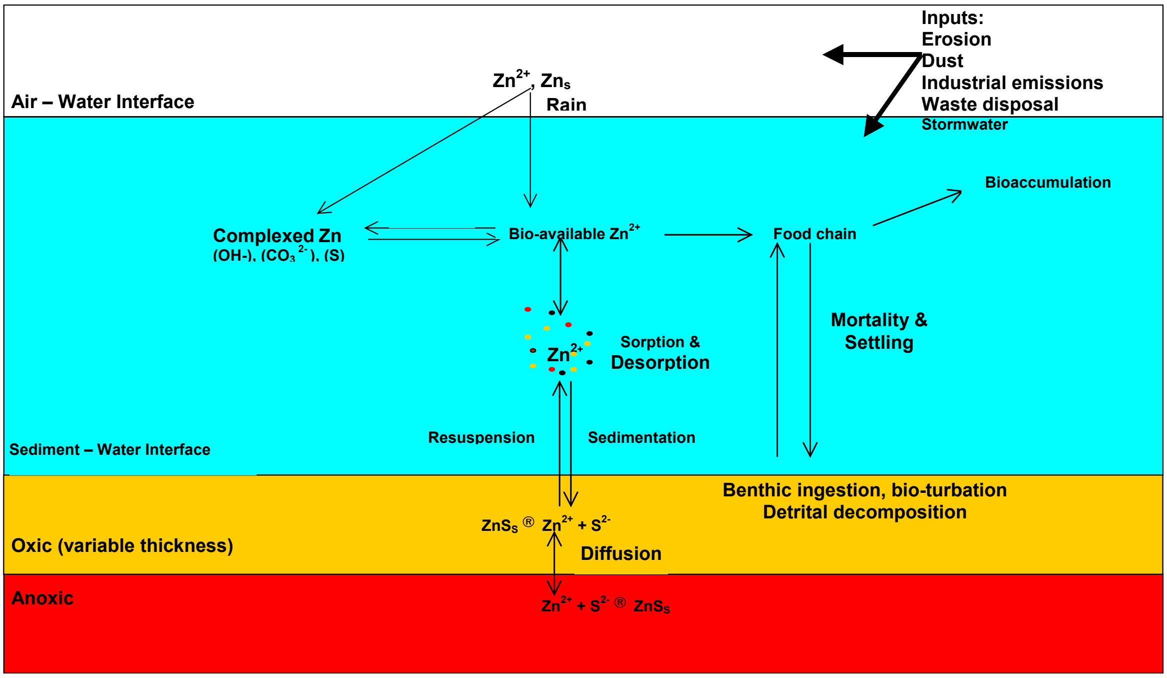
Table 7.3: Proportion of Derwent surface sediments that meet or exceed sediment quality guidelines

Metal	**< ISQG low**	**>ISQG low** but **> ISQG high**	**< ISQG high**
Arsenic	79%	14%	7%
Cadmium	36%	52%	12%
Copper	74%	23%	4%
Lead	23%	38%	39%
Mercury	1%	34%	65%
Zinc	32%	20%	48%

A TAFI based study on the distribution of organisms living on and within Derwent estuary sediments may illustrate this, as areas with high total heavy metals sustain abundant faunal populations suggesting bioavailability of the metals was low, or that some organisms are not particularly sensitive to the contaminants (Macleod and Helidoniotis 2005). Further research has identified that heavy metal toxicity effects are quite pronounced in some organisms (notably brittlestars) (Eriksen *et al.* 2008). There is not a clear relationship between heavy metal levels in biota and total heavy metal concentrations within sediments, highlighting the need for more research into the processes that release sediment bound heavy metals and the biological pathways that these metals subsequently travel. See **Section 5** for further discussion.

The heavy metals within Derwent estuary sediment appear to be strongly bound to abundant sulphides, iron and organic matters and are not readily leached to the overlying water column under normal conditions. Under normal Derwent estuary conditions the release of heavy metals from sediments appears to be a relatively minor source compared to external point and diffuse sources (e.g., zinc smelter site) (DEP 2007). However, experimental work suggests that heavy metals in Derwent sediments may become more bio-available under low oxygen conditions (see **Section 5.3.1** for details). Changing sediment geochemical conditions (e.g., through altered water column dissolved oxygen, organic loading, or sediment resuspension) can lead to the remobilisation of metals from the solid phase to the aqueous phase rendering them potentially more toxic and biologically available (Calmano *et al.* 1993, Eggleton and Thomas 2004). Based on summer and winter redox surveys, there does not appear to be any major seasonality associated with releases from sediments.

Figure 7.9: Conceptual model of zinc sources, sinks and transport in the Derwent estuary (DEP 2007)



8.0 SEAFOOD SAFETY

A number of chemicals are known to accumulate in fish and shellfish that are harmful to humans. Many of these contaminants persist for relatively long periods, especially in sediments where they can be accumulated in estuarine organisms and passed up the food chain. Concentrations of these chemicals may be increased at each successive level of the food chain such that levels in top predator fish may be more than 1,000,000 times the concentration in the water column (USEPA 2000).

Bivalve molluscs such as oysters and mussels are filter feeders that accumulate contaminants directly from the water column or via ingestion of contaminants adsorbed to phytoplankton, detritus, and sediment particles. Bivalves are efficient bioaccumulators of heavy metals, polycyclic aromatic hydrocarbons (PAHs) and other organic compounds, and because they are sessile they may reflect local contaminant concentrations more accurately than more mobile crustacean or fin-fish species (USEPA 2000). Bottom-dwelling fin-fish, such as flathead, may accumulate high concentrations of contaminants from direct physical contact with contaminated bottom sediments or through ingestion of contaminated prey species. Thus, shellfish and fish monitoring serves as an important indicator of contaminated sediments and water quality and is frequently included as part of comprehensive environmental quality monitoring programs (USEPA 2000).

In addition to the toxicants described above, several other contaminants can affect the seafood safety of bivalves, in particular toxic algal blooms and contamination by faecal pathogens.

8.1 Toxicants of concern

Toxicants in seafood include heavy metals, organochlorine pesticides, organophosphate pesticides, chlorophenoxy herbicides, PAHs, polychlorinated biphenyls (PCBs) and dioxins/furans. The toxicants for which the majority of seafood advisories have been issued are mercury, organochlorine pesticides, PCBs and dioxins (USEPA 2000).

8.1.1 Heavy metals

The heavy metals identified as having the greatest potential toxicity to humans resulting from ingestion of contaminated fish and shellfish are mercury (Hg), arsenic (As) and cadmium (Cd) (USEPA 2000). Primary anthropogenic sources of mercury include mining and smelting, industrial processes including chlorine-alkali production facilities and atmospheric deposition resulting from combustion of coal and other fossil fuels. Mercury has also been used as a slimicide in the pulp and paper industry. Practically all mercury in fish tissue is in the form methylmercury which is toxic to humans. Mercury is a neurotoxicant and is of particular concern in developing foetuses (USEPA 2000). Bottom-feeding fish and predator fish – particularly sharks – accumulate mercury at higher levels, and a number of studies have shown that mercury concentrations in fish tissue generally increase with age.

Cadmium is a cumulative human toxicant that enters the environment from smelting and refining of ores, electroplating, and application of phosphate fertilisers. Cadmium has been found to bioaccumulate in fish and shellfish tissues from fresh, estuarine and marine waters. Major anthropogenic sources of arsenic include mining and smelting operations, emissions from coal-burning electrical generating facilities, leaching from hazardous waste facilities and from insecticide, herbicide or algicide applications. Inorganic arsenic, which is a minor component of the total arsenic content of fish and shellfish, is very toxic to mammals and has also been classified as a human carcinogen. Arsenic has not been shown to bioaccumulate to any great extent in aquatic organisms (USEPA 2000).

8.1.2 Organochlorine pesticides, PCBs and dioxins

The major source of pesticides to aquatic systems is from agricultural runoff. Organochlorine pesticides such as DDT, dieldrin and toxaphene are neurotoxins and suspected human carcinogens. Many of the organochlorine pesticides which are now banned were used in large quantities for over a decade and are still present in sediments at high concentrations because they are not easily metabolised or degraded. These compounds are readily stored in fatty tissues and can bioaccumulate to high concentrations through aquatic food chains to secondary consumers, including humans (USEPA 2000).

PCBs are closely related to many chlorinated pesticides in their chemical and toxicologic properties and in their widespread occurrence in the aquatic environment. Once used extensively by industry, PCBs were used as lubricants, hydraulic fluids and as insulating fluids in electrical transformers and capacitors. The highest environmental concentrations of PCBs are associated with paper mills, refineries and other industrial sites (USEPA 2000). PCBs are extremely persistent in the environment and are bioaccumulated throughout the food chain.

Dioxin contamination is found in proximity to industrial sites, particularly bleached kraft paper mills, and industrial combustors and incinerators. Dioxins are persistent in the environment and have high potential to bioaccumulate. Extremely low doses of some dioxins have been found to elicit a wide range of toxic responses. The dioxin 2,3,7,8-TCDD is the most potent animal carcinogen evaluated by the U.S. Environment Protection Agency (USEPA 2000).

Toxic algal blooms

Toxic algae – particularly dinoflagellates such as *Gymnodinium catenatum* – can pose a significant risk to human health as they contain potent neurotoxins. During blooms these microscopic algae occur in high concentrations throughout the water column, with a resting stage (cysts) being found in sediments. There are about 20 toxins responsible for paralytic shellfish poisoning (PSP), all of which are derivatives of saxitoxin. Numerous animals feed on algae, including filter-feeding species (e.g. bivalves) and zooplankton. Neurotoxins from toxic algae can accumulate in the bodies of these animals and can be passed along the food chain. Bivalve molluscs are particularly good at accumulating toxins because of their ability to filter and accumulate particles suspended in the water column. Blue mussels, *Mytilus edulis*, can accumulate in excess of 20,000 μg saxitoxin/100 gram tissue (RaLonde 1996). Ingestion of affected shellfish by humans, and other organisms, can cause PSP. In extreme cases, PSP causes muscular paralysis, respiratory difficulties, and can lead to death (Ochoa *et al*. 1998).

8.2 Food Safety Guidelines

Results for the most recent seafood surveys are presented in the following sections, and can be compared to Food Standards Australia New Zealand (FSANZ) guidelines, within the Joint Australia New Zealand Food Standards Code (FSANZ 2002). The code uses a combination of maximum permitted levels (MLs) and Generally Expected Levels (GELs). MLs have been set only for those foods that provide significant contributions to total dietary exposure for a given contaminant, and are based on human health risk calculations. In contrast, GELs were developed for those contaminant/commodity combinations with a low level of risk to the consumer and where adequate data were available; these provide a benchmark against which to measure contaminant levels in food. It should be noted that some GELs (particularly for zinc) did not incorporate Tasmanian data and may not be entirely appropriate to this region. (***Note:*** MLs are legally enforceable in regard to food offered for commercial sale, but do not have any legal significance in regard to consumption of home grown produce or self-procured fish/shellfish).

The current guidelines for human consumption of seafood are shown in **Table 8.1.** The FSANZ guidelines set MLs for arsenic, cadmium, mercury and lead (Pb). GELs have been set for copper (Cu) and zinc (Zn), on the basis of observed concentrations in commercial seafood. These are intended to identify the minimum level of contamination that is reasonably achievable, and may provide a trigger for remedial action if a level is exceeded (FSANZ 2005).

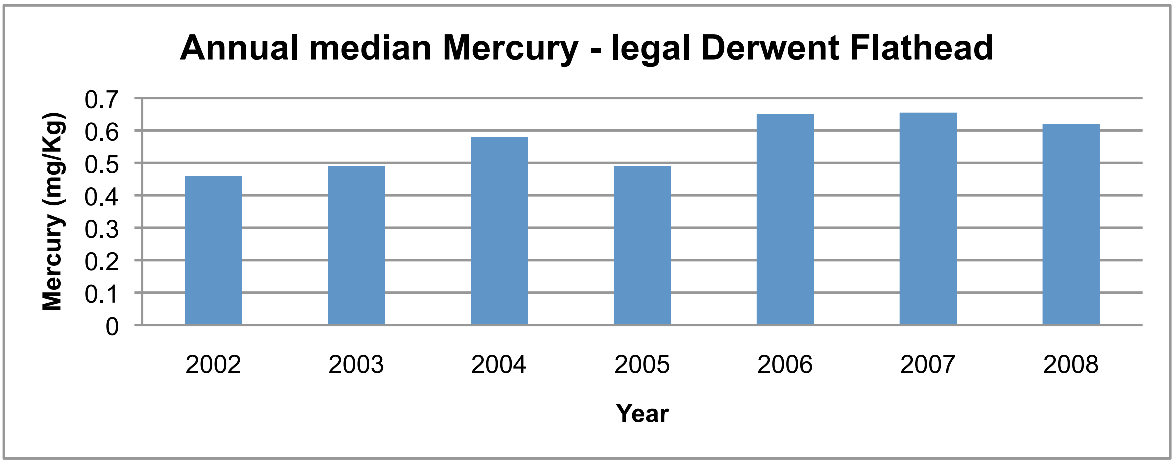
In 2004, FSANZ issued updated advice on mercury in fish, recommending that pregnant women and young children limit their consumption of certain types of fish (e.g. billfish, shark, orange roughy and catfish), which tend to accumulate higher levels of mercury. This change in advice was due in part to a new stricter health standard for methylmercury established by the *Joint FAO/WHO Expert Committee on Food Additives* in 2003 (approximately half the amount used by the previous health standard). In association with this advice, FSANZ also provided the methodology used to calculate recommendations for fish consumption based on the

Table 8.1: National food guidelines for heavy metal levels in seafood (FSANZ 2005)

	Maximum Permitted Levels (mg/kg)				**Generally Expected Levels (median/90 percentile) (mg/kg)**	
	As	**Cd**	**Hg**	**Pb**	**Cu**	**Zn**
Fish	2	no set limit	mean level of 0.5 for most fish mean level of 1 for large/pred fish	0.5	0.5/2	5/15
Molluscs	1	2	0.5 (mean)	2	3/30	130/290
Crustaceans	2	no set limit	0.5 (mean)		10/20	25/40

Note: Cu GELs are from the FSANZ Code Review 1999

Figure 8.2: Annual median mercury levels in Derwent estuary legal sized flathead (2002-2008)



new stricter standard. This method uses median mercury levels in the target fish species to estimate the maximum number of serves that can be consumed per week for the Australian population groups of women of child-bearing age, the general population and young children. This method is used to calculate dietary advice (J. Baines, FSANZ 2007, *pers. comm.*), and is the basis used for the health advice issued by the Tasmanian Department of Health and Human Services (DHHS).

8.3 Heavy metals in Derwent estuary fish

As discussed in **Section 5** (Integrated Studies), heavy metals have been discharged to the Derwent from a variety of sources, particularly historic industrial discharges associated with zinc and paper production. Numerous investigations of heavy metal concentrations in Derwent estuary biota have been carried out since the early 1970s, when oysters produced at a shellfish farm in Ralphs Bay caused severe emetic (vomiting) symptoms in consumers, as a result of high concentrations of zinc and other heavy metals. Early surveys of heavy metals in seafood include those of Thrower and Eustace (1973a; 1973b), Ratkowsky *et al*. (1974), Bloom (1975), and Dineen and Noller (1995). All of the studies documented elevated concentrations of zinc and cadmium whilst Bloom (1975) also found elevated concentrations of lead and mercury. Elevated mercury levels were later found in certain species of fish as well (Ratkowsky *et al*. 1975). Data from these studies were reviewed in the 1997 *State of the Derwent Estuary* report (DEP 1997).

The most comprehensive and continuous seafood monitoring program in the Derwent has been carried out by Nyrstar Hobart zinc smelter, and previous site managers. This program has monitored mercury levels in flathead since 1984, and heavy metal levels in oysters and mussels since 1992. In addition, caged oyster experiments have been carried out annually since 2004 to evaluate uptake rates of heavy metals in different parts of the Derwent. Full details about sampling methodologies, locations, and results are provided in *Nyrstar Hobart's Environmental Management Plan (EMP)* and *EMP Annual Reviews*.

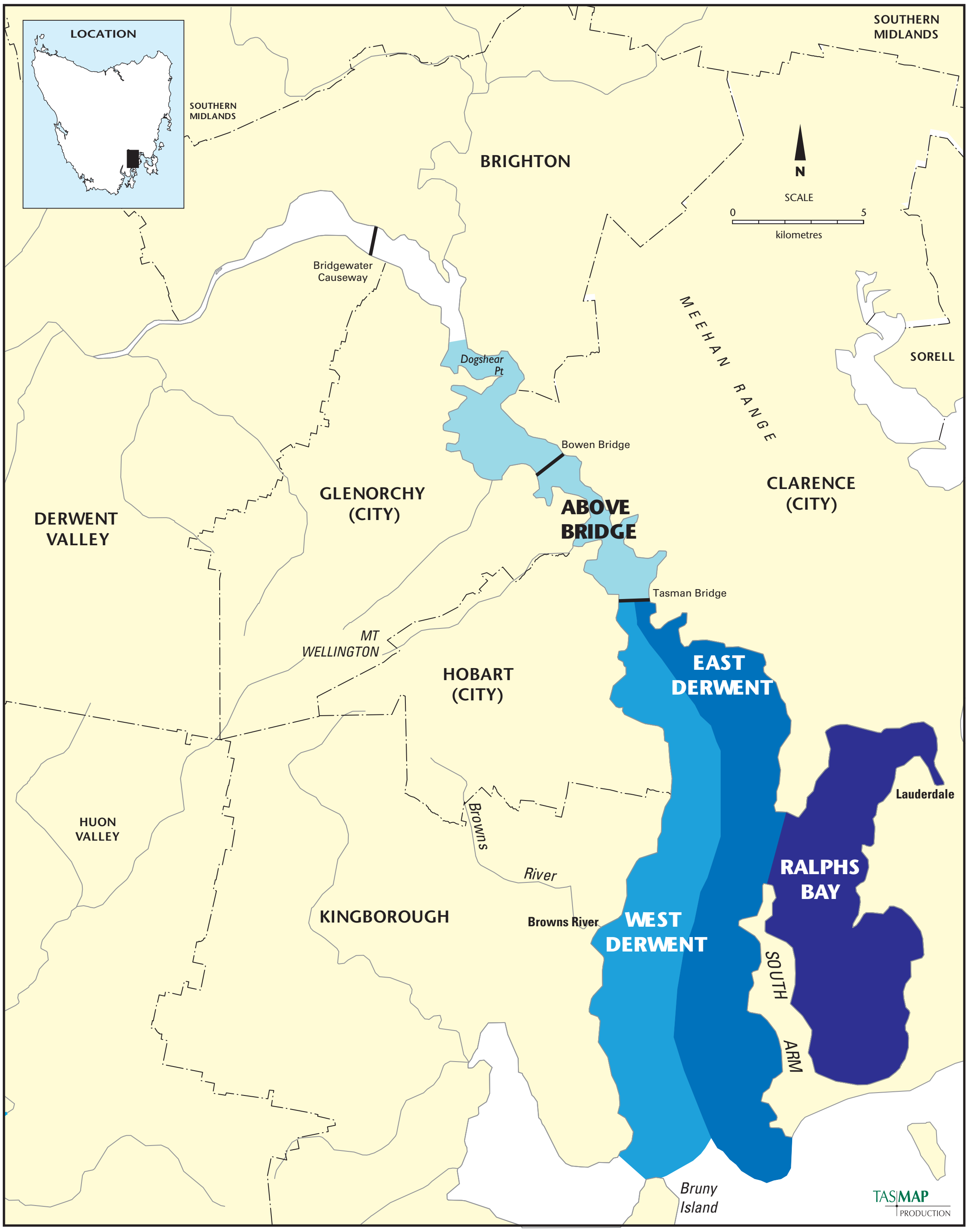
Recent investigations have included a pilot survey of other recreationally-targeted fish species (Verduow, 2008) and investigations into heavy metal bioaccumulation in other biota (Swadling and McLeod 2008) and food-chain pathways (Hunt 2008). These surveys and investigations are reviewed in the following sections.

8.3.1 Mercury levels in flathead

Flathead *(Platycephalus bassensis)* are considered to be good bio-indicators for mercury as they are bottom-feeders, live year round in the Derwent and are relatively territorial. Mercury levels in flathead have been monitored annually since 1984 by Nyrstar Hobart zinc smelter, and previous managers of the site.

The monitoring program divides the estuary into four regions, as illustrated in **Figure 8.1**: i) upstream of the Tasman Bridge, ii) eastern shore, iii) western shore, and iv) Ralphs Bay. Additional sampling is also undertaken for background comparison in Fredrick Henry Bay and the d'Entrecasteaux Channel. Sampling of flathead is conducted in the period from August to November every year to minimise potential seasonal variations in hydrology and life cycles. Twenty common flathead *(Platycephalus bassensis)* are caught by hand-line within each region and analysed for total mercury. A range of different fish sizes are targeted to allow for an assessment of size versus mercury concentration, and typically about 30-40 of the fish in a given year are of legal size (i.e. ≥ 300 mm in length). The analyses provided here are based on mercury levels in legal-sized fish only.

Figure 8.1: Biota monitoring regions in the Derwent estuary



Annual median mercury levels in legal sized flathead From the Derwent estuary as a whole are presented in **Figure 8.2**, for the years 2002 through 2008. Median mercury concentrations during this time have fluctuated from year to year, but suggest a gradual increasing trend.

In 2008 Nyrstar Hobart commissioned a statistical review of their flathead data, with a focus on temporal changes in mercury levels in flathead in the Derwent estuary between 1991 and 2007 (Macpherson 2008). Some of the principal findings of this analysis include:

- In the region above the Tasman Bridge there is weak evidence of an upward trend in mercury levels in flathead, with the estimated average level rising 34% over the 17 year period. This increasing trend is unexpected, given the overall reductions in heavy metal emissions over the same time period. Further investigations have recently commenced at Tasmanian Aquaculture and Institute (TAFI)/University of Tasmania into mercury bioaccumulation pathways in the Derwent that may provide further insight into this issue (McLeod 2009, TAFI *pers. comm.*).
- Flathead from other regions (eastern shore, western shore, and Ralphs Bay) did not show any trends in mercury levels.
- There is strong evidence of a decrease in the average length in flathead throughout the region over the 17 year period, particularly in the Channel and western shore region.

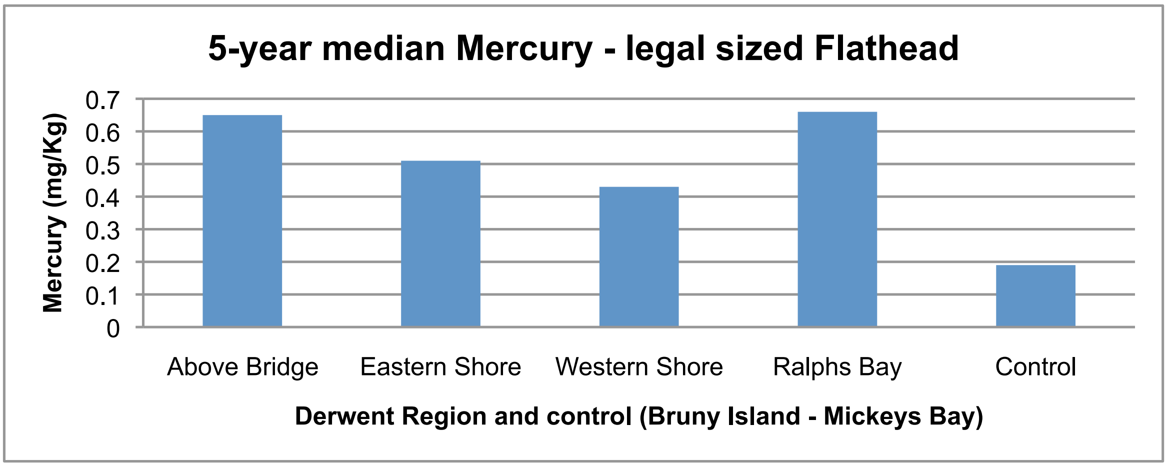
Median mercury levels in flathead collected from the four regions and control site (Mickeys Bay – southern Bruny Island) over the past five years are presented in **Figure 8.3**. This figure indicates that median mercury levels in fish collected from the area above the Tasman Bridge and from Ralphs Bay are generally higher than from the eastern or western shores of the lower estuary.

Monitoring data collected in recent years indicate that median mercury levels in legal-sized flathead are above the recommended FSANZ guideline of 0.5 mg/kg, notably in the Derwent estuary regions i) above the Tasman Bridge, ii) eastern shore and iii) Ralphs Bay. For the Derwent as a whole, the five year median (2004 to 2008) is 0.58 mg/kg. This information has been used in developing public health advice to recreational fishermen, presented in **Section 8.6**.

8.3.2 Heavy metal levels in other recreationally-targeted fish

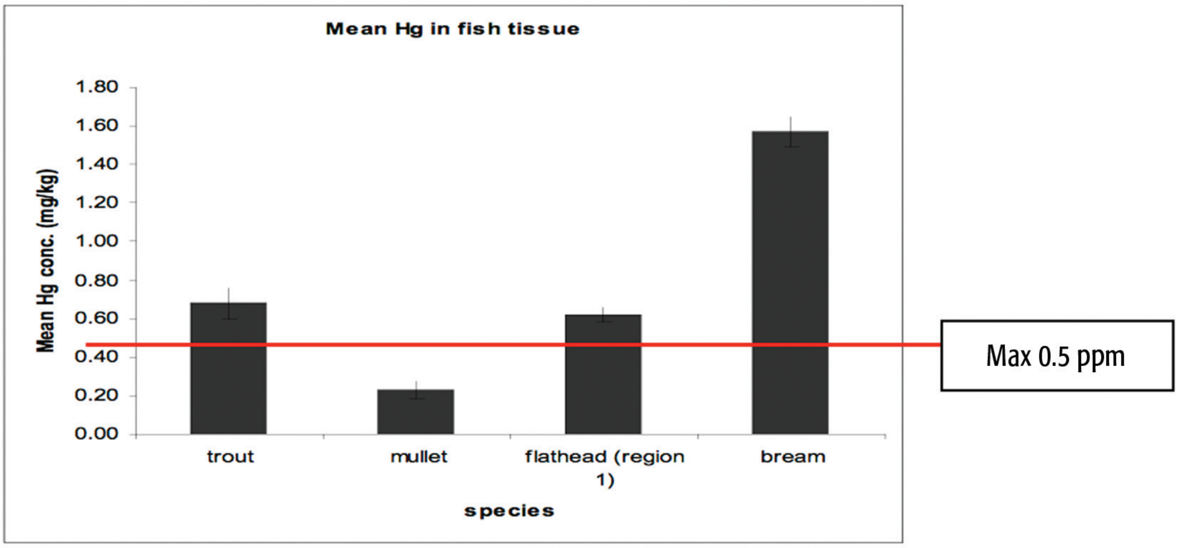
Heavy metals in other recreationally-targeted fish were investigated in a University of Tasmania Honour's project by Verdouw (2008). This study measured levels of mercury, arsenic, cobalt, chromium, copper, iron, manganese, nickel, lead, selenium and zinc in the muscle tissue of four fish species: yellow-eye mullet *(Aldrichetta forsteri)*, black bream *(Acanthopagrus butcheri)*, sand flathead *(Platycephalus bassensis)* and sea-run trout *(Salmo trutta)* from the Derwent estuary. Approximately 30 fish of each species were tested. As shown in **Figure 8.4**, mean mercury levels in black bream (1.57 mg/kg), sea run trout (0.68 mg/kg) and flathead (0.53 mg/kg) were found to be in excess of the 0.5 mg/kg Food Safety guidelines, while mean mercury levels in mullet (0.23 mg/kg) were well below. These results were used as the basis for a precautionary health advisory by the Tasmanian Director of Public Health (see **Section 8.6**), until more extensive surveys are carried out. Mean levels for other heavy metals were below the FSANZ maximum permitted and generally expected levels.

Figure 8.3: Median Mercury levels in Derwent estuary legal sized flathead (2004-2008)



Source: data provided by Nyrstar Hobart

Figure 8.4: Mean mercury levels in Derwent estuary fish from region one (Tasman Bridge to New Norfolk)



Source: Verdouw, 2008

8.4 Heavy metals in Derwent estuary shellfish

8.4.1 Heavy metals in wild growing oysters and mussels

Regular surveys of heavy metal levels in wild growing Derwent estuary oysters and mussels have been carried out since 1991 by Nyrstar Hobart Smelter and previous managers of the site. Surveys were done annually from 1991 to 2002 and since 2002 this had been modified to a three-yearly survey. Shellfish are analysed for zinc, cadmium, copper, mercury and lead.

The two shellfish types tested in the estuary – oysters and mussels – exhibit different responses to heavy metal uptake. Wild oysters (both the native *Ostrea angasi* and the introduced *Crassostrea gigas*) accumulate zinc to a higher degree than mussels *(Mytilus edulis)*, while mussels preferentially accumulate lead.

In the summers of 2002-03, 2005-06 and 2008-09, wild oysters and mussels were collected from between 12 to 21 sites within the Derwent estuary. Several control sites were also sampled outside of the estuary (from d'Entrecasteaux Channel and Frederick Henry Bay) to provide a basis for comparison. Median heavy metal levels have been calculated from a combination of data from these surveys and are summarised in **Table 8.2** below.

Median values for lead exceed FSANZ (2005) maximum permitted levels in Derwent wild oysters and mussels. Lead levels were considerably higher in mussels than in oysters, as has previously been observed.

In oysters, median values for copper and zinc also exceed FSANZ GELs. Median values for cadmium and mercury were below FSANZ guidelines in both oysters and mussels.

Figure 8.5 illustrates regional differences in cadmium, copper, lead and zinc levels in Derwent estuary oysters for the 2002-03, 2005-06 and 2008-09 surveys, as compared to background levels and FSANZ limits. As in previous surveys, median zinc levels remain well above the GELs of 130 mg/kg throughout the estuary – particularly in the area above the Tasman Bridge. Elevated zinc levels in the d'Entrecasteaux Channel may reflect regional zinc contamination from the Derwent. Copper levels are also well above the GELs of 3 mg/kg throughout most of the estuary. Median lead levels are slightly above FSANZ standards in the area above the Tasman Bridge and in Ralphs Bay, while cadmium levels are slightly elevated in the area above the Tasman Bridge. Comparison with earlier surveys suggests a declining trend in heavy metal levels in oysters in some regions of the Derwent estuary, particularly above the Tasman Bridge.

Figure 8.6 illustrates regional differences in lead levels in Derwent estuary mussels for the 2002-03, 2005-06 and 2008-09 surveys, as compared to background levels and FSANZ limits. Lead levels are substantially higher than the FSANZ (2005) maximum permitted levels, particularly in the area above the Tasman Bridge and in Ralphs Bay. There are some indications of an overall declining trend in lead levels in mussels, particularly as compared to earlier surveys.

8.4.2 Deployed oyster experiments

The Nyrstar Hobart smelter has conducted deployed or caged oyster experiments in the Derwent estuary annually since the summer of 2003-04. These experiments involve the deployment of uncontaminated, cultured oysters *(Crassostrea gigas)* at locations around the estuary, with a focus on the middle estuary. The objective is to quantify metal uptake rates and investigate accumulation factors in oysters of known age, in order to eliminate the variability encountered in the wild oyster surveys. Metal analyses are undertaken for zinc, cadmium, lead, copper, and mercury.

Cultured oysters sourced from a marine farm on Tasmania's East Coast are typically deployed at nine sites plus a background site in the d'Entrecasteaux Channel. At each site about 30 oysters are placed in plastic mesh cages, and secured sub-tidally as close to the seafloor as possible. Deployed oysters are retrieved after being immersed in the Derwent estuary for six weeks, removed from their shells and analysed as a pooled sample.

Metal levels are also analysed in the cultured oysters pre-deployment to provide a baseline value. Several additional trials have been included in this design over the years, including staged oyster retrieval, deployment of cages at different depths and analyses of individuals to assess variability. See Nyrstar Hobart EMP Reviews for further details.

Table 8.3 provides a summary of results from the last five years' deployment experiments, with further details provided in **Figure 8.7.**

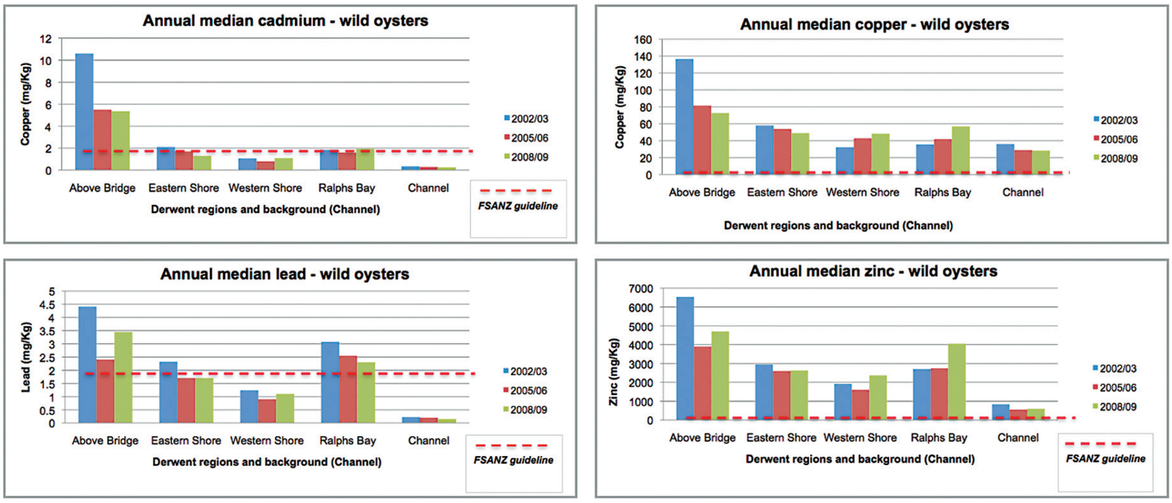
In summary, the oyster experiments carried out over the past five years indicate that within six weeks, clean oysters deployed at mid-estuary sites are able to accumulate levels of zinc, lead and copper well in excess of FSANZ guidelines. **Figure 8.7** suggests that uptake of zinc and cadmium seems to be particularly widespread, while uptake of copper, mercury and lead appears to be more localized to the vicinity of the Nyrstar wharf. The only notable instances of variation between near-surface and bottom levels are for zinc and cadmium at

Table 8.2: Median metal levels in Derwent shellfish (2002-08)

	Maximum Permitted Levels (mg/kg)			**Generally Expected Levels (median/90 percentile) (mg/kg)**	
	Cd	**Hg**	**Pb**	**Cu**	**Zn**
Molluscs	2	0.5	2	3	130
Derwent 2002, 05, 08					
Oysters	1.85	0.12	2.4	54	2930
Mussels	1.13	0.08	9.8	1	45

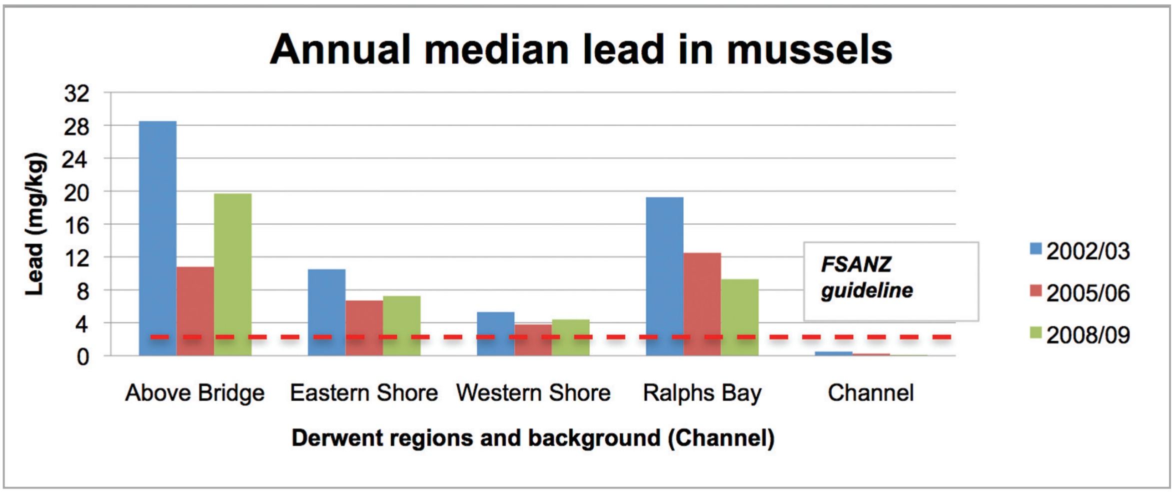
Note: heavy metal levels in seafood figures from (FSANZ 2005). Cu GELs are from the FSANZ Code Review 1999.

Figure 8.5: Cadmium, copper, lead and zinc levels in Derwent wild oysters (2002-03 – 2008-09)



Source: data provided by Nyrstar Hobart

Figure 8.6: Lead levels in Derwent wild mussels (2002-03 – 2008-09)



Source: data provided by Nyrstar Hobart

the Nyrstar Wharf site, and to a lesser degree zinc at the Beltana Bay site. Further details are provided in the Nyrstar 2007-08 EMP.

8.4.3 Heavy metals in other species and food-web pathways

In 2008, an Honours project investigated the relationship between diet and heavy metal concentrations in the sand flathead (Hunt 2008). Heavy metal concentrations were measured in muscle, liver and gonad tissues of sand flathead *(Platycephalus bassensis)*, as well as in two major prey groups of flathead (crabs and fish), from four different regions within the Derwent estuary. Metal concentrations in flathead organs showed positive relationships with prevalence of certain prey groups in the diet (based on fish stomach contents analysis). Of regions studied in the Derwent, Ralphs Bay has the highest heavy metal contamination level in flathead (see **Figure 8.3**). However, the relationship between prey and total sediment heavy metal contamination was not apparent (Hunt 2008).

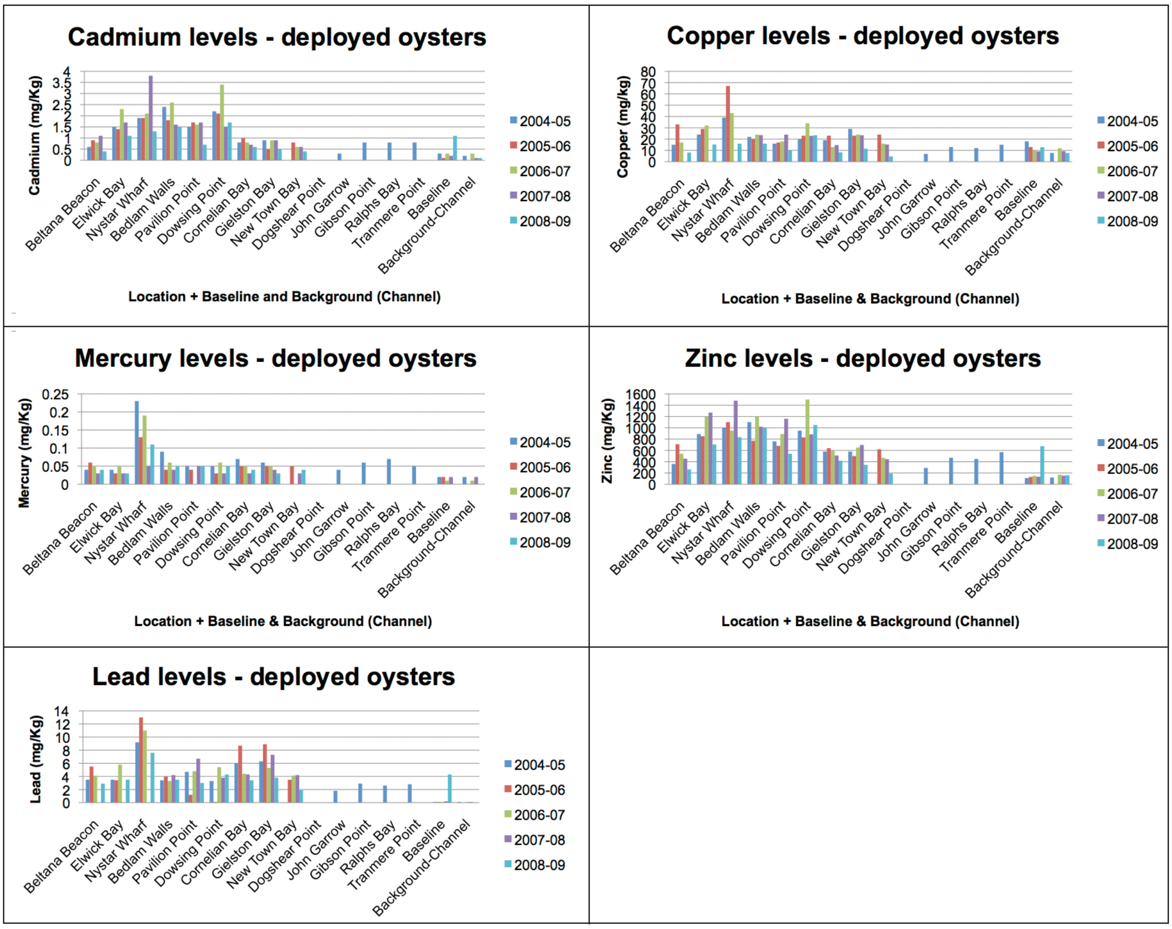
A pilot study has recently been undertaken into heavy metal levels in selected fauna from the Derwent estuary and surrounding areas in order to assess spatial and biotic differences in heavy metal contamination (Swadling and Macleod 2008). Differences in heavy metal levels were also observed amongst different biotic groups from different locations, however the level of faunal contamination did not directly correlate to total heavy

Table 8.3: Metals in oysters deployed on the Derwent seafloor, (2004-05, 2005-06, 2006-07, 2007-08, 2008-09)

	Maximum Permitted Levels (mg/kg)			**Generally Expected Levels (median/90 percentile) (mg/kg)**	
	Cd	**Hg**	**Pb**	**Cu**	**Zn**
Molluscs	2	0.5	2	3	130
Total metal level in oysters deployed 6 weeks					
average	*1.3*	*0.05*	*4.7*	*21.1*	*749*
median	*1.1*	*0.05*	*4.1*	*20.0*	*70*
Oysters deployed 6 weeks – change from east coast baseline					
average	0.9	0.0	3.7	7.9	517
median	0.7	0.0	3.6	6.1	495

Note: heavy metal levels in seafood figures from (FSANZ 2005) Cu GELs are from the FSANZ Code Review 1999

Figure 8.7: Variations in metal levels (mg/kg) from cultured oysters deployed near the seabed of the Derwent estuary for six weeks over summer



Source: data provided by Nyrstar Hobart

Note: Pb and Cu values not obtained for 2006-07

metal levels in seafloor sediments. See **Section 5.3.3** for details. Study findings from Hunt (2008) and Swadling and Macleod (2008) highlights the need for more research into biologically available heavy metals and the food-web pathways through which seafood contamination occurs.

8.5 Other toxicants

8.5.1 Toxic algal blooms

The toxic dinoflagellate *Gymnodinium catenatum* was introduced to Tasmanian waters in the 1980s via international shipping (McMinn *et al.* 1997), and toxic algal blooms associated with this species are a periodic feature of the Huon estuary and d'Entrecasteaux Channel. These blooms are likely to also extend into the Derwent estuary at times. The Tasmanian Shellfish Quality Assurance Program (TASQAP) surveys commercial shellfish-growing areas around the state for the presence of toxic algae, as well as other potential contaminants such as faecal indicator bacteria. There are a number of TASQAP monitoring sites located in Northwest Bay and the d'Entrecasteaux Channel. However, no toxic algal monitoring is carried out in the Derwent as there are no commercial shellfish operations.

8.5.2 Organic contaminants

In 2001, a selection of fish and shellfish (flathead, bream, trout, mullet, oysters and mussels) from the Derwent were analysed for PCBs and organochlorine pesticides (such as DDD, DDE and DDT). Of the 21 samples analysed for nine toxic organic compounds all results returned <0.10 ppm of the target compound (see the *2003 State of the Derwent Estuary* report for further details). In 2003, dioxins were surveyed from two Derwent estuary sediment samples and one shellfish sample by the National Research Centre for Environmental Toxicology (Muller *et al.* 2004). It was found that the levels of dioxins measured were moderate to low, compared to samples from other urbanized estuaries around Australia.

8.6 Discussion and health advice

Although there seem to be declining trends in heavy metal levels in shellfish at some Derwent estuary locations, concentrations remain well in excess of the national food guidelines, particularly for lead in mussels and zinc in oysters. Mercury levels in flathead have not declined substantially since the 1970s, and appear to have increased somewhat in recent years in the area above the Tasman Bridge. As discussed in **Section 8.3.1**, median mercury levels in Derwent flathead are currently in excess of the national food guidelines, particularly in the region above the Tasman Bridge and in Ralphs Bay. The 2007 pilot survey of other recreationally targeted fish indicates that mercury may be elevated in other species, in particular black bream.

In response to this information, the DEP has liaised with DHHS to develop precautionary health advice for recreational fishers in the Derwent. The following advice has been provided to recreational fishers by the Tasmanian Director of Public Health:

Do not eat any Derwent-harvested shellfish and Derwent-caught black bream.

Limit consumption of flathead and other Derwent caught fish:
- *pregnant women and young children should limit consumption of flathead or other Derwent-caught fish to no more than one meal per week and avoid eating other fish in the same week; and*
- *other adults should limit consumption of flathead or other Derwent-caught fish to no more than two meals per week.*

The advice regarding bream and other Derwent-caught fish is precautionary, and may be amended as new information becomes available. In 2009, the DEP was granted funding through the Australian Government's *Caring for our Country* program to extend the bream and trout surveys and to investigate heavy metal levels in Derwent flounder and eel.

As discussed in **Section 5** (Integrated Studies), mercury and other heavy metals historically discharged to the Derwent have been derived from several sources, and there have been major reductions in loads over the past few decades. Contemporary sources appear to be largely associated with groundwater contamination at the Nyrstar Hobart smelter site, which is undergoing further remediation (see **Section 4.2.1**). Nonetheless, the significant reductions in heavy metal loads discharged to the estuary are not consistently represented in the results of biota monitoring over the same time period.

In addition to the current emissions, there are a number of other significant factors that influence the heavy metal concentration in biota of the Derwent estuary. These include:
- bioaccumulation from historically contaminated estuarine sediments;
- inherent variability within the population being sampled, such as size, reproductive status, depuration rate of metals and spatial distribution;
- estuarine dynamics such as currents and sediment deposition/accumulation; and
- estuarine chemistry such as sediment remobilisation, acid volatile sulphide levels, and organic components.

Further investigations are recommended to better understand the sources, sediment chemistry, food chain pathways and impacts of heavy metals in the Derwent estuary.

9.0 ESTUARINE HABITATS AND NATIVE SPECIES

9.1 Derwent estuary habitats

The Derwent estuary supports a wide variety of habitat types, which have been broadly mapped over an area of 197 km^2. Information on estuarine habitat types and their distribution has recently been compiled by the Derwent Estuary Program (DEP) into a web-based *Derwent Estuary Habitat Atlas*, through a grant supported by the Australian Government. Major estuarine habitat types are summarised in **Table 9.1** and their distributions illustrated in **Figures 9.1 – 9.3**. Further information about the habitat atlas is available on the DEP website at www.derwentestuary.org.au (go to Derwent Habitat and Species section), while the full GIS mapping products can be accessed on the Land Information Services Tasmania (LIST) website at www.thelist.tas.gov.au (under 'Manage Layers', go to Natural Environment/Coastal Values/Derwent Estuary Habitat Atlas). The distribution maps were created using data from: Lucieer *et al*. (2007), Seacare, Information Land Services (DPIPWE), Coastal Marine Branch (DPIPWE), and mapping projects undertaken for the DEP by North Barker Ecosystem Services.

As indicated in **Table 9.1**, unvegetated subtidal sand and silt habitats are the most abundant habitat type within the Derwent estuary, occupying over 86% of the estuary area. The next most abundant types are aquatic macrophytes (6.6%; dominated by *Ruppia* spp. growing on mudflats in the upper estuary), followed by intertidal sands (5.8%; mostly as sand flats in the lower estuary). Other habitats (wetlands, saltmarshes, seagrasses, kelp forests, reefs and rocky shores) comprise the remaining 1.5% of the estuary area. Although collectively small in area these other habitat types are critical for sustaining many species found within the estuary. These different habitats types are discussed in more detail in subsequent sections, as is the fringing coastal vegetation that borders much of the estuary.

There has been extensive pressure on estuarine habitats from urban and industrial development, climate change, and changes in catchment use and River Derwent flow. These pressures have contributed to siltation and organic deposition in the upper and middle estuary, as well as deterioration in water and sediment quality throughout the estuary. In addition, there have been extensive habitat losses, notably amongst wetlands, saltmarshes, tidal flats and other foreshore habitats due to development and foreshore reclamation, particularly in the middle reaches of the estuary, where many wetlands were used as municipal and industrial tips and later redeveloped as recreation areas. Giant kelp forests and seagrass beds also appear to have declined in the estuary. Overfishing of some native species and the introduction of non-native marine and intertidal species, have dramatically changed the community of organisms living in the Derwent estuary. Recent analyses of sediment records from bays in the middle and lower estuary also suggest significant declines have occurred in sediment quality and native mollusc assemblages over the past 120 years (**see Section 9.4.1**). There are, however, significant areas of habitat remaining within the Derwent estuary that support healthy functioning ecosystems, with abundant and diverse populations of native species, as described below.

Table 9.1: Summary of habitats in the Derwent estuary

Habitat	Area sq km	Percentage %
Subtidal	**174.05****	**88.21**
Sand	92.97	47.05
Silt	77.62	39.28
Rocky Reef	3.00	1.52*
Cobble Reef	0.27	0.14
Kelp Forest	0.26	0.13
Seagrass	0.18	0.09
Shallow subtidal to intertidal	**6.58**	**3.33**
Aquatic Macrophytes	6.58	3.33
Intertidal	**13.23**	**6.69**
Intertidal sand (sand flat / beach)	11.37	5.75
Unvegetated mud flat	0.96	0.48
Rocky shorelines	0.90	0.46
Intertidal to supratidal	**3.49**	**1.77**
Saltmarsh	2.16	1.09
Wetland	1.34	0.68
Other		
Shipwreck	0.01	0.00
TOTAL AREA OF ESTUARY	197.61	

Notes:
* = includes overlap between reef and kelp
** = kelp subtracted from subtidal due to overlap with reef

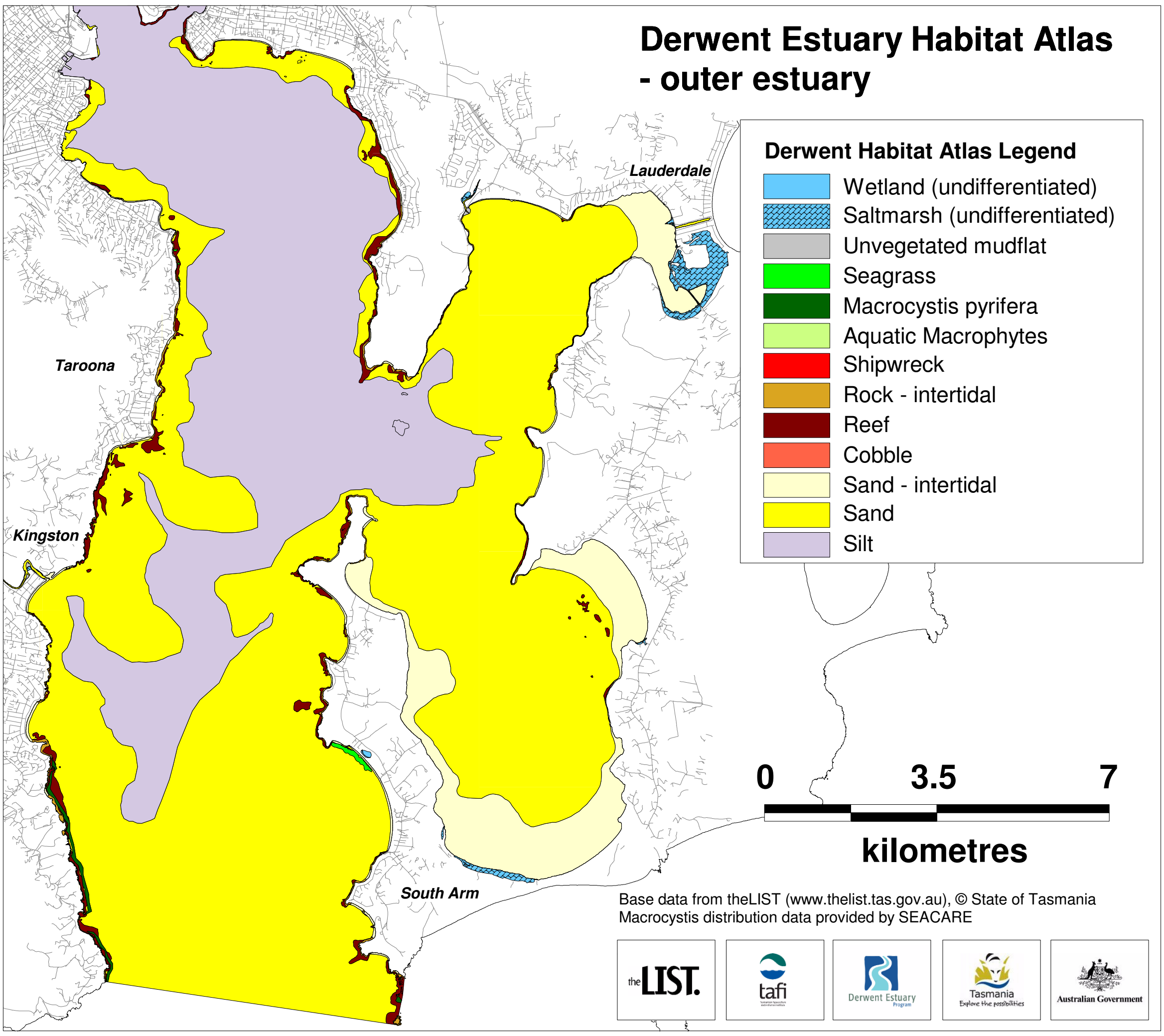
9.1.1 *Subtidal sands and silts*

Subtidal sands and silts are the dominant habitat types in the Derwent estuary. Sand predominates at shallower depths, covering 93 km^2 (i.e. 47%) of the estuary, while silt predominates in deeper areas, covering approximately 78 km^2 (i.e. 39%) of the estuary. The depth at which silt dominates becomes shallower up-estuary, from 25 m at the seaward extreme of the lower estuary to <5 m at Sullivan Cove and Kangaroo Bay. Subtidal sediments provide important substrate for microscopic algae, macroalgae, seagrasses and macrophytes and are a key habitat for benthic invertebrates. These sediments also perform a number of important ecological functions that maintain the overall health of the estuary, including denitrification, as discussed in **Section 5.4**.

Siltation has occurred in many Derwent subtidal (and intertidal) habitats as a result of land clearance, agriculture and urban development (Edgar *et al*. 2005). It appears that over the last 200 years silts have accumulated within many sheltered bays, particularly in the middle and upper estuary, impacting on public amenity and the biological values of these areas. These habitats have also been heavily impacted by historical discharges of heavy metals and organic matter (see **Sections 6.0 and 7.0**). Sediment-bound heavy metal concentrations are typically higher in subtidal silt than subtidal sand (see **Section 7.0**). Changes within soft sediment subtidal habitats can be detected through changing heavy metal, organic sediment, and mud (versus sand) concentrations and changes in benthic invertebrate species (see **Section 9.4.1**). Declining water quality and habitat disturbance has probably also contributed to the loss of seagrass beds from subtidal sediments in the middle and lower estuary, and Ralphs Bay, as described in **Section 9.1.3**.

Overfishing during the last 120 years has dramatically altered the structure and biology of subtidal sedimentary habitats in the Derwent estuary, most notably the conspicuous loss of native oyster and scallop beds along with their associated communities (Edgar and Samson 2004). The introduction of non-native species is also likely to have caused major impacts on these habitats, as introduced marine species can significantly alter the biological and chemical processes in subtidal sediments (Ross and Keough 2006). A notable example has been the formation of extensive beds of New Zealand screw shells (*Maoricolpus roseus*) within subtidal sands near the estuary entrance, as described by Macleod and Helidoniotis (2005), modifying this habitat into shelly gravel.

Figure 9.1: Distribution of habitat types in the lower reaches of the Derwent estuary



9.1.2 Rocky reefs and kelp forests

Subtidal rocky reefs

Subtidal rocky reefs collectively cover 3.2 km^2 (i.e., 1.6%) of the estuary (Lucieer *et al*. 2007). Although rocky reefs cover such a relatively small area, they are important to the overall species diversity within the estuary. Derwent estuary reef habitat varies substantially in structure, between the eastern and western shorelines, and in position along the estuary. In the lower estuary rocky reefs primarily occur as seaward extensions of the rocky shoreline. However in several places isolated reefs occur away from the coast and are surrounded by soft sediments (Lucieer *et al*. 2007). Sixty eight macroalgae species have been identified on the rocky reefs in the lower estuary (Sanderson 2000). In the lower estuary macroalgal distribution varies with water depth, with shallow areas dominated by *Lessonia corrugate* and *Ecklonia radiata*, and deeper areas dominated by *Carpoglossum confluens, E. radiata, Caulerpa* sp. and red algae species. Variation has also been observed in macroalgae between the eastern and western reefs in the lower estuary, with *Macrocystis pyrifera* (giant kelp) and introduced *Undaria pinnatifida* only observed on the western reefs. Along the eastern shore, the macroalgal assemblage was largely absent below 3 m water depth, and north of Opossum Bay the macroalage is less abundant. A greater oceanic influence from Storm Bay is thought to be a possible cause for some of the east-west macroalgal variation observed (Luccier *et al*. 2007). The subtidal rocky reef communities within, and just outside of, the Tinderbox Marine Protected Area were surveyed in 1992 and 1997 (Edgar and Barrett 2002) and can be used for the basis of future reef comparisons. The DEP and Tasmanian Aquaculture and Fisheries Institute (TAFI) are about to commence biological surveys on subtidal reef systems throughout the middle and lower Derwent estuary.

Figure 9.2: Distribution of habitat types in the middle reaches of the Derwent estuary

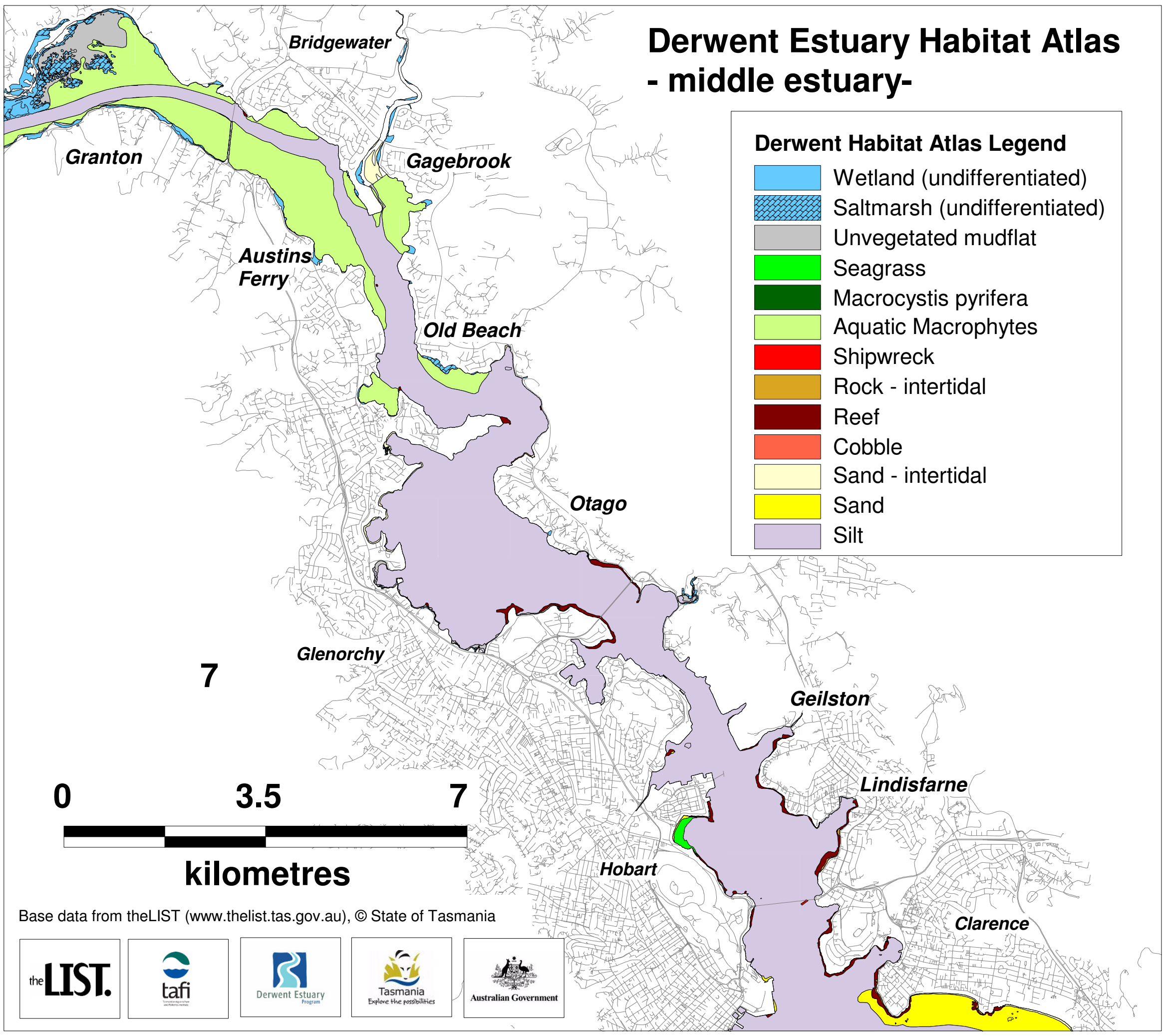
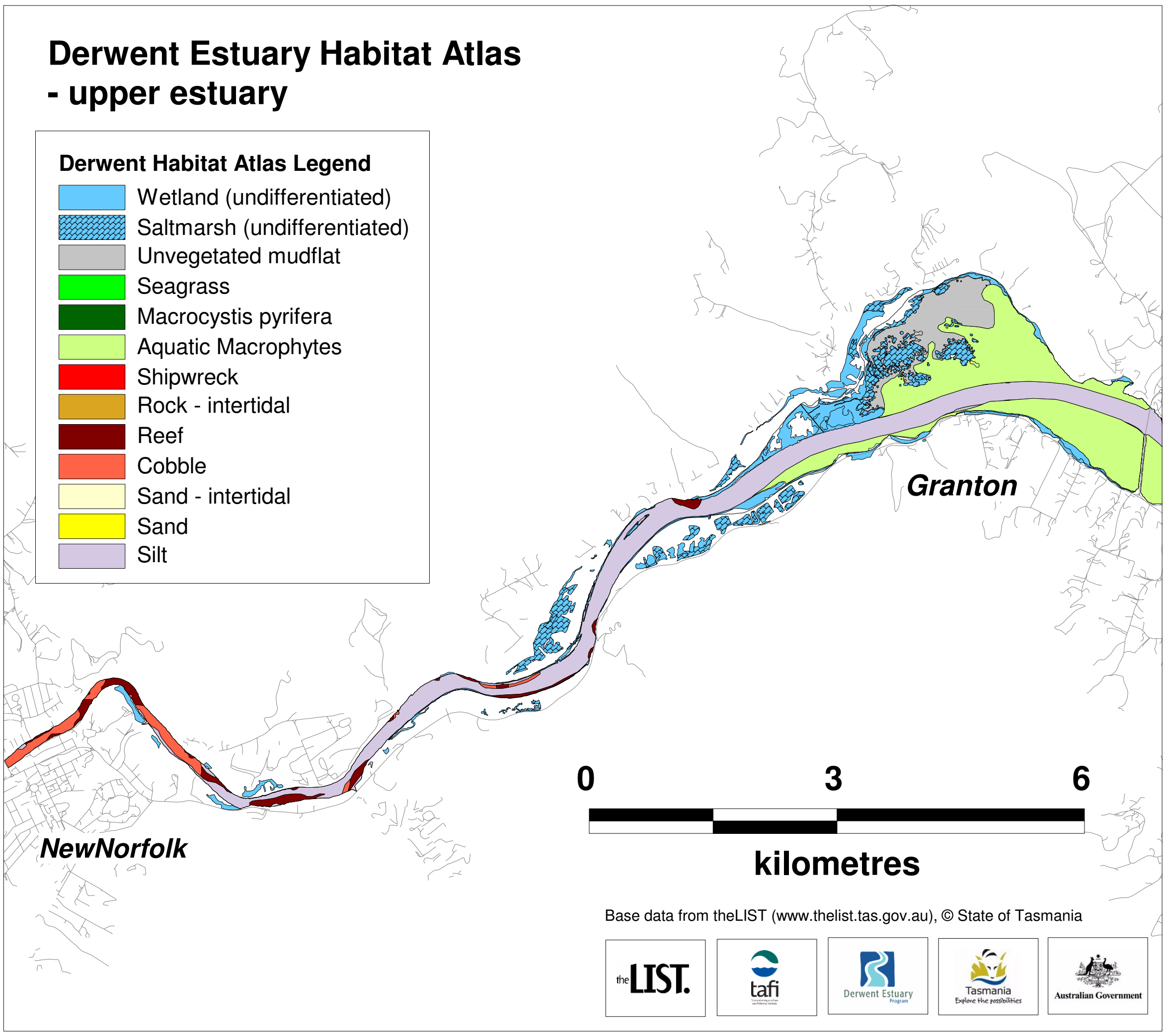


Figure 9.3: Distribution of habitat types in the upper reaches of the Derwent estuary



In the middle estuary, rocky reefs are narrow extensions of the rocky shoreline. There is a decrease in macroalgal abundance and diversity in the middle, estuary compared to the lower estuary (Jordan *et al*. 2001) and typically only small amounts of red and brown algae are present (Lucieer *et al*. 2007). Reef habitat of the middle estuary is influenced by environmental perturbations, both human-induced (enhanced turbidity and nutrients) and natural (intervals of high River Derwent flows result in lower salinity and reduce light levels due to high tannin levels). Freshwater events have been known to change the whole structure of reef habitats in the Derwent from macroalgae dominated systems to invertebrate dominated (A. Jordan, TAFI, *pers. comm. in:* Green and Coughanowr 2003).

Several subtidal rocky reefs and cobble areas occur in the upper estuary, within the main channel of the estuary, but there is little algal growth on these due to the low light levels and frequent freshwater flushing (Lucieer *et al*. 2007).

Giant string kelp forests

Several areas of the lower Derwent, along the Tinderbox Peninsula, contain giant string kelp forests (*Macrocytis pyrifera*) with brown algae (*Lessonia corrugate*) as a dominant species in the understory (Jordan *et al*. 2001). Giant kelp often grows to lengths of 30 m or more and provides habitat for many marine fish and invertebrates, including rock lobster, abalone, sea urchins and trumpeter. The most recent giant kelp survey in 1999 by Seacare Inc. Tasmania found that kelp covered 0.26 km^2 of the Derwent estuary (Sanderson 2000).

Declines in kelp beds within the Derwent estuary have been reported since the 1950s, particularly along the estuary's eastern shore. Reefs affected by siltation in the Lindisfarne area have lost their kelp beds. The loss of this habitat has implications for the biodiversity of the middle and lower Derwent estuary. Major factors causing these losses include excessive sedimentation, warmer water temperatures and sea urchin infestation. Conversely, giant kelp appears to respond favorably to increased nutrient supply and is flourishing locally near the Blackmans Bay sewage outfall (C. Sanderson, TAFI, *pers. comm.* in: Green and Coughanowr 2003). Giant kelp transplanting trials were undertaken in the Derwent by Seacare Inc. Tasmania to assess the viability of reintroducing kelp to areas where it is believed to have disappeared or is in decline. A subsequent resurvey of these sites has indicated that the transplant trials have not been successful (S. Ibbott, 2009, Seacare, *pers. comm.*).

9.1.3 Aquatic macrophytes and seagrasses

Aquatic macrophytes and seagrasses generally occur in relatively shallow water, where there is adequate light penetration. These communities provide food, shelter and structural habitat for many invertebrates and fish, including a number of commercially important species. In the upper estuary these plants are the major primary producers and sustain an ecosystem with a considerably higher diversity and abundance of animals than in non-vegetated habitats.

Aquatic macrophytes are vascular plants that grow as submergent or floating vegetation, occasionally exposed above water during low tides. In this report, the term aquatic macrophyte is used to describe non-seagrass species which occur as a vegetation type defined by TasVeg as a *saline aquatic herbland*. This vegetation consists of a few species, dominated by *Ruppia* spp. (typically *R. megacarpa*), and in some places abundant *Lepilaena cylindrocarpa, Lamprothamnium* spp. and *Myriophyllum salsugineum* (NSR 2001). In the Derwent, aquatic macrophytes occur in the upper estuary in water depths <1.5 m.

Seagrasses are flowering plants adapted for life submerged in marine or estuarine environments. The dominant seagrass species in the Derwent estuary is *Heterozostera nigricaulis* (formerly *Heterozostera tasmanica*), with small populations of *Zostera mulleri*. The shallow aquatic macrophyte community around the Bridgewater causeway, dominated by *Ruppia megacarpa*, also contains less abundant seagrass *Heterozostera nigricaulis*, which becomes dominant towards the edge of the main channel of the Derwent estuary (at depths of 2 m) (Lucieer *et al*. 2007). This macrophyte/seagrass complex occurs south of the Bridgewater Causeway, in the mouth of the Jordan River, and adjacent to Austins Ferry, but is mapped as aquatic macrophytes (in **Figure 9.2**) due to the dominance of *Ruppia* (Lucieer *et al*. 2007).

Seagrass (*Heterozostera or Zostera*) dominated habitats are restricted to small beds within the lower and middle parts of the Derwent estuary with a combined area of around 0.18 km^2 (Lucieer *et al*. 2007). Seagrass beds in the lower Derwent occur within the northern part of Halfmoon Bay and consist entirely of *Heterozostera nigricaulis* to a depth of about 5 m. In the middle estuary, small seagrass beds consist primarily of *Heterozostera nigricaulis* and are found to a depth of about 3 m at: Cornelian Bay, Wilkinsons Point, the northern end of Dogshear Point, Woodville Bay and Old Beach (Jordan *et al*. 2001). Small amounts of *Zostera mulleri* are present in Cornelian Bay and Prince of Wales Bay (Lucieer *et al*. 2007).

Some changes in seagrass coverage were noted since an earlier Derwent estuary survey in Jordan *et al*. (2001), which include loss of seagrass beds at Opposum Bay, Dogshear Point, Wilkinsons Point, Woodville Bay and Old Beach. The seagrass beds of Cornelian Bay were previously noted to be in very poor health with sparse coverage and high epiphyte loading (Jordan *et al*. 2001). However their extent has now expanded across shallow areas of the bay (Lucieer *et al*. 2007). Many intertidal areas within middle estuary bays support seagrass (J. Whitehead, 2009, DEP, *pers. obs.*), but have not been included in previous boat based surveys as they were too shallow. Intertidal areas in Prince of Wales Bay support minor seagrass remnants amongst an extensive coverage of macroalgae (*Ulva* sp.), which is typically an indicator of eutrophication and may be contributing to low seagrass presence (J. Whitehead, 2009, DEP, *pers. obs.*). It is believed that the seagrass beds of the middle estuary are remnants of previously more widespread populations and there is concern that the remaining biomass may be insufficient for recruitment and maintenance of this habitat (A. Jordan, TAFI, *pers. comm.,* in: Green and Coughanowr 2003). Subsequent loss of some seagrass coverage throughout the middle estuary since the previous *State of the Derwent Estuary Report* supports this hypothesis.

Analysis of historic aerial photographs suggests that seagrass beds were formerly abundant throughout Ralphs Bay (Rees 1994). Recent surveys have not documented any regrowth of seagrass in Ralphs Bay (Lucieer *et al*. 2007, Aquenal 2008a), and further work is recommended to substantiate the past distribution of seagrass in this area of the estuary. The DEP is exploring different techniques for surveying and monitoring macrophyte and seagrass extent and condition, in collaboration with researchers from the University of Tasmania and TAFI.

9.1.4 Intertidal sand flats and mudflats

Intertidal sand flats and mudflats are low-lying areas that are inundated during high tides and are exposed during low tides. The Derwent estuary contains large areas of tidal flats (13.2 km^2), with mudflats predominating in the upper estuary and sand flats predominating in Ralphs Bay (particularly at Lauderdale, Mortimer Bay and the eastern side of South Arm). Tidal flats perform a wide range of essential functions. For example, these areas:

- contain large amounts of microscopic algae (microphytobenthos) and bacteria that play important roles in nutrient and organic matter cycling, denitrification and other biogeochemical processes;
- contain large numbers of invertebrates upon which fish, birds and other animals are dependent;
- are critically important habitats for wading shore birds;
- provide substrate for aquatic macrophytes, seagrass, and saltmarsh vegetation;
- protect shorelines from erosion and flood damage;
- moderate water temperatures.

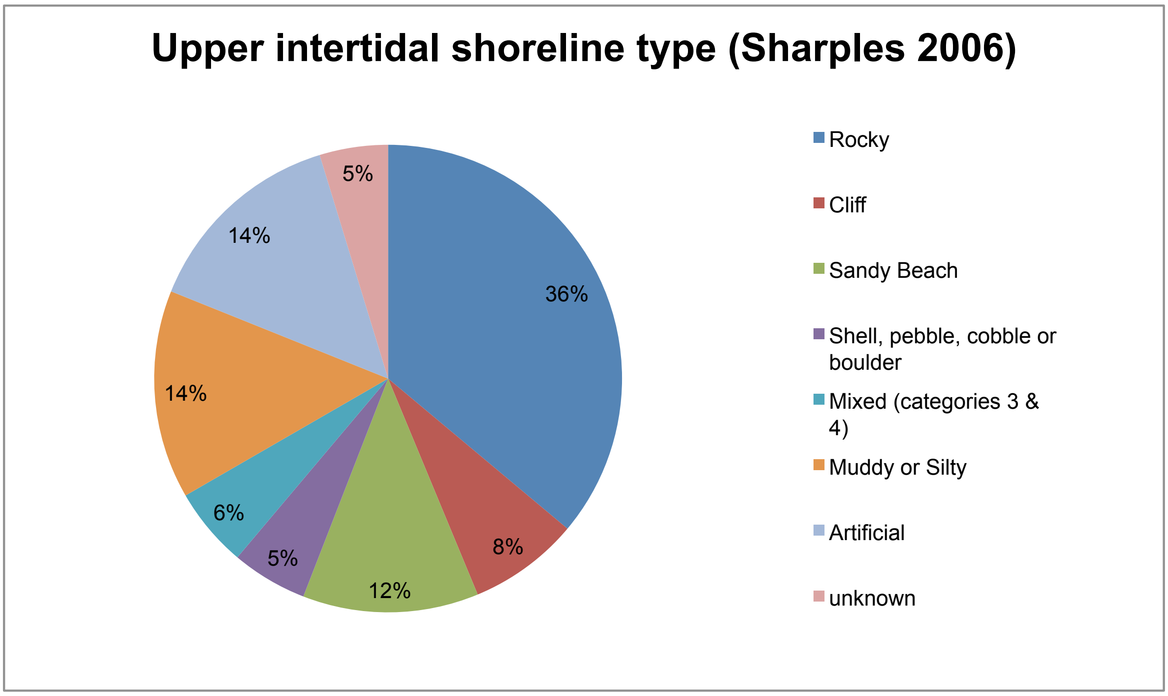
Although many of the sand and mudflats in the Derwent estuary appear to be unvegetated, these areas support large numbers of microscopic benthic algae (microphytobenthos). In the upper estuary, the relative abundance of microphytobenthos on the intertidal mudflats varies in proportion to the presence or absence of larger plants (notably macrophytes), which shade the underlying tidal flats and reduce the amount of light available for microphytobenthos photosynthesis (NSR 2001). In Ralphs Bay, the microscopic benthic algae distribution is relatively homogenous across the intertidal flats, but experiences some seasonal variation in algal abundance and species composition (Cook *et al*. 2007). The intertidal sand flats at Ralphs Bay are critically important for maintaining high levels of primary productivity in this intertidal ecosystem, with flow-on benefits to higher trophic levels, such as wading shorebirds (Cook *et al*. 2007).

The intertidal sand flats in Ralphs Bay, in conjunction with sand flats in the nearby Pittwater estuary, are internationally recognised for their significance to resident and migratory shorebirds (see **Section 9.4.3**). In contrast, intertidal mudflats (typically in the upper estuary) are not considered to be favourable habitats for wading shorebirds (Harrison 2008), but remain important areas for waterfowl and other species that also use the adjacent wetlands and saltmarshes.

9.1.5 Beaches and rocky shorelines

Beaches and rocky shorelines are a conspicuous part of the Derwent estuary, providing habitat for native species as well as public amenity and access to the estuary. The intertidal mean high water mark (MHWM) around the Derwent estuary is approximately 233 km long, and represents the length of the intertidal zone (the coastal strip between high and low tide). In reality this may be

Figure 9.4: Upper intertidal shoreline type in the Derwent estuary



Source: Sharples 2006

longer, as the convoluted salt marsh islands in the upper estuary have not been included in this calculation. It is possible to assess the relative proportion of intertidal beach and rocky shoreline around most of the estuary from geological and geomorphological data collected by Sharples (2006), based on mapping that extends up-estuary as far as Boyer. The following summary can be made about the nature of the Derwent estuary intertidal zone from the Sharples (2006) assessment (**Figure 9.4**).

Rocky shorelines comprise 84 km or 36% of the length of the Derwent intertidal zone and are notably found in the middle and lower estuary. Recent surveys of rocky intertidal communities in Ralphs Bay have documented 21 to 39 invertebrate species per site, falling within the range documented for other areas of eastern Tasmania (Aquenal 2008b). A number of intertidal rocky habitats within the Derwent estuary are now dominated by introduced species. Approximately 14% of the Derwent intertidal zone is artificial, largely as a result of land reclamation and wharf construction in the middle estuary. Sandy shorelines occur along approximately 12% of the Derwent estuary MHWM. The majority of sandy intertidal habitat is associated with sand flats.

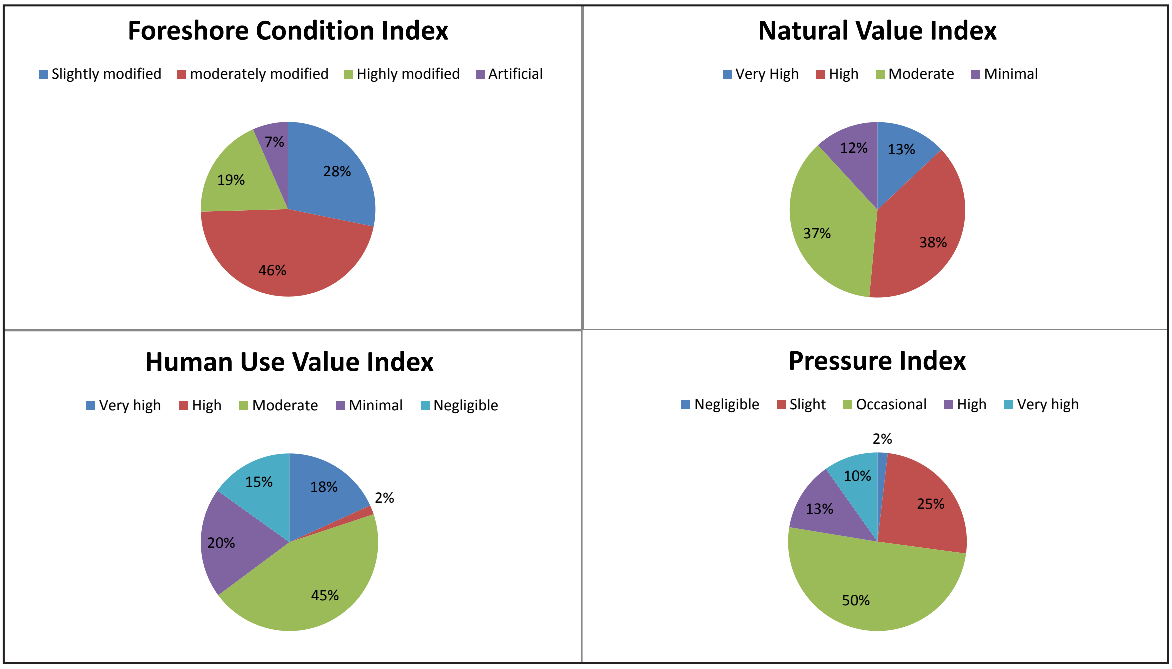
Assessment and mapping of intertidal zone values, condition and pressures in the Southern NRM Region (including the Derwent estuary) were commissioned by NRM South to better inform future management (Aquenal 2008b). Seventeen electronic mapping layers were produced, which were used to grade the intertidal zone based upon parameters such as biological values and conditions. **Figure 9.5** provides a summary of the Derwent estuary intertidal zone assessment for the key indices.

9.1.6 Wetlands and saltmarshes

Wetlands and saltmarshes are characterised by the presence of water, either permanently or periodically, and cover a 3.5 km area of the Derwent estuary. Saltmarshes occur on saline flats and estuarine areas fringing low energy coasts and are characterised by a high cover of salt tolerant species. They are variously dominated by succulent shrubs (samphire), grasses, sedges, rushes or herbs. Wetlands typically occur in the upper estuary (where more fresh water conditions typically occur) and in some places occur adjacent to saltmarsh vegetation.

Wetlands and saltmarshes provide valuable wildlife habitat, fish spawning grounds and nurseries, flood and erosion control, pollution abatement as well as visual and recreational amenities. Many wetland and saltmarsh plants actively regulate hydrology through a range of mechanisms such as transpiration, water-shading and sediment trapping. As water passes through wetlands and saltmarshes the combination of reduced current velocities

Figure 9.5: Derwent estuary intertidal zone assessment of i) natural value, ii) foreshore condition, iii) human use value, and iv) pressure (expressed as a relative % of the approximate 233 km of intetidal zone)



Source: data from Aquenal 2008b

and biochemical interactions with soils and plants acts as a natural filter, removing or attenuating silt, nutrients, pathogens, metals, hydrocarbons and other pollutants.

Many of the Derwent estuary's original wetlands and saltmarshes have been lost through land filling, foreshore reclamation, and draining and clearing for agriculture. The most extensive remaining area of wetland and saltmarsh complex is found along a 22 km stretch of the upper estuary, between New Norfolk and Dogshear Point. Other important wetlands and saltmarshes occur at Goulds Lagoon, Lauderdale (Racecourse Flats), southern Ralphs Bay and several other smaller communities. Several key wetland and saltmarsh areas are described in more detail below.

Derwent River Conservation Area and upper Derwent saltmarshes and wetlands

The Derwent River Conservation Area (gazetted in 1941) includes most of the upper Derwent estuary saltmarsh and wetland system below high water mark from near New Norfolk to Dogshear Point (22 km downstream). A coastal reserve of 30 m is present above the high water mark along some of the shoreline, but large areas of wetlands are in private ownership. The saltmarshes and wetlands of the upper Derwent estuary consist of several large areas of *saline sedgeland/rushland* (0.94 km^2, representing 70% of this vegetation type in the estuary) and *fresh water aquatic sedgeland and rushland* (1.05 km^2, representing 80% of this vegetation in the estuary). This vegetation borders the estuary and ranges in width from a few metres to several hundred metres in width. On better drained areas within the saltmarsh and wetland are large stands of *Leptospermum lanigerum* scrub, dry scrub dominated by *Acacia mearnsii*, and smaller stands of *Acacia – Bursaria* scrub, and *Eucalyptus ovata* woodland.

A complex network of saltmarsh islands between Granton and Bridgewater emerge from unvegetated and vegetated mudflats (dominated by the macrophtye genus *Ruppia*). These islands are relatively recent landforms that have largely developed since the 1940s. This is part of Tasmania's largest deltaic depositional environment and as such the region is listed as having geoheritage significance. See MacDonald (1995) for further detail. A study of the upper Derwent estuary was conducted as part of the *Norske Skog Ecological Risk Assessment* (Aquenal 2000), which included some mapping of saltmarshes, wetlands and other aquatic habitats.

In 2000, the DEP coordinated an initiative to purchase the 66 hectare wetland known as 'Murphys Flat', with support from the Natural Heritage Trust's National Reserve System Program and matching funding provided by the State Government, Derwent Valley Council and Norske Skog paper mill. The purchase of Murphys Flat increased the total area of upper estuary saltmarsh and wetland now under protection by approximately 30%. In 2006 several studies were conducted on vegetation, hydrology, water quality, and aquatic communities to assist in management of this site. The wetlands were found to support important populations of birds, fish, and platypus and also act as a natural filter, removing sediments, nutrients and other pollutants from the estuary waters. Murphys Flat receives freshwater input from the River Derwent and saltwater input from tidal action, creating a diversity of aquatic habitats, including saltmarsh, freshwater wetlands, and a possible meromictic pond located in the western part of the site (Kirkpatrick *et al*. 1997). Meromictic ponds (stratified water bodies with well defined halocline and saline bottom water) support a unique microscopic flora and fauna, and are extremely uncommon (Barmuta *et al*. 1995). If the meromictic pond is confirmed this may represent a limnological feature of national importance.

In 2008, the DEP commissioned further mapping of the Derwent's upper estuary saltmarshes and wetlands, as part of a National Heritage Trust funded project (North Barker 2008a). These vegetation maps have been incorporated within the *Derwent Estuary Habitat Atlas*.

The saltmarshes and wetlands of the upper Derwent estuary are listed as wetlands of national importance and state significance in the *Directory of Important Wetlands* (Environment Australia 2001). However, much of this habitat remains unprotected. The security of these saltmarshes and wetlands would be greatly enhanced by increasing their conservation status and preparing a regional management plan.

Goulds Lagoon Wildlife Sanctuary

The Goulds Lagoon Wildlife Sanctuary is located on the western shore of the Derwent estuary, 19 km northwest of Hobart. This shallow lagoon (8 hectares) is important as a feeding, resting and breeding ground for water birds and is a noted bird watching area. The major management issues at Goulds Lagoon are related to subdivision development in its small catchment, resulting in water quality decline (particularly from nutrient enrichment and sedimentation), weed invasion and disturbance of wildlife. The management issues of Goulds Lagoon have been reviewed in the *Goulds Lagoon Impact Study* (GCC, 1997). Protection of remnant wetlands, such as Goulds Lagoon, is very important as many of the original wetlands of the Derwent estuary have been destroyed, particularly those at the heads of small bays in the middle estuary. Goulds Lagoon and Otago Lagoon represent some of the last remnants of this type of wetland.

Lauderdale saltmarsh (including Racecourse Flats)

The Lauderdale saltmarsh occupies an area of approximately 1 km^2 and the vegetation communities were mapped in 2008 by North Barker for the DEP, using 2001 aerial photos. The vegetation is dominated by *succulent saline herbland* (ASS), 0.7 km^2, representing 88% of the Derwent estuary coverage of this vegetation type. This herbland can be divided into at least four different vegetation communities, which differ in species dominance (North Barker, 2008b). The next most common vegetation type within the Lauderdale saltmarsh is *saline sedgeland/rushland* (ARS), 0.2 km^2, representing 15% of the Derwent estuary coverage of this vegetation type. The complex mosaic of vegetation communities occurring here is in part due to variations in salinity, water and disturbance regimes. The Lauderdale wetland and saltmarsh is a critical habitat for the endemic Tasmanian saltmarsh moth, *Dasybela achroa*, which is listed as vulnerable under the Tasmanian *Threatened Species Protection Act 1995*. Only a few specimens of this moth have been recorded outside of this area. The saltmarsh community also contains two plants considered rare in Tasmania: the salt lawrencia (*Lawrencia spicata*) and the many-stemmed bluebell (*Wahlenbergia multicaulis*). This area has been impacted through past and current land uses, including infilling for the Lauderdale tip and associated leachate, altered hydrology, grazing, off-road vehicles, road construction, weeds and climate change (Clarence City Council 2008, North Barker 2008b).

9.2 Foreshore vegetation

Vegetation along the entire Derwent estuary foreshore (within 100 m of mean high water) has been mapped in detail by North Barker through projects supported by the Australian Government, NRM South, State Government and DEP (DTAE 2007, NorthBarker 2008a). The major foreshore vegetation groups and communities are listed in **Table 9.2**, with the relative proportions of the major vegetation groups illustrated in **Figure 9.6**. These vegetation groups can be broadly categorised as: 1) saltmarsh and wetland, 2) dry eucalypt forest and woodland, 3) non-eucalypt forest and woodland (e.g. she-oak forests), 4) scrub, heath and coastal complexes, and 5) native grassland she-oak forest, grassy woodlands/grasslands and dry eucalypt forest. Further information on specific foreshore vegetation groups, communities and their respective areas is provided in **Table 9.2**. Twelve of these vegetation communities are listed as threatened in the *Nature Conservation Act 2002*, in particular the dry eucalypt forest communities and saltmarsh and wetland communties.

An analysis of this information indicates that 51% of the foreshore has been cleared of native vegetation and consists predominantly of urban and rural land or exotic vegetation. The remaining 49% of the foreshore retains its native vegetation, of which about two-thirds consists

Figure 9.6: Derwent foreshore vegetation type (%), as mapped within a 100m swath above the mean high water mark

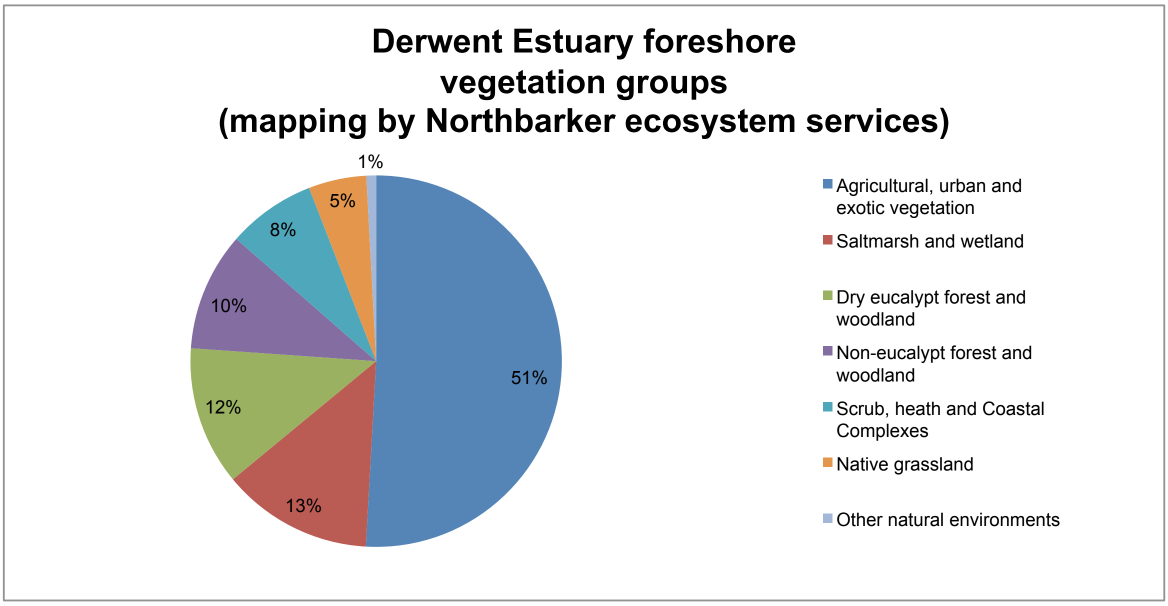


Table 9.2: Vegetation communities of the Derwent estuary foreshore

Vegetation Groups TASVEG code	Vegetation type	**Area sq km**	**Area sq km**
Agricultural, urban and exotic vegetation			13.52
FUM	Extra-urban miscellaneous	0.48	
FWU	Weed infestation	0.43	
FUR	Urban areas	8.60	
FMG	Marram grassland	0.12	
FPF	*Pteridium esculentum* fernland	0.06	
FPE	Permanent easements	0.03	
FPL	Plantations for silviculture	0.15	
FAG	Agricultural land	3.58	
FRG	Regenerating cleared land	0.07	
Other natural environments			0.22
ORO	Rock (cryptogamic lithosere)	0.07	
OSM	Sand, mud	0.06	
OAQ	Water, sea	0.09	
Scrub, heath and Coastal Complexes			2.04
SDU	Dry scrub	0.86	
SLW	*Leptospermum* scrub	0.93	
SBR	Broadleaf scrub	0.00	
SCA	Coastal scrub on alkaline sands	0.01	
SSC	Coastal scrub	0.16	
SAC	*Acacia longifolia* coastal scrub	0.05	
SRC*	Seabird rookery complex	0.04	
SRI*	Riparian scrub	0.01	
Dry eucalypt forest and woodland			3.21
DAM	*Eucalyptus amygdalina* forest and woodland on mudstone	0.10	
DAS	*Eucalyptus amygdalina* forest and woodland on sandstone	0.00	
DGL*	*Eucalyptus globulus* dry forest and woodland	1.20	
DOB	*Eucalyptus obliqua* dry forest and woodland	0.01	
DOV*	*Eucalyptus ovata* forest and woodland	0.31	
DPU	*Eucalyptus pulchella* forest and woodland	0.05	
DRI*	*Eucalyptus risdonii* forest and woodland	0.05	
DTO*	*Eucalyptus tenuiramis* forest and woodland on sediments	0.58	
DVG	*Eucalyptus viminalis* grassy forest and woodland	0.50	
DVS	*Eucalyptus viminalis* shrubby/heathy woodland	0.10	
DVC*	*Eucalyptus viminalis* – Eucalyptus globulus coastal forest and woodland	0.32	
Wet eucalypt forest and woodland			0.01
WGL	*Eucalyptus globulus* wet forest	0.01	
Non-eucalypt forest and woodland			2.74
NAV	*Allocasuarina verticillata* forest	1.74	
NBA	*Bursaria – Acacia* woodland and scrub	1.00	
Native grassland			1.34
GHC	Coastal grass and herbfield	0.22	
GCL	Lowland grassland complex	0.54	
GTL	Lowland *Themeda* grassland	0.16	
GPL	Lowland P*oa labillardierei* grassland	0.38	
GSL	Lowland sedgy grassland	0.03	
Saltmarsh and wetland			3.49
ARS*	Saline sedgeland/rushland	1.32	
ASF*	Fresh water aquatic sedgeland and rushland	1.32	
AHL*	Lacustrine herbland	0.00	
AHS*	Saline aquatic herbland	0.02	
ASS*	Succulent saline herbland	0.83	

*NOTE: North Barker vegetation mapping data were used to estimate the amount and type of native vegetation (TASVEG community categories) remaining along the Derwent estuary foreshore, based upon 2001 aerial photographs and field surveys. In the majority of areas mapping represents a 100 m strip of the foreshore above the MHWM. However, in those areas covered by wetlands and saltmarsh a wider vegetation swath has been mapped, adding approximately 3.18 km^2 in area to the mapping region).

* = vegetation communities listed as threatened through the *Nature Conservation Act 2002*.

See Harris and Kitchener (2005) for descriptions of the vegetation mapping units.

Table 9.3: Key attributes of major vegetation types along the Derwent estuary foreshore (excluding wetlands and saltmarshes)

Vegetation Type	Description	Areal extent/location	Conservation value/vulnerability
Scrub, Heath and Coastal complexes	Coastal vegetation consists of several structural formations, which contain species with morphological or physiological adaptions to salt spray. They include herbland, grassland, heath and scrub. The composition and structure of the vegetation is related to landform (e.g.dunes, swales, cliffs), soil conditions, erosional/accretional factors and exposure to salt laden winds.	In the Hobart region, coastal vegetation is best-developed on South Arm, with some of the most diverse and intact associations found within the South Arm State Recreation Area. Other important remnants of coastal complex vegetation include the Howrah-Bellerive dunes.	Coastal vegetation has a high priority for conservation because of its biological and aesthetic attributes. It is vulnerable to coastal erosion, mechanical disturbance and invasion by weeds (e.g. marram grass).
She-oak forest (non- eucalypt forest and woodland)	She-oaks (*Allocasuarina* spp.) are morphologically adapted to tolerate desiccating salt-laden winds and are typically associated with succulent scramblers and other salt-tolerant species.	Remnant she-oak forests are widely distributed around various parts of the lower Derwent foreshore. She-oaks are the dominant species in many foreshore reserves, for example in the Rosny Point / Kangaroo Bluff area.	CMany stands of she-oak forests have been lost to urban expansion along the foreshore. She-oaks forests are vulnerable to weed invasion and degradation by recreational use.
Native grasslands and grassy woodlands	Native grasslands and grassy woodlands are dominated by native grasses and widely-spaced eucalypts (particularly white gum – *E. viminalis*). They occur mainly in dry areas on dolerite or basalt soils. In the past, many grasslands were maintained by firing and marsupial browsing. This prevented dominance by woody species and maintained diversity of grassland flora.	Most grassy woodlands/grasslands along the foreshore are found in drier regions, particularly Clarence and Brighton (e.g. East Risdon Nature Reserve). The Domain also contains several important grassland communities, containing threatened species.	Native grasslands/ grassy woodlands are some of Tasmania's most endangered ecosystems. Expanding urban development, agriculture and poor fire management are the main threats.
Dry eucalypt forest	These forests are typically dominated by eucalypts with an understorey of hard-leaved shrubs, bracken, grasses and graminoids. There are many different communities, grading into grassy woodlands, she-oak forests and wet sclerophyll forests.	Dry sclerophyll forests are found along the Alum Cliffs between Taroona and Kingston.	

of forest/woodland and coastal scrub and the remainder consist of non-woody communities (e.g. wetlands, saltmarshes, and native grasslands). A number of important vegetation types remain along the foreshore of the Derwent estuary, particularly in areas protected as reserves. Further comments on Derwent estuary foreshore vegetation types other than wetlands and saltmarshes are provided in **Table 9.3.**

9.3 Threatened flora

A search of the DEP area on the DPIPWE *Natural Values Atlas* database indicates that there are 138 threatened plant species within the region, as indicated in **Table 9.4**. According to Tasmanian threatened species legislation, these threatened flora are classified as:

- Two species presumed extinct;
- 22 species endangered;
- 19 species vulnerable (one unofficial); and
- 88 species rare (five unofficial).

Note: unofficial species have not yet been formally listed under the *Threatened Species Protection Act 1995*.

Of the 138 threatened Tasmanian plant species in the DEP area, 21 species have 50% or more of their known distribution found in this area, and of these, nine species are found only in this region. The nine threatened endemic species include: *Caladenia sylvicola* (forest fingers), *Hydrocotyle laxiflora* (stinking pennywort), *Ozothamnus reflexifolius* (reflexed everlastingbush), *Parmelina pallida, Plantago gaudichaudii* (narrow plantain), *Prasophyllum perangustum* (knocklofty leek-orchid), *Thelymitra bracteata* (leafy sun-orchid), *Thesium australe* (southern toadflax) and *Veronica notabilis* (forest speedwell).

Table 9.4: Tasmanian-listed threatened plant species within the Derwent Estuary Program region

Threatened flora in DEP area	**Common name**	**Code**		**Cons.**	**RFA**	**NVA**	**obs**	**% TAS obs**
Scientific name		Tas	Aust	**Signif.**	**Priority**	DEP	Tas	in DEP area
Acacia ulicifolia	juniper wattle	r		y	Y	2	242	0.83
Allocasuarina duncanii	conical sheoak	r		y	Y	23	23	13.04
Anogramma leptophylla	annual fern	v		y	Y	2	15	13.33
Aphelia gracilis	slender fanwort	r		y	Y	1	59	1.69
Arthropodium strictum	chocolate lily	r		y	Y	69	382	18.06
Asperula scoparia var. scoparia	prickly woodruff	r		y	Y	23	116	19.83
Asperula subsimplex	water woodruff	r		y	Y	2	28	7.14
Atriplex suberecta	sprawling saltbush	v				2	14	14.29
Austrodanthonia induta	tall wallabygrass	r		y	Y	159	201	79.10
Austrodanthonia popinensis	blue wallabygrass	e	EN			63	159	39.62
Austrostipa bigeniculata	doublejointed speargrass	r		y	Y	13	27	48.15
Austrostipa blackii	crested speargrass	r		y	Y	3	12	25.00
Austrostipa nodosa	knotty speargrass	r		y	Y	55	219	25.11
Austrostipa scabra	rough speargrass	r		y	Y	43	106	40.57
Austrostipa scabra subsp. falcata	sickle speargrass	pr		y	Y	10	19	52.63
Austrostipa scabra subsp. scabra	rough speargrass	pr		y	Y	3	6	50.00
Bolboschoenus caldwellii	sea clubsedge	r				11	53	20.75
Bossiaea obcordata	spiny bossia	r		y	Y	2	94	2.13
Brachyglottis brunonis	tasmanian daisytree	r		y	Y	19	48	39.58
Brachyscome perpusilla	tiny daisy	r		y	Y	1	3	33.33
Brachyscome radicata	spreading daisy	r		y	Y	1	32	3.13
Brachyscome rigidula	cutleaf daisy	v		y	Y	2	38	5.26
Brachyscome sieberi var. gunnii	forest daisy	r		y	Y	9	28	32.14
Caladenia anthracina	blacktip spider-orchid	e	CR	y	Y	4	23	17.39
Caladenia caudata	tailed spider-orchid	v	VU	y	Y	36	157	22.93
Caladenia filamentosa	daddy longlegs	r		y	Y	20	60	33.33
*Caladenia sylvicola**	forest fingers	e	CR	y	Y	6	6	100.00
Calocephalus citreus	lemon beautyheads	r				29	127	22.83
Calocephalus lacteus	milky beautyheads	r				5	121	4.13
Calystegia soldanella	sea bindweed	r				1	21	4.76
Carex gunniana	mountain sedge	r		y	Y	11	44	25.00
Carex longebrachiata	drooping sedge	r		y	Y	4	70	5.71
Carex tasmanica	curly sedge		VU	y	Y	46	133	34.59
Colobanthus curtisiae	grassland cupflower	r	VU	y	Y	1	121	0.83
Comesperma defoliatum	leafless milkwort	r		y	Y	1	32	3.13
Corunastylis nuda	tiny midge-orchid	r		y	Y	3	37	8.11
Corunastylis nudiscapa	bare midge-orchid	e		y	P	14	15	93.33
Cotula vulgaris var. australasica	slender buttons	r				1	34	2.94
Cuscuta tasmanica	golden dodder	r				4	10	40.00
Cynoglossum australe	coast houndstongue	r				21	145	14.48
Cyrtostylis robusta	large gnat-orchid	r		y	Y	8	66	12.12
Damasonium minus	starfruit	r				1	3	33.33
Deyeuxia benthamiana	benthams bentgrass	r		y	Y	4	31	12.90
Deyeuxia densa	heath bentgrass	r				3	44	6.82
Dianella amoena	grassland flaxlily	r	EN	y	Y	38	238	15.97
Diuris palustris	swamp doubletail	e		y	Y	6	48	12.50
Epacris acuminata	claspleaf heath	r	VU	y	Y	26	252	10.32
Epacris virgata (Kettering)		pv	PEN	y	Y	9	158	5.70
Epilobium pallidiflorum	showy willowherb	r				2	65	3.08
Eryngium ovinum	blue devil	v		y	Y	11	58	18.97
Eucalyptus morrisbyi	morrisbys gum	e	EN	y	Y	14	31	45.16
Eucalyptus risdonii	risdon peppermint	r		y	Y	249	406	61.33
Euphrasia scabra	yellow eyebright	e		y	Y	10	35	28.57
Gratiola pubescens	hairy brooklime	v		y	Y	1	13	7.69
Haloragis aspera	rough raspwort	v		y	Y	2	7	28.57
Haloragis heterophylla	variable raspwort	r		y	Y	8	71	11.27
Hibbertia basaltica	basalt guineaflower	e	EN	y	y	59	90	65.56
Hovea tasmanica	rockfield purplepea	r		y	Y	6	93	6.45
Hyalosperma demissum	moss sunray	e		y	Y	5	29	17.24
*Hydrocotyle laxiflora**	stinking pennywort	v		y	Y	5	5	100.00
Hypoxis vaginata	sheathing yellowstar	r		y	Y	4	77	5.19
Hypoxis vaginata var. brevistigmata	sheathing yellowstar	pr		y	Y	4	154	2.60
Isoetopsis graminifolia	grass cushion	e		y	Y	9	29	31.03
Isolepis habra	wispy clubsedge	r		y	Y	3	13	23.08
Juncus amabilis	gentle rush	r		y	Y	40	142	28.17
Juncus vaginatus	clustered rush	r		y	Y	1	29	3.45
Lachnagrostis punicea subsp. filifolia	narrowleaf blowngrass	r				2	3	66.67
Lachnagrostis punicea subsp. punicea	bristle blowngrass	r		y	Y	1	11	9.09
Lachnagrostis robusta	tall blowngrass	r				4	17	23.53
Lepidium hyssopifolium	soft peppercress	e	EN	y	Y	22	140	15.71
Lepidium pseudotasmanicum	shade peppercress	r		y	Y	111	221	50.23
Lepidosperma tortuosum	twisting rapiersedge	r		y	Y	6	36	16.67
Lepilaena patentifolia	spreading watermat	r				5	35	14.29
Lepilaena preissii	slender watermat	r				3	11	27.27

Threatened flora in DEP area	**Common name**	**Code**	Aust	**Cons.**	**RFA**	**NVA obs**		**% TAS obs**
Scientific name		Tas		**Signif.**	**Priority**	DEP	Tas	in DEP area
Leucopogon virgatus var. brevifolius	shortleaf beardheath	r		y	Y	2	8	25.00
Limonium australe	yellow sea-lavender	r				3	39	7.69
Lobelia pratioides	poison lobelia	v		y	Y	1	30	3.33
Lotus australis	australian trefoil	r				2	59	3.39
Lythrum salicaria	purple loosestrife	v		y	Y	1	76	1.32
Olearia hookeri	crimsontip daisybush	r		y	Y	12	20	60.00
*Ozothamnus reflexifolius**	reflexed everlastingbush	v	VU	y	Y	10	10	100.00
Parietaria debilis	shade pellitory	r				1	54	1.85
*Parmelina pallida**		e		y	Y	1	1	100.00
Parmelina whinrayi		r				1	3	33.33
Pellaea calidirupium	hotrock fern	r		y	Y	3	62	4.84
Pentachondra ericifolia	fine frillyheath	r		y	Y	1	55	1.82
Pimelea curviflora var. gracilis	slender curved riceflower	r		y	Y	2	56	3.57
Pimelea flava subsp. flava	yellow riceflower	r		y	Y	20	648	3.09
*Plantago gaudichaudii**	narrow plantain	v		y	Y	1	1	100.00
Pomaderris elachophylla	small-leaf dogwood	v		y	Y	4	503	0.80
Pomaderris intermedia	lemon dogwood	r		y	Y	1	97	1.03
Potamogeton pectinatus	fennel pondweed	r				3	26	11.54
Prasophyllum amoenum	dainty leek-orchid	e	EN			1	14	7.14
Prasophyllum apoxychilum	tapered leek-orchid	e	EN	y	Y	2	33	6.06
*Prasophyllum perangustum**	knocklofty leek-orchid	e	CR	y	Y	4	4	100.00
Pterostylis squamata	ruddy greenhood	r		y	Y	3	46	6.52
Pterostylis wapstrarum	fleshy greenhood	e	CR			1	14	7.14
Pterostylis ziegeleri	grassland greenhood	v	VU	y	y	1	72	1.39
Pultenaea prostrata	silky bushpea	v		y	Y	1	53	1.89
Ranunculus pumilio var. pumilio	ferny buttercup	r		y	Y	4	29	13.79
Ranunculus sessiliflorus var. sessiliflorus	rockplate buttercup	r		y	Y	12	114	10.53
Rhodanthe anthemoides	chamomile sunray	r				1	90	1.11
Ruppia megacarpa	largefruit seatassel	r				7	21	33.33
Ruppia tuberosa	tuberous seatassel	r				3	5	60.00
Schoenoplectus validus	river clubsedge	r				1	25	4.00
Scleranthus brockiei	mountain knawel	r		y	Y	5	116	4.31
Scleranthus fasciculatus	spreading knawel	v		y	Y	18	126	14.29
Senecio squarrosus	leafy fireweed	r		y	Y	26	101	25.74
Senecio velleioides	forest groundsel	r		y	Y	5	38	13.16
Spyridium eriocephalum var. eriocephalum	heath dustymiller	e		y	Y	12	17	70.59
Spyridium vexilliferum var. vexilliferum	helicopter bush	r		y	y	5	208	2.40
Stellaria multiflora	rayless starwort	r		y	Y	3	129	2.33
Stenopetalum lineare	narrow threadpetal	e		y	Y	3	7	42.86
Stylidium despectum	small triggerplant	r				1	26	3.85
Teucrium corymbosum	forest germander	r		y	Y	15	101	14.85
*Thelymitra bracteata**	leafy sun-orchid	e				4	4	100.00
Thelymitra malvina	mauvetuft sun-orchid	e		y	Y	1	46	2.17
*Thesium australe**	southern toadflax	x	VU			1	1	100.00
Thismia rodwayi	fairy lanterns	r		y	Y	7	69	10.14
Triglochin minutissimum	tiny arrowgrass	r				1	26	3.85
Triptilodiscus pygmaeus	dwarf sunray	v				2	22	9.09
Uncinia elegans	handsome hooksedge	r		y	Y	1	26	3.85
Velleia paradoxa	spur velleia	v		y	Y	21	58	36.21
*Veronica notabilis**	forest speedwell	x		y	Y	1	1	100.00
Viola cunninghamii	alpine violet	r		y	Y	3	296	1.01
Vittadinia burbidgeae	smooth new-holland-daisy	pr		y	Y	3	31	9.68
Vittadinia cuneata var. cuneata	fuzzy new-holland-daisy	r		y	Y	8	144	5.56
Vittadinia gracilis	woolly new-holland-daisy	r		y	Y	57	193	29.53
Vittadinia muelleri	narrow leaf new holland daisy	r		y	Y	144	313	46.01
Vittadinia muelleri	narrowleaf new-holland-daisy	pr		y	y	144	313	46.01
Westringia angustifolia	narrowleaf westringia	r		y	Y	8	107	7.48
Wilsonia rotundifolia	roundleaf wilsonia	r				2	93	2.15
Xanthoparmelia amphixantha		e				2	21	9.52
Xanthoparmelia jarmaniae		v		y	Y	1	5	20.00
Xanthoparmelia molliuscula		e		y	Y	1	8	12.50
Xanthoparmelia oleosa		r		y	Y	1	2	50.00
Xanthoparmelia vicariella		r		y	Y	1	3	33.33
Xerochrysum bicolor	eastcoast everlasting	r		y	Y	1	59	1.69

* These type of species found only with the Derwent Region.

NOTES: Threatened species in Tasmania are listed subject to the following national and state Acts:

National: *Environment Protection and Biodiversity Conservation Act 1999* – Threatened species under the national schedule are classified as: EX) Extinct, EW) Extinct in the Wild, CR) Critically Endangered, EN) Endangered, VU) Vulnerable and CD) Conservation Dependent.

Tasmania: *Threatened Species Protection Act 1995* – Threatened species under Tasmanian legislation are classified as: x) presumed extinct (on the ground that no occurrence of the taxon in the wild can be confirmed during the past 50 years); e) endangered (in danger of extinction because long term survival is unlikely while the factors causing the species to be endangered continue operating); v) vulnerable (a species which is likely to become endangered while the factors causing it to be vulnerable continue operating) and; r) rare (a species which has a small population in Tasmania that is not endangered or vulnerable but is at risk).

9.4 Derwent estuarine fauna

9.4.1 *Benthic macroinvertebrates*

Benthic macroinvertebrates are organisms that live in or on sediments and are visible to the naked eye, including crustaceans (e.g. crabs and amphipods), molluscs (e.g. gastropods, bivalves, slugs and snails) and polychaetes (worms). Benthic macroinvertebrates are a critical component of a healthy ecosystem and occur in all Derwent estuary habitats. They can be used to assess the condition of biological communities with certain components being used as indicators of environmental stress. Infaunal and sessile epifaunal (surface dwelling) benthic macroinvertebrates make good environmental indicators because these species are relatively immobile and as such are unable to evade impacts such as nutrient enrichment and toxicant loading, and as a consequence they will reflect the cumulative impacts of environmental conditions.

Macroinvertebrate studies carried out in the Derwent estuary prior to 2003 – including Edgar *et al*. (1999), Aquenal (2000) and Sanderson 2000 – are reviewed in the previous *State of the Derwent Estuary Report* (Green and Coughanowr 2003). More recent investigations are summarised below.

A major decline has been seen in mollusc species diversity and abundance in the Derwent estuary over the last 120 years, as documented in sediment cores analysed by Edgar and Samson (2004) from five sites in the estuary (Geilston Bay, Kangaroo Bay, Tranmere, Ralphs Bay north and entrance). The mean shell number (per 5 cm sediment core interval) in 1890 was approximately 105, but had declined to approximately 45 by 1990. Similarly, mean shell diversity in 1890 was approximately 17 (per 5 cm sediment core interval), declining to approximately 8 by 1990. This decline in mollusc abundance and diversity has been linked to historic overfishing of scallops (*Pecten fumatus* and *Chlamys asperrimus*) and native oysters (*Ostrea angasi*), and the associated dredge fishing methods used in their capture (Edgar and Samson 2004). Native oyster and scallop beds would have provided an important habitat type within the Derwent estuary that are now absent. During the past century, the abundance of some native molluscs has declined in synchrony with rises in abundance of introduced taxa (Edgar *et al*. 2005). For example, the native mollusc *Theora fragilis* has disappeared since the 1950s, coinciding with the arrival and increased abundance of a similar species *Theora lubrica* (introduced from southeast Asia) (Edgar *et al*. 2005). The native species *Theora fragilis* has not been seen alive for the last two decades, and this is also the case for over 1000 of Tasmania's native mollusc species (Edgar *et al*. 2005).

A more recent survey of benthic macroinvertebrate communities associated with subtidal sediment habitats at 55 sites in the Derwent estuary was undertaken in 2004 (Macleod and Helidoniotis 2005). This survey assessed the macro-invertebrate community relationship to abiotic environmental variables. Eight major benthic invertebrate community groups were identified in the Derwent estuary, with each community group characterised by a particular combination of polychaete, bivalve, amphipod, ostracod, crab, gastropod, nemertean and/or brittle star species. The community distribution in the Derwent was found to be most strongly related to the sediment type, organic content and salinity regime. Species diversity in general increased and total abundance decreased towards the mouth of the estuary. The lowest diversity was in the upper estuary and in areas subject to tidal emersion, with certain upper estuary species found to be indicative of high organic loading. Heavy metal content in sediments (when calculated as a total) was not found to be a major determinant of benthic invertebrate community distribution, except in the most contaminated areas (Macleod and Helidoniotis 2005). However, the readily biologically available portion of the heavy metals that can be released into the porewater and overlying water column may influence benthic invertebrate distribution within subtidal habitats (Jeff Ross, 2009, TAFI, *pers. comm.*).

A study conducted on the benthic invertebrate communities of the intertidal sandflats in Ralphs Bay (near Lauderdale, Mortimer Bay and east of South Arm) found that this area also supports relatively healthy benthic invertebrate communities (Aquenal 2008a). The species richness of these intertidal sandflats indicated mid-range values when compared to other locations throughout south eastern Tasmania (Aquenal 2008a). The Shannon-Wiener diversity indices (a measure of species richness with regard to the proportion of the total count contributed by each species) calculated for the Ralphs Bay sandflats were high, indicating that the invertebrate communities generally consisted of a range of species at similar densities rather than a mixture of highly abundant and rare species (Aquenal 2008a).

Introduced marine species are also altering macroinvertebrate communities and habitats within the Derwent estuary (see **Section 11.0**).

9.4.2 *Fish*

Approximately 150 fish species have been documented in the middle and lower parts of the Derwent estuary (**Table 9.5**). The distribution of fish species depends primarily on their tolerance to salinity changes and available habitat. The fish communities in the Derwent estuary can be broadly classified as i) pelagic (living in the mid water column), ii) demersal (bottom dwelling on soft sediments) and, iii) reef species. Some species, such as flathead (typically associated with soft sediments)

Table 9.5: Fin fish of the middle and lower Derwent estuary

Scientific Name	Common Name	Scientific Name	Common Name
Acanthaluteres spilomelanuru	bridled leatherjacket	*Meuschenia freycineti*	six-spined leatherjacket
Acanthaluteres vittiger	toothbrush leatherjacket	*Mitotichthys mollisoni*	mollison's pipefish
Acanthopagrus butcheri	black bream	*Mugil cephalus*	sea mullet
Aldrichetta forsteri	yellow eye mullet	*Mustelus antarcticus*	gummy shark
Allomycterus pilatus	porcupine fish	*Neoplatycephalus richardsoni*	tiger flathead
Ammotretis liturata	spotted flounder	*Neosebastes thetidis*	thetis fish
Ammotretis rostratus	long snouted flounder	*Nesogobius hinisbyi*	orange-spotted goby
Aracana aurita	Shaw's cowfish	*Nesogobius pulchellus*	castelnau's goby
Anguilla reinhardtii	long-finned eel	*Nesogobius sp.1*	girdled goby
Aplodactylus arctidens	Marblefish	*Norflokia clarkei*	common threefin
Arenigobius bifrenatus	bridled goby	*Notolabrus fucicola*	purple wrasse
Argentina australiae	silverside	*Notolabrus tetricus*	blue-throat wrasse
Arripis spp.	Australian salmon-eastern/western	*Notopogon lilliei*	crested bellows fish
Aspasmogaster tasmaniensis	Tasmanian Clingfish	*Notorhynchus cepedianus*	seven-gilled shark
Asymbolus sp.	orange spotted catshark	*Omegophora armilla*	ringed toadfish
Atherinason brevirostrus	short-headed hardyhead	*Parablennius tasmanianus*	blenny
Atherinosoma microstoma	small-mouthed hardyhead	*Parablennius tasmanianus*	Tasmanian blenny
Atherinosoma presbyteroides	silverfish	*Parapercis allporti*	barred grubfish
Atypichthys strigatus	Mado Sweep	*Parascyllium ferrugineum*	rusty catshark
Bovichtus angustifrons	Dragonet	*Parika scaber*	velvet leatherjacket
Brachaluteres jacksonianus	pigmy leatherjacket	*Paristiopterus labiosus*	giant boarfish
Callorhynchus milii	elephant fish	*Parvicrepis parvipinnis*	smallfin clingfish
Cephaloscylliumlaticeps	draughtboard shark	*Pavoraja nitida*	peacock skate
Cheilodactylus spectabilis	banded morwong	*Pegasus lancifer*	sculptured seamoth
Chelidonichthys kumu	red gurnard	*Pempheris multiradiata*	common bullseye
Contusus brevicaudas	prickly toadfish	*Pentaceropsis recurvirostris*	long-snout boarfish
Crapatalus munroi	pink sandfish	*Platycephalus laevigatus*	rock flathead
Cristiceps australis	crested weedfish	*Pristiophorus cirratus*	common sawshark
Cyttus australis	silver dory	*Pristiophorus nudipinnis*	southern sawshark
Cyttus novaezelandiae	New Zealand dory	*Pseudaphritis urvilli*	congolli
Dasyatis thetidis	black stingray	*Pseudocaranx dentex*	silver trevally
Dinolestes lewini	long-finned pike	*Pseudogobius olorum*	blue-spotted goby
Diodon nichthemerus	globe fish	*Pseudolabrus psittaculus*	rosy wrasse
Dotalabrus aurantiacus	Castlenau's wrasse	*Pseudophycis bachus*	red cod
Emmelichthys nitidus	redbait	*Pseudophycis barbatus*	bearded rock cod
Engraulis australis	Australian anchovy	*Pseudorhombus jenynsii*	small toothed flounder
Eubalichthys gunnii	Gunn's leatherjacket	*Pterygotrigla polyommata*	latchet
Eubalichthys mosaicus	mosaic leatherjacket	*Raja cerva*	white spotted skate
Favonigobius tamarensis	tamar goby	*Raja lemprieri*	thornback skate
Foetorepus calauropomus	common stinkfish	*Raja sp.a*	long-nosed skate
Galaxias maculatus	common jollytail	*Raja whitleyi*	whitley's skate
Galaxias truttaceus	spotted mountain galaxias	*Rhombosolea tapirina*	greenback flounder
Galeorhinus galeus	school shark	*Sardinops neopilchardus*	pilchard
Genypterus tigerinus	rock ling	*Scobinichthys granulatus*	rough leatherjacket
Gnathagnus innotablis	bulldog stargazer	*Scomber australasicus*	blue mackerel
Gymnapistes marmoratus	soldierfish	*Seriolella brama*	blue warehou
Helicolenus percoides	red gurnard perch	*Seriolella punctata*	spotted trevalla
Heptranchias perlo	seven-gilled shark	*Sillago flindersi*	eastern school whiting
Heteroclinus perspicillatus	common weedfish	*Sphyraena novaehollandiae*	short-finned seapike
Heteroclinus puellarum	the girl's weedfish	*Squalus acanthias*	white-spotted dogfish
Hippocampus abdominalis	pot bellied seahorse	*Squalus megalops*	piked dogfish
Hippocampus breviceps	short-headed seahorse	*Stigmatopora argus*	spotted pipefish
Hydrolagus ogilbyi	Ogilby's ghost shark	*Stigmatopora nigra*	wide-bodied pipefish
Hyporhamphus melanochir	sea garfish	*Synchiropus calauropomus*	common stinkfish
Kathetostoma canaster	speckled stargazer	*Taratretis derwentensis*	Derwent flounder
Kathetostoma laeve	common stargazer	*Tasmanogobius lasti*	Lagoon goby
Latridopsis forsteri	bastard trumpeter	*Tetractenos glaber*	smooth toadfish
Latris lineata	Striped Trumpeter	*Thyrsites atun*	barracouta
Lepidotrigla modesta	grooved gurnard	*Torpedo macneilli*	torpedo ray
Lepidotrigla mulhalli	round-snouted gurnard	*Trachurus declivis*	jack mackerel
Lepidotrigla papilio	spiny gurnard	*Upeneichthys vlamingii*	southern goatfish
Lepidotrigla vanessa	butterfly gurnard	*Urolophus cruciatus*	banded stingaree
Leptatherina presbyteroides	silverfish	*Urolophus paucimaculatus*	sparsely spotted stingaree
Lesueurina platycephala	common sandfish	*Vanacampus poecilolaemus*	long-snouted pipefish
Lophonectes gallus	crested flounder	*Vincentia conspersa*	southern cardinal
Macruronus novaezelandiae	blue grenadier	*Zeus faber*	john dory
Meuschenia australis	brown-striped leatherjacket		

Source: DPIF (1998) with updates from A. Jordan, TAFI in State of the Derwent Estuary 2003) and cod (reef dwellers) are permanent residents of the estuary, while others are transitory or seasonal migrants.

The following synopsis of pelagic, bottom and rocky reef dwelling fish found in the Derwent estuary is derived from Aquenal (2008a). Common species of pelagic fish include: the eastern Australian salmon *Arripis trutta*, silver trevally *Pseudocaranx georgianus*, barracouta *Thyrsites atun*, jack mackerel *Trachurus declivis*, silver dory *Cyttus australis*, school shark *Galeorhinus galeus*, gummy shark *Mustelus antarcticus* and white spotted dogfish *Squalus acanthias* (Prestedge 1996). Bottom-dwelling fish live over the most widespread habitat type within the estuary, consisting of soft sediments. Common bottom-dwelling fish include: sand flathead *Platycephalus bassensis*, school whiting *Sillago bassensis*, sea mullet *Mugil cephalus*, smooth toadfish *Torquigener glaber*, elephant fish *Callorhynchus milii*, flounder (e.g. long snouted *Ammotretis rostratus*, greenback *Rhombosolea tapirina* and Derwent *Taratretis derwentensis*), and skates (e.g. thornback *Dipturus lemrprieri*, Whitley's *Dipturus whitleyi*) (Prestedge 1996, Edgar *et al*. 1999). Many fish species are associated with the shallow rocky reefs, particularly in the lower estuary. These include: bastard trumpeter *Latridopsis forsteri*, banded morwong *Cheilodactylus spectabilis*, Shaw's cowfish *Aracana aurita*, draughtboard shark *Cephaloscyllium laticeps*, red cod *Pseudophycis bachus*, wrasse and leatherjacket species, seahorses and pipehorses, and a wide range of other species (Jordan *et al*. 2001).

An important component of the fish communities in the Derwent estuary includes those fish species that undertake seasonal migratory 'runs' between marine, estuarine and freshwater environments (**Table 9.6**). Migratory fish cannot pass upstream of Meadowbank Dam on the Derwent River, but do enter the Plenty River, Tyenna River, Styx River and a number of rivulets in the Hobart metropolitan area. An important migratory group

Table 9.6: Migratory fish of the upper Derwent estuary

Species	Life stage	Reason for migration	Direction	Time of year
1) Sea run trout *(Salmo trutta)*	Juveniles (smolts) Adults Adults Adults	Access to Sea Spawning in fresh water Return to Sea Feeding on whitebait	Downstream Upstream Downstream Upstream and Downstream	September to October April to May May to June August to November
2) Tasmanian Whitebait *(Lovettia sealii)*	Larvae Adults	Access to Sea Spawning	Downstream Upstream	September to November August to November
3) Common Jollytail *(Galaxias maculatus)*	Larvae Juveniles Adults	Access to Sea Return to fresh water Spawning in estuary General habitat	Downstream Upstream Downstream Local	May to June August to November April to June All year
4) Tasmanian Mudfish *(Galaxias cleaveri)*	Larvae Juveniles Adults	Access to Sea Return to fresh water General habit (Spawning)	Downstream Upstream Local	June to July August to November All year (May to June)
5) Spotted Galaxias *(Galaxias truttaceus)*	Larvae Juveniles	Access to Sea Return to fresh water	Downstream Upstream	May to June August to November
6) Black Bream *(Acanthopagrus butcheri)*	Larvae Juveniles Adults Adults	Access to estuary Dispersion through estuary Spawning in fresh/estuary Return to estuary	Downstream Downstream Upstream Downstream	November to February All year October to January October to January
7) Yellow Eyed Mullet *(Aldrichetta forsteri)*	Adults	Dispersion through estuary	Local	All year
8) Shortfinned eel *(Anguilla australis)*	Elvers Adults	Access to fresh water Access to sea	Upstream Downstream	November to January November to January
9) Pouched Lamprey *(Geotria australis)*	Velasia Macropthalmia	Spawning in fresh water Access to sea	Upstream Downstream	September to November September to December
10) Short-headed lamprey *(Mordacia mordax)*	Velasia Macropthalmia	Spawning in fresh water Access to sea	Upstream Downstream	November to January September to December

Source: Davies et al. (1988)

consist of small 'whitebait', made up of six separate fish species that migrate into the estuary from oceanic waters each spring. One whitebait species is the Tasmanian endemic *Lovettia sealii*, which is known to have a life cycle of just one year and occurs as a genetically distinct stock in the Derwent estuary (Blackburn 1950, Fulton and Pavuk 1988). Other whitebait species include galaxiids (common jollytail *Galaxias maculatus*, spotted galaxias *G. truttaceus* and the Tasmanian mudfish *G. cleaveri*) and the Tasmanian smelt *Retropinna tasmanica*. Whitebait are an important food source for larger migratory fish, which perform a simultaneous seasonal migration, in particular the introduced trout *Salmo trutta* (Davies *et al*. 1989).

The Tasmanian whitebait (*Lovettia sealii*) is considered to be a commercially threatened species in Tasmania (Zann 1995). After catches peaked in the late 1940s, populations declined leading to the closure of the fishery in 1974. Numbers have slowly increased since that time to sufficient levels for a limited recreational season since 1990 in a few rivers. Tasmanian whitebait is particularly vulnerable to influences on environmental quality since it has only a one-year life cycle. This means that an environmental disturbance that prevents or seriously impacts on reproduction or survival in any one year may have devastating implications.

Other fish with some transitory migratory-like movement within, and in some instances beyond the Derwent estuary, include black bream (*Acanthopagrus butcheri*), yellow-eyed mullet (*Aldrichetta forsteri*), eels (*Anguilla australis*), and lamprey (*Geotria australis and Mordacia mordax*).

Introduced fish species

Introduced trout *Salmo trutta* are a conspicuous species in the Derwent estuary. Two undesirable introduced fish species in the Derwent estuary are redfin perch (*Perca fluviatilis*) and tench (*Tinca tinca*). The Tasmanian native species of blackfish (*Gadopsis marmoratus*) found naturally in rivers from the north of state was also artificially introduced into the River Derwent in the early 1900's (Telfler 2002).

Fish breeding habitats

Nurseries for many small fish species tend to be concentrated in sheltered seagrass habitats since these are highly productive systems that provide food resources and suitable shelter for juvenile fish (Aquenal 2008a). The reported loss of most of the seagrass habitat within Ralphs Bay since the 1950s (Rees 1994) may have impacted the recruitment of some fish species. More recent seagrass declines within some areas of the middle estuary (see **Section 9.1.3**), may also affect recuritment. However, larger fish may still utilize shallow subtidal unvegetated sandy habitats (prevalent throughout large parts of the lower estuary and greater Ralphs Bay) as nursery areas (Aquenal 2008a).

The Derwent is considered to be a nursery area for a number of commercially important species, such as gummy and school shark. Commercial netting of these sharks is prohibited within the estuary (DPIF 1998). School shark recruitment appears to have declined in the Derwent, particularly in Ralphs Bay, where large numbers of school shark pups were recorded during the 1940s and 50s (Olsen 1954) but absent in the 1990s (Stevens and West 1997). This decline in shark numbers may be related to seagrass losses (Rees 1994) or to possible overfishing of the adult breeding stock (Lyle, 2009, TAFI, *pers. comm.*). Nevertheless, Ralphs Bay is still an important region for juvenile school shark, typically of one to two years in age (Stevens and West 1997).

Long-term trends

There is evidence of a decline in the average length of flathead from the Derwent estuary over the period 1991 to 2007 (Macpherson 2008). The estimated rate of decline varies from approximately 0.8 mm per year above Tasman Bridge to about 2.5 mm per year along the western shore of the Derwent (Macpherson 2008).

Big-bellied seahorses (*Hippocampus abdominalis*) have declined 79–98% over the period 2001–2004 in the Derwent estuary (Martin-Smith and Vincent 2005). This decline is possibly due to interactions with invasive species, disease or reproductive limitation (Martin-Smith and Vincent 2005).

Research on 28 Derwent estuary black bream (*Acanthopagrus butcheri*) caught in 2007 suggests that there has been little new recruitment (breeding events) within the upper estuary during the previous 13 years. The mean fish age (as of 2007) was 19, and the age ranges varied between 13 and 28 (Verdouw 2008). However, there have been juvenile black bream caught in the upper estuary during the last two years (T. Farrell, 2009, Inland Fisheries Service, *pers. comm.*)

9.4.3 Birds

A wide variety of birds depend upon the Derwent's diverse environments, including both permanent resident species and migratory visitors. Birds can be broadly categorised as waders, waterfowl, seabirds, woodland/forest birds and raptors. Estuarine habitats of particular importance to birds include the wetlands, tidal flats and shallow waters of the upper Derwent and Ralphs Bay, Goulds Lagoon and sheltered embayments in the middle/upper estuary. The dunes and beaches of the South Arm peninsula are also of great importance to seabirds and shorebirds, as are the bluffs at Fort

Table 9.7: Birds of the Derwent estuary region

Common Name	Scientific Name	Common Name	Scientific Name
Brown Quail	*Coturnix ypsilophora*	Galah	*Cacatua roseicapilla*
Musk Duck	*Biziura lobata*	Sulphur-crested Cockatoo	*Cacatua galerita*
Black Swan	*Cygnus atratus*	Rainbow Lorikeet	*Trichoglossus haematodus*
Australian Shelduck	*Tadorna tadornoides*	Musk Lorikeet	*Glossopsitta concinna*
Australian Wood Duck	*Chenonetta jubata*	Little Lorikeet	*Glossopsitta pusilla*
Mallard	*Anas platyrhynchos*	Green Rosella	*Platycercus caledonicus*
Pacific Black Duck	*Anas superciliosa*	Eastern Rosella	*Platycercus eximius*
Australasian Shoveler	*Anas rhynchotis*	Swift Parrot	*Lathamus discolor*
Chestnut Teal	*Anas castanea*	Blue-winged Parrot	*Neophema chrysostoma*
Australasian Grebe	*Tachybaptus novaehollandiae*	Pallid Cuckoo	*Cuculus pallidus*
Hoary-headed Grebe	*Poliocephalus poliocephalus*	Fan-tailed Cuckoo	*Cacomantis flabelliformis*
Little Penguin	*Eudyptula minor*	Horsfield's Bronze-Cuckoo	*Chrysococcyx basalis*
Short-tailed Shearwater	*Puffinus tenuirostris*	Shining Bronze-Cuckoo	*Chrysococcyx lucidus*
Shy Albatross	*Diomedea cauta*	Southern Boobook	*Ninox novaeseelandiae*
Wilson's Storm-Petrel	*Oceanites oceanicus*	Fork-tailed Swift	*Apus pacificus*
Australasian Gannet	*Morus serrator*	Laughing Kookaburra	*Dacelo novaeguineae*
Little Pied Cormorant	*Phalacrocorax melanoleucos*	Superb Fairy-wren	*Malurus cyaneus*
Black-faced Cormorant	*Phalacrocorax fuscescens*	Spotted Pardalote	*Pardalotus punctatus*
Little Black Cormorant	*Phalacrocorax sulcirostris*	Forty-spotted Pardalote	*Pardalotus quadragintus*
Great Cormorant	*Phalacrocorax carbo*	Striated Pardalote	*Pardalotus striatus*
Australian Pelican	*Pelecanus conspicillatus*	Tasmanian Scrubwren	*Sericornis humilis*
White-faced Heron	*Egretta novaehollandiae*	Scrubtit	*Acanthornis magnus*
Little Egret	*Egretta garzetta*	Striated Fieldwren	*Calamanthus fuliginosus*
Great Egret	*Ardea alba*	Brown Thornbill	*Acanthiza pusilla*
White-bellied Sea-Eagle	*Haliaeetus leucogaster*	Tasmanian Thornbill	*Acanthiza ewingii*
Swamp Harrier	*Circus approximans*	Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*
Brown Goshawk	*Accipiter fasciatus*	Yellow Wattlebird	*Anthochaera paradoxa*
Grey Goshawk	*Accipiter novaehollandiae*	Little Wattlebird	*Anthochaera chrysoptera*
Collared Sparrowhawk	*Accipiter cirrhocephalus*	Noisy Miner	*Manorina melanocephala*
Wedge-tailed Eagle	*Aquila audax*	Yellow-throated Honeyeater	*Lichenostomus flavicollis*
Brown Falcon	*Falco berigora*	Strong-billed Honeyeater	*Melithreptus validirostris*
Peregrine Falcon	*Falco peregrinus*	Black-headed Honeyeater	*Melithreptus affinis*
Spotless Crake	*Porzana tabuensis*	Crescent Honeyeater	*Phylidonyris pyrrhoptera*
Purple Swamphen	*Porphyrio phorphyrio*	New Holland Honeyeater	*Phylidonyris novaehollandiae*
Dusky Moorhen	*Gallinula tenebrosa*	Tawny-crowned Honeyeater	*Phylidonyris melanops*
Tasmanian Native-hen	*Gallinula mortierii*	Eastern Spinebill	*Acanthorhynchus tenuirostris*
Eurasian Coot	*Fulica atra*	White-fronted Chat	*Epthianura albifrons*
Latham's Snipe	*Gallinago hardwickii*	Flame Robin	*Petroica phoenicea*
Bar-tailed Godwit	*Limosa lapponica*	Scarlet Robin	*Petroica multicolor*
Whimbrel	*Numenius phaeopus*	Pink Robin	*Petroica rodinogaster*
Eastern Curlew	*Numenius madagascariensis*	Dusky Robin	*Melanodryas vittata*
Common Greenshank	*Tringa nebularia*	Olive Whistler	*Pachycephala olivacea*
Red-necked Stint	*Calidris ruficollis*	Golden Whistler	*Pachycephala pectoralis*
Curlew Sandpiper	*Calidris ferruginea*	Satin Flycatcher	*Myiagra cyanoleuca*
Pied Oystercatcher	*Haematopus longirostris*	Grey Fantail	*Rhipidura fuliginosa*
Sooty Oystercatcher	*Haematopus fuliginosus*	Black-faced Cuckoo-shrike	*Coracina novaehollandiae*
Red-capped Plover	*Charadrius ruficapillus*	Dusky Woodswallow	*Artamus cyanopterus*
Double-banded Plover	*Charadrius bicinctus*	Grey Butcherbird	*Cracticus torquatus*
Hooded Plover	*Thinornis rubricollis*	Australian Magpie	*Gymnorhina tibicen*
Masked Lapwing	*Vanellus miles*	Black Currawong	*Strepera fuliginosa*
Pacific Gull	*Larus pacificus*	Grey Currawong	*Strepera versicolor*
Kelp Gull	*Larus dominicanus*	Forest Raven	*Corvus tasmanicus*
Silver Gull	*Larus novaehollandiae*	Skylark	*Alauda arvensis*
Caspian Tern	*Sterna caspia*	Richard's Pipit	*Anthus novaeseelandiae*
Crested Tern	*Sterna bergii*	House Sparrow	*Passer domesticus*
Rock Dove	*Columba livia*	Beautiful Firetail	*Stagonopleura bella*
Spotted Turtle-Dove	*Streptopelia chinensis*	European Greenfinch	*Carduelis chloris*
Common Bronzewing	*Phaps chalcoptera*	European Goldfinch	*Carduelis carduelis*
Brush Bronzewing	*Phaps elegans*	Welcome Swallow	*Hirundo neoxena*
Yellow-tailed Black-Cockatoo	*Calyptorhynchus funereus*	Tree Martin	*Hirundo nigricans*

Source: D. Abbott and P. Park, Birds Tasmania, May 2009

Direction which support a short-tailed shearwater colony (also known as mutton-birds, *Puffinus tenuirostris*). Little penguins (*Eudyptula minor*) breed at a number of sites along the Derwent foreshore, particularly along the western shore of the lower estuary. The remnant bushland around the Derwent estuary supports a number of important woodland birds, including several threatened species such as forty-spotted pardalotes (*Pardalotus quadragintus)* and swift parrots (*Lathamus discolor)*. Over 120 birds have been recorded within the Derwent estuary region, as listed in **Table 9.7**. This list includes all bird species found within terrestrial and coastal habitats of greater Hobart, however, the following review focuses on those species utilizing estuarine habitats.

Shorebirds

Shorebirds feed along the shoreline and on intertidal flats, especially in the Ralphs Bay area. Derwent estuary shorebird habitats are closely linked to similar habitats in the Pittwater area (including the Pittwater-Orielton Lagoon Ramsar site), and the combined Derwent Estuary – Pittwater Area (DEPA) provides vital habitat for at least eight migratory (two Charadriidae, six Scolopacidae) and six resident shorebird species (Birds Tasmania records 2009). The DEPA is the southernmost destination on the East Asian-Australasian Flyway (EAAF), along which millions of Arctic-breeding migratory shorebirds travel to reach regular non-breeding grounds in Australia and New Zealand. Several of these species regularly occur in the DEPA, and the area is considered an internationally important site for one of these species, the red-necked stint (*Calidris ruficollis*) (Bamford *et al*. 2007). Another migratory species, the double-banded plover (*Charadrius bicinctus*) breeds in New Zealand and migrates to south eastern Australia in winter and has been observed in the DEPA (E. Woehler, 2009, Birds Tasmania, *pers. comm.*).

There has been a long-term decrease in the abundance of many of the migratory shorebirds observed in the DEPA (**Figure 9.7**), most notably the eastern curlew, which has experienced a decrease from the 1960s, to less than 25% of former numbers in 2003 and only 15% in 2008 (Reid and Park 2003, Mike Newman, in Olson (2008)). The decrease in migratory shorebird abundance in the DEPA is thought to be largely due to habitat loss throughout different parts of the EAAF (E. Woehler, 2009, Birds Tasmania, *pers. comm.*), however, local habitat loss is also contributing to this decrease.

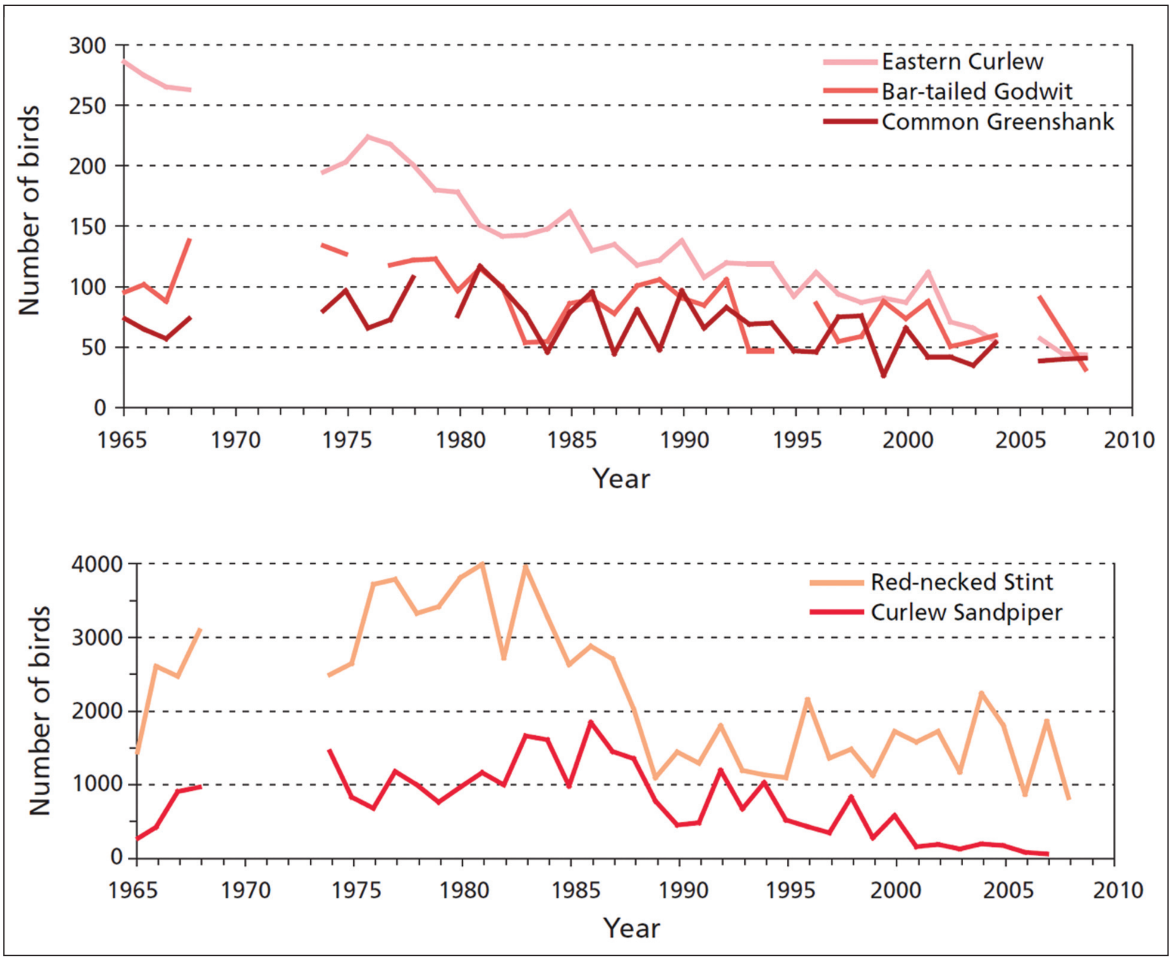
Habitat in the DEPA also supports at least six resident shorebird species (two Haematopodidae, four Charadriidae), including a nationally significant, sedentary population of Australian pied oystercatchers (*Haematopus longirostris*). The DEPA Australian pied oystercatcher population is the second-largest in mainland Tasmania and one of the largest in Australia (Lane 1987). The DEPA pied oystercatcher population has increased over the last 40 years, but shows considerable interannual variability (**Figure 9.8**). Another DEPA resident shorebird is the red-capped plover *(Charadnus ruficapillus)*. The red-capped plover is the most common breeding species of wader in Tasmania, and the South Arm area has been identified as one of the most important breeding areas for this species in southeastern Tasmania (BOAT 1982).

The effect of disturbance on breeding birds is complex, with differing effects with respect to stage in the breeding season, the type, intensity and duration of disturbance, and the availability of resources in the surrounding area (Aquenal 2008a). It is thought that disturbance to birds is only important when it has a fitness cost, through either reduced survival or fecundity (Gill *et al*. 2001). In the Ralphs Bay – South Arm area, human induced disturbance to shorebirds has included use of trail bikes, presence of horses and dogs on beaches, increasing coastal development (notably at South Arm and Rokeby), human recreational uses of the foreshore, and most recently, exceptional high tides causing roosting birds (notably pied oystercatchers) to move onto the roads at South Arm neck where they have subsequently been killed by cars (E. Woehler, 2009, Birds Tasmania, *pers. comm.*).

Wetland and saltmarsh birds

The upper Derwent estuary wetlands and saltmarshes support very high numbers of waterfowl, particularly in mid-summer, when over 2,500 black swans and 2000 ducks of several species are frequently present (**Figure 9.9**) (data from Stewart Blackhall, 2009, DPIPWE. This shallow, brackish area contains large expanses of submerged aquatic macrophytes (**Section 9.1.3**) making it an important and reliable feeding area for a wide range of species. As a gazetted Conservation Area, it also serves as a refuge for ducks during the annual three month hunting season, while its permanence means it may be a drought refuge for some species during dry periods. Several species of raptors (eagles, hawks and falcons) and ambush predatory birds (Australasian bittern, herons and egrets) are frequently observed hunting over the Derwent estuary marshes, and some of these birds have nesting sites in the region. Commonly observed birds of the Derwent estuary wetlands include the black swan, black duck, chestnut teal, musk duck, Eurasian coot, hoary headed grebe, pelican, great cormorant, little pied cormorant, silver gull, Pacific gull, great egret, white-faced heron, white-bellied sea eagle, marsh harrier, brown falcon, and masked lapwing (E. Woehler, 2009, Birds Tasmania, *pers. comm.*).

Figure 9.7: Trends in numbers of five species of migratory shorebirds in summer counts in the Hobart area



Source: Olson (2008)

Seabirds

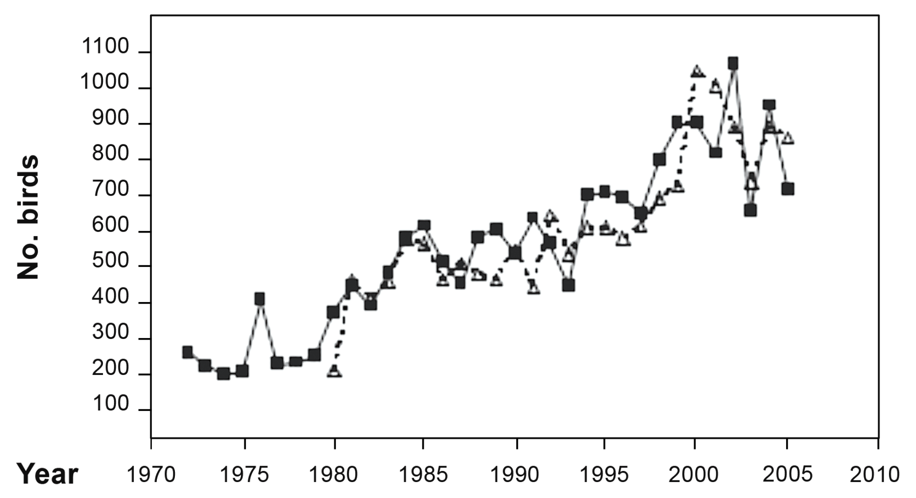
Seabirds include both resident species (gulls, cormorants and some species of terns) and several important migratory species such as short-tailed shearwaters (*Puffinus tenuirostris*) and Caspian terns (*Sterna caspia*) that breed locally. Winter counts have been undertaken since the 1980s on three species of gull that are resident in south eastern Tasmania. The annual counts are made during June, when the gulls have moved from their breeding islands to the coast, sports and agricultural fields, and urban rubbish tips. Kelp gulls are a relatively recent arrival to Tasmania, with the first record in the late 1950s and the first breeding record in the early 1960s. Their numbers in south eastern Tasmania have increased to between 6000 and 8000 birds. In contrast, there has been a decrease in the numbers of silver and Pacific gulls to half that observed 25 years ago throughout southeastern Tasmania (E. Woehler, Birds Tasmania, in Olson (2008)).

Penguins

The lower Derwent estuary supports several colonies of breeding little penguins (*Eudyptula minor* formerly known as fairy penguins) along its shoreline. Little penguins were historically more abundant in the estuary, but their population has been much reduced (Stevenson 2003, Stevenson and Woehler 2007). In Tasmania, less than 5% of the total little penguin population is found on the mainland, with the majority now found on off-shore islands. Derwent estuary little penguin populations face a variety of threats, including habitat degradation, human disturbance, predation (particularly by domestic pets) and gill netting.

In 2004, the DEP initiated a multi-staged collaborative project between local councils, State Government, industry, business and the community to address these threats, with financial support from the Australian

Figure 9.8: Trends in numbers of Australian pied oystercatchers observed in the Derwent estuary – Pittwater area during summer (solid line) and winter (dashed)



Source: data presented in Woxvold (2008)

Government. This project commenced with a detailed inventory of the distribution and abundance of little penguin habitat and nesting sites along the Derwent estuary shoreline, followed by regular monitoring of penguin numbers and breeding success.

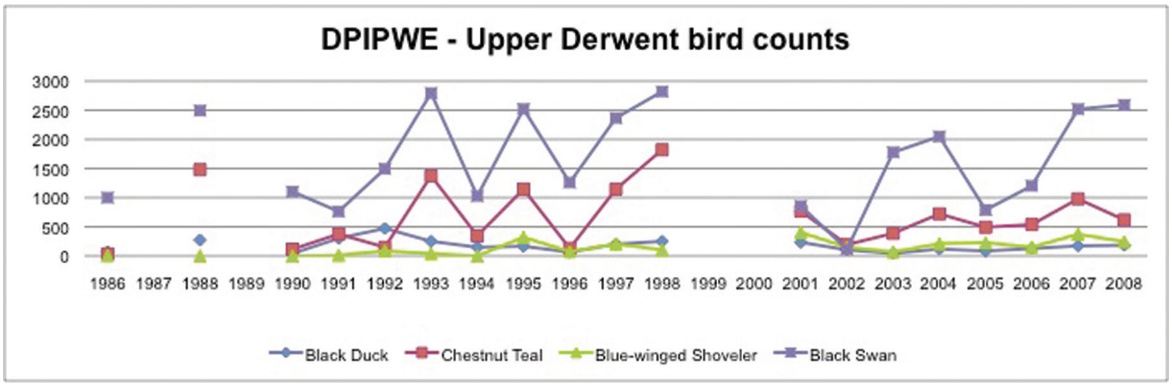
In stage one of the project, a total of 21 existing and former penguin-nesting areas were identified along the Derwent foreshore. Of these, nine were no longer occupied by little penguins, ten had fewer than ten breeding pairs, and the remaining two had fewer than 25 breeding pairs. A total of 98 breeding pairs were found during the 2004-05 survey, with two thirds of these located on land managed by local government.

All the existing nesting sites and some of the former sites surveyed on the Derwent foreshore exhibited the following features:

- hollows, cavities and shelter provided by natural features, vegetation, man-made structures and/or debris, that provide shade and adequate protection from wind, rain and predators;
- sheltered areas or refuges between landing spot and nesting site;
- an accessible landing point such as a beach or rock platform;
- no excessive noise, vibrations (such as those from earth moving equipment) or regular disturbance;
- limited foreshore illumination; and
- over 85% of occupied burrows in the Derwent estuary consisted of boulders, rock falls, rock crevices or rock walls.

This information was used to develop the *Derwent Estuary Penguin Project Management Recommendations and Guidelines (2005)*. This report addressed both

Figure 9.9: Trends in numbers of four waterfowl species observed in the upper Derwent estuary wetlands



Source: data from Stewart Blackhall, Wildlife Biologist, DPIPWE, March 2009 habitat management issues and the need for an ongoing community education campaign, and recommended that initial management activities focus on:

- protecting colonies from potential predators;
- limiting disturbance and habitat modification in and around existing colonies;
- maintaining unimpeded penguin access from landing site to nest site;
- maintaining and establishing protective cover from landing site to nest site;
- minimising illumination within penguin colonies; and
- creating a custodial relationship between local residents and local penguin colonies.

Stage two implemented a number of strategic management actions, including on-ground works at key sites to improve breeding success, educational activities and further monitoring. Key actions included the installation of over 125 artificial burrows, upgrading nearly 30 existing burrows, revegetating sites with more than 1,000 native plants grown by Understorey Network volunteers, and reducing encroachment by predators through erecting fencing, swing gates and signs at critical sites. The project raised awareness and understanding of how to protect penguins, particularly in primary schools and communities near penguin colonies, and was strongly supported by volunteers and local community groups. A total of 120 breeding pairs of penguins were found during more extensive monitoring in 2005-06.

Stage three involved further on-ground works at key sites (installation of another 150 artificial burrows, re-location of an existing walking track, weeding and revegetation with 1100 plants), educational and awareness-raining activities and further monitoring. In 2008-09, penguin colonies were found at 12 sites with the total breeding population estimated at 192 pairs, while in 2008-09, the total number of breeding pairs in the Derwent estuary was approximately 177 at 13 sites. The variation in population between years is within the range of natural fluctuation, and may be associated with factors such as changing availability of food resources. The on-going monitoring of penguin sites has shown that artificial burrows and burrow enhancement, fencing and signage have proven successful in expanding and protecting penguin habitat.

The knowledge and experience gained about little penguin management in the Derwent estuary has been captured in management guidelines: *Co-existing with Little Penguins in the Derwent Estuary: Information and Management Guidelines 2009.* The guidelines provide practical information for land managers and community groups/volunteers about managing little penguins in urban environments. A companion document was also developed that focuses on site-specific management information and recommendations for around the Derwent estuary. A forum for local government planners, community groups and natural resource managers was held to promote the management guidelines and share information to help conserve this species and its crucial habitats in Tasmania.

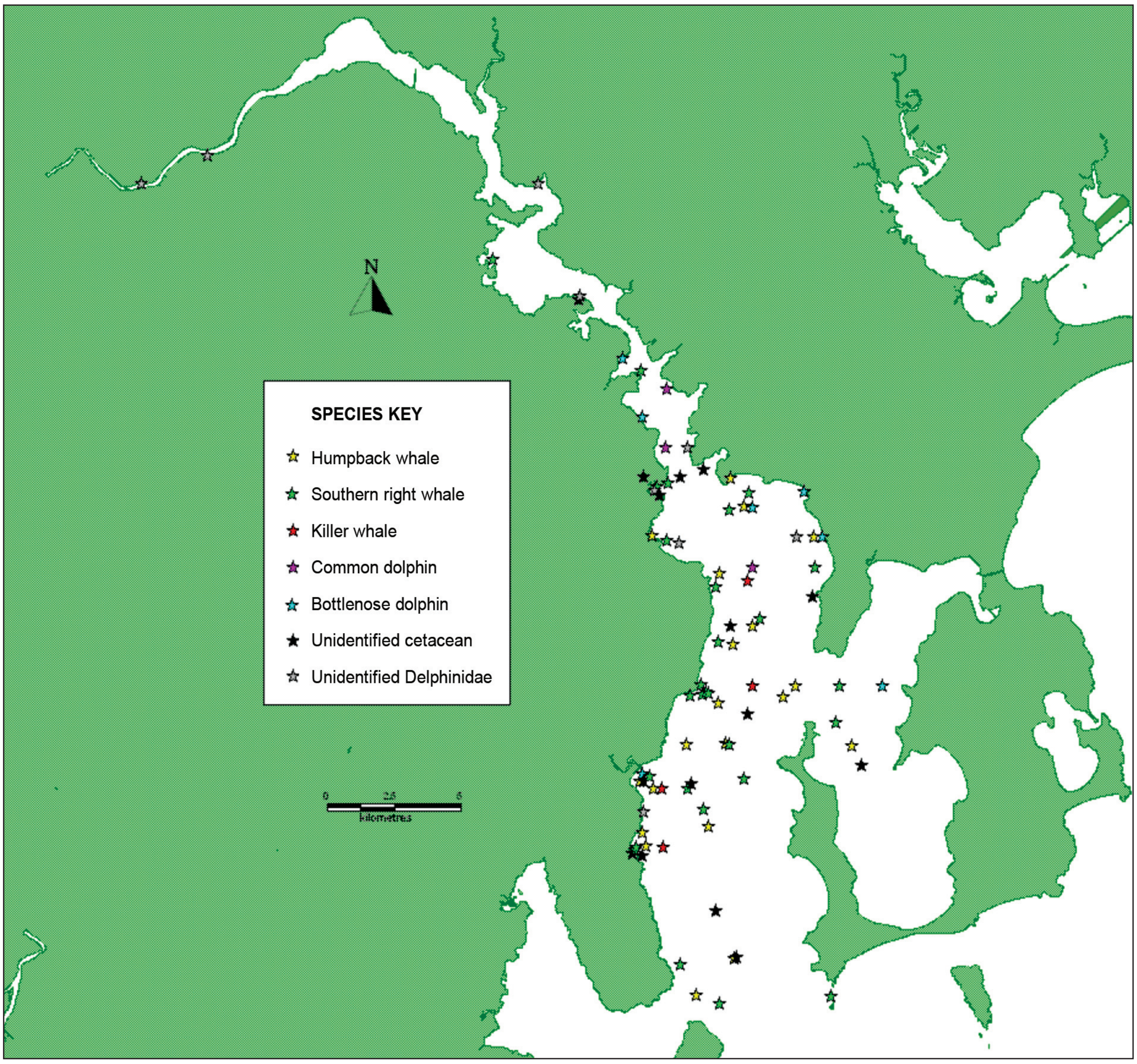
9.4.4 Marine mammals

Several species of marine mammals visit the Derwent estuary, particularly in its lower reaches. These include dolphins, whales (southern right, humpback and orca) and seals. Both bottle-nosed and common dolphins are sighted frequently in the Derwent, at times as far up-river as Old Beach. Southern right whales and humpback whales (both endangered) are migratory, arriving in Tasmanian latitudes on their way from the Southern Ocean starting in mid-May, with numbers peaking in June and July. Both of these species were hunted close to extinction in the 19th century. Records of mother and calf sightings and even births in southeastern Tasmania have increased in recent years (RPDC 2006), suggestingthat populations may be slowly starting to recover. Seals are seen in the Derwent estuary and occasionally haul out on the foreshore, however, no regular haul-out or breeding sites occur in the estuary. Australian fur seals are regularly observed in the estuary, and occasionally other species are reported, including the leopard seal, New Zealand fur seal, southern elephant seal and Australian sea lion. In recent years the Biodiversity Conservation Branch (DPIPWE) has created and maintained cetacean (*Whalebase*) and pinniped (*Sealbase*) observation databases. It should be noted that these data have not been derived from methodical survey programs but represent opportunistic sightings data.

A review of Derwent estuary cetacean observations, cetacean strandings and pinniped observations is presented in Aquenal (2008a), derived from the DPIPWE *Whalebase* and *Sealbase* databases. According to this review, five cetacean species have been sighted in the Derwent estuary, including the southern right whale *Eubalaena australis*, humpback whale *Megaptera novaeangliae*, bottlenose dolphin *Tursiops truncatus*, killer whale *Orcinus orca* and common dolphin *Delphinius delphis*. As indicated in **Figure 9.10**, the majority of cetacean sightings have occurred within the lower estuary, with only approximately 10% of sightings occurring within the middle and upper estuary combined. The majority of middle to upper estuary sightings were of dolphins, with just two sightings of southern right whales in the middle estuary. In the lower estuary, the majority of sightings occurred along the western shoreline and mid channel of the estuary, with clusters of sightings occurring around Blackmans Bay, Kingston Beach and Taroona (Aquenal 2008a). This is possibly biased due to increased observational opportunities adjacent to higher human habitation along these regions of the estuary (D. Lee, 2009, DPIPWE, *pers. comm.*). Humpback whales have also been sighted near the entrance to Ralphs Bay, and other cetacean species observed within Ralphs Bay. The timing of cetacean sightings in the Derwent estuary are consistent with known seasonal migration patterns, with the largest number of southern right and humpback whalessighted in the estuary during June and July, and killer whales present during late summer to early autumn. The common dolphin occurs in the estuary during winter (June to August), whilst bottlenose dolphins are present in the estuary at any time throughout the year (Aquenal 2008a).

A review of cetacean strandings in the Derwent estuary was also undertaken by Aquenal (2008a) using DPIPWE's Whalebase database records. Forty-seven cetacean strandings have been documented in the Derwent between 1912 and 2006, typically involving individual common dolphins *Delphinus delphis* or bottlenose dolphins *Tursiops truncates*. A total of 34 of these stranding occurred in Ralphs Bay, primarily on the shallow intertidal sandflats at the southern end of the bay, adjacent to the South Arm neck. This intertidal area has also experienced the majority of the mass stranding events within the estuary (11 of 12), with the largest occurring in 1998 (45 common dolphins) (Aquenal

Figure 9.10: Distribution of cetacean sightings recorded in the Derwent estuary between 1983 and 2006



Source: Aquenal 2008a – based on data contained in the Whalebase database of the Biodiversity Conservation Branch, DPIPWE 2008

2008a). It is likely that the bathymetry of southern Ralphs Bay intertidal flats posses a natural stranding risk to small cetaceans (D. Lee, DPIPWE, *pers. comm.*).

A review of seal (pinniped) sightings in the Derwent estuary was also undertaken by Aquenal (2008a) using DPIPWE's Sealbase database records (note that only unusual pinnipeds or those of management interest (e.g. injured or causing nuisance) are recorded in this database). Five pinniped species have been observed in the estuary: the Australian fur seal *Arctocephalus pusillus*, New Zealand fur seal *Arctocephalus fosteri*, leopard seal *Hydrurga leptonyx*, southern elephant seal *Mirounga leonina* and Australian sea-lion *Neophoca cinerea.* The latter species is represented by a solitary observation in Ralphs Bay. Pinniped sightings were distributed throughout the estuary, although the majority occurred in the lower estuary. The timing of the majority of sightings were as follows: leopard seals (winter/early spring), New Zealand fur seals (mostly recorded in autumn months), and Australian fur seals were recorded throughout the year (Aquenal 2008a). All recorded sightings of southern elephant seals occurred in the 1980s, and none have been documented in the estuary since 1982 (Aquenal 2008a), although it is likely unreported visitations have continued.

9.5 Threatened fauna

As listed in **Table 9.8**, 16 threatened species visit or inhabit the Derwent estuary, with an additional 18 species recorded along the foreshore and adjacent terrestrial habitats (note – this list excludes the greater River Derwent and Jordan River catchments). Threatened marine and estuarine species include the humpback and southern right whales (both endangered), fairy tern (rare), the New Zealand fur seal (rare) and the spotted handfish (endangered).

9.5.1 Spotted handfish

The critically endangered spotted handfish *Brachionichthys hirsutus* is endemic to southeastern Tasmania, and is currently only found in several sites in the lower Derwent estuary within a total area of less than 3 km^2 (Aquenal 2008a). Areas with spotted handfish have been periodically surveyed by CSIRO, with additional surveys conducted in 2007 by Aquenal, enabling the 2007 population to be estimated at between 1600 and 3550 adult individuals (Aquenal 2008a). More recent surveys by CSIRO in 2008 at some of the known occupied areas indicate these local populations are stable. Other CSIRO surveys in 2008 examined additional potential locations for the presence of spotted handfish but no new occupied areas were found. (M. Green, 2009, CSIRO, *pers. comm.*).

Throughout the 1960s, 70s and early 80s, handfish were frequently sighted by divers on the sediments along the eastern and western shores of the Derwent, and adjoining bays typically associated with sandy, or mixed sand/silt, subtidal sediments in water depths of 5-12 m. However, major declines occurred in the mid 1980's and extensive surveys of the estuary floor in 1994 and 1996 found only a handful of specimens at several locations throughout their former range. The levels of fish movement between remnant colonies is believed to be limited, as spotted handfish are relatively sedentary. They have a low breeding capacity, with eggs wrapped around erect structures on the seabed that consist primarily of stalked ascidians *Sycozoa* spp. but also include seagrass, sponges, small macroalgae (e.g. *Caulerpa* spp.) and polychaete worm tubes.

The spotted handfish is threatened by the loss or degradation of foraging and spawning habitat, possibly due to siltation, pollution and/or predation of the handfishes' preferred spawning habitat (the ascidian *Sycozoa* sp.) by the introduced seastar, *Asterias amurensis*. Other threats to the spotted handfish include poaching of fish for sale as aquarium specimens and – historically – scallop dredging and Danish seine fishing techniques that altered seafloor habitat conditions (Spotted Handfish Recovery Team 2002). The only known spotted handfish location outside the Derwent estuary, in Frederick Henry Bay, had a substantial population in 1999 but appears to have suffered a local extinction sometime prior to resurvey in 2005. The cause of this apparent local extinction is not known as the habitat remains good at this site. In Ralphs Bay, a population of adult fish occurs at a site previously thought to be lacking natural spawning substrates. However CSIRO surveys in Ralphs Bay during 2008 indicate that small sponges are predominantly used for egg attachment at this site. These sponges are fragile and egg loss appears to be high resulting in poor recruitment and a population dominated by adults (M. Green, 2009, CSIRO, *pers. comm.*). Seasonal filamentous algal growth has also been recently observed in this area, which is actively avoided by the spotted handfish (Aquenal 2008a).

Recovery Plan actions have been carried out since 1999, guided by the *Spotted handfish Recovery Plan 1999-2001,* a Tasmanian government Recovery Plan for 2002-2006 and more recently by the Commonwealth's Department of Environment and Water Resources *Recovery plan for four species of handfish.* The overall objective of the recovery efforts is 'to locate and secure existing populations of spotted handfish, reduce the

Table 9.8: Threatened fauna – Derwent estuary and surrounding catchment

Threatened flora in DEP area		**Code**	
Scientific name	**Common name**	*Tas*	*Aust*
ESTUARY			
+*Arctocephalus forsteri*	New Zealand fur seal	r	
+*Arctocephalus tropicalis*	sub-Antarctic fur seal	e	VU
* *Brachionichthys hirsutus*	spotted handfish	e	CR
+*Eubalaena australis*	southern right whale	e	EN
+*Carcharodon carcharias*	great white shark	v	VU
Diomedea cauta subsp. cauta	shy albatross	pv	PVU
Haliaeetus leucogaster	white-bellied sea-eagle	v	
* *Marginaster littoralis*	seastar	e	
+*Megaptera novaeangliae*	humpback whale	e	VU
+*Mirounga leonina*	southern elephant seal	e	VU
Numenius madagascariensis	eastern curlew	e	
Pateriella vivipara	live-bearing seastar	pv	
Podiceps cristatus	great crested grebe	v	
Poliocephalus cristatus subsp. australis	great crested grebe subspecies	pv	
Prototroctes maraena	Australian grayling	v	VU
Sterna nereis subsp. nereis	fairy tern	v	
ESTUARY CATCHMENT			
Accipiter novaehollandiae	grey goshawk	e	
Amelora acontistica	chevron looper moth	v	
Antipodia chaostola	chaostola skipper	e	
Antipodia chaostola subsp. leucophaea	chaostola skipper	e	
Aquila audax fleayi	wedge-tailed eagle	e	EN
Dasyurus maculatus	spotted-tailed quoll	r	VU
Dasyurus maculatus subsp. maculatus	spotted-tailed quoll	r	VU
Dasybela achroa	saltmarsh looper moth	v	
Discocharopa vigens	land snail	v	
Lathamus discolor	swift parrot	e	EN
Lissotes menalcas	mt. mangana stag beetle	v	
Litoria raniformis	green and gold frog	v	VU
Pardalotus quadragintus	forty-spotted pardalote	e	EN
Perameles gunnii	eastern barred bandicoot		VU
Pseudemoia pagenstecheri	tussock skink	v	
Roblinella agnewi	silky snail	r	
Sarcophilus harrisii	tasmanian devil	e	VU
Tyto novaehollandiae castenops	masked owl	e	

*Endemic to the estuary and surrounding bays
+ Source: Threatened Species Unit, DPIWE.
Note – pv and PVU = presumed vulnerable (this is an unoffical listing)

NOTES: Threatened species in Tasmania are listed subject to the following national and state Acts:

National: *Environment Protection and Biodiversity Conservation Act 1999*
Threatened species under the national schedule are classified as: EX) Extinct, EW) Extinct in the Wild, CR) Critically Endangered, EN) Endangered, VU) Vulnerable and CD) Conservation Dependent.
Tasmania: *Threatened Species Protection Act 1995*

Threatened species under Tasmanian legislation are classified as: x) presumed extinct (on the ground that no occurrence of the taxon in the wild can be confirmed during the past 50 years); e) endangered (in danger of extinction because long term survival is unlikely while the factors causing the species to be endangered continue operating); v) vulnerable (a species which is likely to become endangered while the factors causing it to be vulnerable continue operating) and; r) rare (a species which has a small population in Tasmania that is not endangered or vulnerable but is at risk).

chances of future decline, enhance populations in areas where numbers have been seriously depleted or lost and subsequently achieve down listing from the current *endangered* status' (Spotted Handfish Recovery Team 2002). A number of Australian Government funded projects have been carried out by CSIRO since 1996 to improve understanding of spotted handfish biology and to assess its status. These include the collection of baseline biological data, examination of habitat requirements, monitoring of the known colonies, development of techniques to assess population size and stability, and the establishment of captive husbandry protocols. The captive breeding program was successful in spawning and rearing juvenile spotted handfish. In addition, trials in the wild have succeeded in getting spotted handfish to spawn around artificial spawning substrates.

Several projects have been undertaken to assist handfish recovery through the installation of artificial and natural spawning substrates at sites lacking structure to which handfish can attach their eggs. Six-hundred artificial spawning substrates were deployed in 2002 at two sites in the Derwent and a trial was undertaken to see if translocated algae (*Caulerpa* spp.) from Frederick Henry Bay could be used as a handfish spawning substrate in the Derwent estuary. The trial was then expanded in 2004-05 with additional funding from NRM South and CSIRO. The transplant site was checked at the end of 2005 and most recently at the end of 2008. This transplanted algae was still growing in patches and handfish eggs had been found attached. In 2008 artificial structures were tested at the Ralphs Bay location with positive results regarding use by handfish for spawning and retention of the subsequent egg masses (M. Green, 2009, CSIRO, *pers. comm.*). Future surveys are needed late in 2009 to see if these retained eggs have resulted in a recruitment of juvenile handfish at the site. CSIRO have also collected 250 tissue samples for genetic study on the known populations but resources are required to complete this investigation.

9.5.2 Derwent estuary endemic seastar (Marginaster littoralis)

A Derwent estuary endemic seastar, *Marginaster littoralis*, has previously being recorded within intertidal habitats in the middle estuary. The status of this species is uncertain, and it may now be extinct due in part from the combined effects of pollution, invasive species pressures and habitat loss. A component of future DEP habitat surveys will include searches for *Marginaster littoralis*.

10.0 DERWENT FORESHORE MANAGEMENT

At the national and international level, there is a growing trend towards increasing use and redevelopment of urban foreshores that is resulting in major social and economic benefits as well as more liveable cities. This trend is now becoming apparent along the Derwent foreshore, with increasing interest and investment in new restaurants, marinas, residential and commercial facilities.

The Derwent foreshore is remarkable for its scenery, diversity and ease of public access. Approximately 50% of the foreshore is still in the public domain, providing enormous scope and opportunities for enhanced public use and recreation, together with associated economic and tourism benefits. The Derwent foreshore is used for a wide range of purposes and is managed by multiple land and infrastructure managers, each with their own management frameworks and codes. These include six council planning schemes as well as the management systems used by Parks and Wildlife, Crown Lands, Department of Infrastructure, Energy & Roads, Marine and Safety Tasmania and the Sullivans Cove Waterfront Authority. The foreshore is a particularly critical area, as development here has greater potential to affect estuarine water quality, coastal ecosystems, public use, views and heritage values. The sensitivity of foreshore land to development varies, depending on slopes, soils, vegetation type, fauna, threatened species and susceptibility to sea level rise.

At present there is no estuary-wide vision or planning framework for the Derwent foreshore. The *State Coastal Policy* provides some guidance, but has been under review for a number of years. The Sullivans Cove Waterfront Authority was established in 2005 to plan and manage development along Hobart's historic waterfront; and a Master Plan for this area is due out in 2009-10. A number of local plans have also been developed by councils for areas such as Kingston Beach, Blackmans Bay and Kangaroo Bay, and numerous site specific plans have been developed for specific foreshore parks and reserves by councils, Parks and Wildlife and community groups.

It is important to improve links and coordination between existing council and state government planning processes to better address foreshore issues and opportunities, and to provide a more consistent and streamlined assessment process. Comprehensive and user-friendly information about foreshore values and constraints would greatly assist in planning and assessment. In addition, much could be done to develop (and implement) guidelines that address both design and construction aspects of foreshore development.

Finally, it is important to emphasise the critical role played by the community, as a private land manager, as a user of public lands and – increasingly – as a hand-on manager of public lands through Coastcare, Landcare and other programs.

A number of key foreshore issues and priorities have been identified by the Derwent Estuary Program in the recently published *Derwent Estuary Environmental Management Plan* (2009). These include development of a regional foreshore tracks network, interpretation, improved management of foreshore vegetation and careful management of foreshore reclamation and dredging activities.

10.1 Tracks and paths

The Derwent estuary foreshore extends for 233 km, and approximately half of the foreshore is publicly owned and managed by state and local governments, largely as parks and reserve areas. These areas contain a significant network of existing tracks and paths that are increasingly being used by walkers and cyclists. The opportunities for walking on the foreshore are therefore numerous and development and expansion of existing tracks to form an integrated regional tracks network is a priority for the DEP.

An initial survey of Derwent estuary foreshore tracks was carried out in 2005 as part of the *DEP Tracks and Paths Strategy* and it was noted that while many of the Derwent foreshore tracks and paths are located within the urban setting, they retain natural and cultural heritage features that give them both scenic and interpretative value. However, there is a consistent lack of directional signage, little interpretation, and many have significant unresolved management issues that detract from the walking experience.

The local demand for walking tracks is high. In Tasmania, recreational walking was the most frequently participated in activity, with a participation rate of 42% (Australian Sports Commission 2008). Council surveys also reveal a strong local interest in walking tracks that are easily accessible from urban areas.

To determine a demand profile for Derwent estuary walking tracks by visitors to southern Tasmania, a survey of visitors about their interest in and usage of tracks was commissioned by the DEP (Myriad 2005). The survey found that 96% of respondents had undertaken urban/historic walks (or were planning to) on their visit. The main reasons for taking these walks were to: enjoy nature, scenery and views: to experience and see more of Tasmania; and to explore new areas. Close to 80% of respondents had undertaken walks around some part of the Derwent estuary foreshore on their trip. When provided with a background to walking opportunities and other natural, cultural and heritage aspects of the Derwent estuary, seven in ten respondents indicated that they would be likely to increase their walking around the estuary. In terms of facilities, priorities were for toilets and signage (both interpretative and directional). Preferred features of walks were natural bushland, river views and heritage sites and beaches. Cafes and shops were not given a high priority.

Based on the high level of interest expressed by both locals and visitors, a network of foreshore tracks would provide valuable recreational infrastructure and educational opportunities. A more detailed inventory of Derwent foreshore tracks was prepared in 2007 and includes GIS maps for 111 km of tracks and potential routes, information on track condition, and recommendations for upgrading tracks to Australian Standards. Priorities for works were also suggested based on scenic value (Schmidt and Hughes 2007).

Ongoing work to improve foreshore walking opportunities is undertaken by public land managers including local councils and the Parks and Wildlife Service. Since 2003 a number of track extensions and upgrades have been undertaken by all of the councils within the DEP area. In 2007 the *Trails Tasmania Strategy* was prepared by the State Government to provide for the planning, development and sustainable management of an integrated recreational trails network in Tasmania. As identified in the strategy, the highest priority needs are for trails close to where people live. The State Government announced in 2008 that $4 million was available for community trails and bikeways with urban and urban fringe areas being the focus for works. It is the aim of the DEP to work with these land managers to optimise linkages. Our aim is to create a regional tracks network for the Derwent with consistent directional and interpretative signage.

10.2 Interpretation

In 2006 the DEP commissioned the *Derwent Estuary Interpretations Plan* to address the need for a regional interpretation plan, in conjunction with regional branding and a regional marketing strategy (Housego 2006). The Plan was developed using the thematic interpretive structure supported by Tourism Tasmania. A workshop was held with representatives of local and state government, industry, community organisations and the Tasmanian Land and Sea Council to develop a collection of themes that convey a sense of meaning for place.

Themes are creative tools that provide a focus for strategic communication and provide a starting point for planning, development and the delivery of effective messages that can be adjusted to accommodate local 'colour and flavour'. Proposed themes for the Derwent estuary include:

- The Derwent estuary has been – and remains – a powerful force in shaping Hobart's character and the way that locals work and play.
- Right here, right now is where environmental change can happen for the Derwent estuary and its foreshore. It all depends on what you do next.
- Hobart's harbour is a remote port of safety at the bottom of the world – and the last stop before Antarctica.
- The Derwent estuary inspires, nurtures, and invites creativity and celebration.
- The Derwent estuary has both united and divided local communities.
- The mountain and estuary landscape holds memories of 1,600 generations of Tasmanian Aborigines and these memories live on for today's Aboriginal community.

Based on the consultation, it was recommended in the *Interpretation Plan* that a signage strategy, self guided map or brochure for foreshore walking tracks and a collection of 'call to action' environmental messages that respond to the question 'what can I do?' be developed.

10.3 Vegetation management

The management of vegetation in the Derwent is complicated because of the many public and private land owners that are responsible for the foreshore. As discussed in **Section 9**, recent mapping has shown that 49% of the foreshore retains its native vegetation. The Dewent foreshore includes twelve state-listed threatened communities and a number of threatened species of flora and fauna.

There are many threats to the Derwent's foreshore vegetation, including slow acting and widespread threats such as climate change and weed invasion through to fast acting and localised threats like minor earth works or firewood cutting. Threats may also be the result of direct activities such as land clearing or as a result of indirect actions, such as the incidental spread of plant pathogens by vehicles or walkers.

Vegetation management in Tasmania is guided by a number of plans, strategies and legislation. To ensure the full range of vegetation and communities in Tasmania is protected, areas of publicly owned and privately owned land need to be set aside and managed for conservation. Reservation and land management agreements of various kinds can achieve this. Reserves are declared under the *Nature Conservation Act 2002* that sets out the values and purposes of each reserve class. They are managed under the *National Parks and Reserves Management Act 2002* according to management objectives for each class. There are numerous state-managed reserves along the Derwent estuary foreshore, as listed in **Section 2.1.2**. Native vegetation on private land can be protected through the State Government's *Private Land Conservation Program* (PLCP) through voluntary conservation covenants and other agreements – including *Land for Wildlife*. The PLCP provides ongoing support to participating landowners to support the protection and sustainable management of high conservation value communities.

Other legislation relevant to managing vegetation includes the *Threatened Species Protection Act 1995* and the *Tasmanian State Coastal Policy 2006*. The Coastal Policy has recently been revised and is being reviewed by the Resource Planning and Development Commission (RPDC). At a Federal level the *Environment Protection and Biodiversity Conservation Act 1999* provides legal measures to protect threatened vegetation communities and species. Also of relevance is the *Tasmanian Wetland Strategy* (DPIW 2004).

There are a number of resources to help manage threats to foreshore vegetation. These include the *Tasmanian Bushcare Toolkit* (Kirkpatrick and Gilfedder 1999) and the *Wetland and Waterways Works Manual* created by DPIWE which provides practical methods for minimising environmental harm when undertaking works in these sensitive areas. Both are available on the Department of Primary Industries, Parks, Water and Environment (DPIPWE) website at www.dpipwe.tas.gov.au. Detailed recent mapping of Derwent foreshore vegetation, including information of vegetation types and condition, can also be accessed via the LIST (www.thelist.tas.gov.au/listmap – in 'Layer Management', go to 'Natural Environment Layers' and click on 'Coastal Values').

10.4 Foreshore reclamation and dredging

Development on the foreshore is commonly associated with practices such as reclamation and dredging. Reclamation typically involves the filling of intertidal or subtidal areas to extend the landward boundary, but has also historically included the draining of wetlands and saltmarshes. Dredging is usually associated with the maintenance of existing shipping and navigation channels, or capital dredging projects for the construction of new or deeper channels. Land reclamation projects are often developed in tandem with capital or maintenance dredging works, with the dredge spoil used to provide fill material for accreted land.

In the Derwent there has been some significant historical reclamation, particularly around the Hobart waterfront including Sullivans Cove, Hunter Street and Macquarie Point in the early 1800's. Often wetlands and other low-lying foreshore areas were reclaimed as tips, recreational areas or for commercial and industrial purposes. For example, the Kangaroo Bay and Eastlands commercial site are located on a former wetland as is Wentworth Park at Howrah. Wetlands at Geilston Bay and Lindisfarne Bays are now recreational and park areas. Parts of Cornelian Bay, Self's Point, New Town Bay, Wilkinsons Point at Elwick Bay and the Boyer paper mill were also built on reclaimed land. Current reclamation activities require permits from the State Government's Crown Land Services, and must demonstrate that reclamation will not impair water quality or harm estuarine habitats or species. There are relatively few applications made for Derwent estuary reclamation activities, however a number of non-permitted activities have been observed.

Dredging in the Derwent has typically been limited to small projects such as the redevelopment or expansion of marinas, or maintenance of deep water access at wharves and jetties. However, there are several larger developments recently proposed (e.g. Lauderdale Quay canal estate) or under consideration (e.g. Prince of Wales Bay marine precinct) that could involve large-scale dredging if implemented.

Given the extent and severity of heavy-metal contamination in Derwent estuary sediments, as described in **Section 7**, it is essential that dredging activities are managed carefully to avoid potential disturbance of highly contaminated materials. In 2009 the DEP commissioned *Dredging and Land Reclamation in the Derwent: A Guidance Document to Support Best Practice Management,* which outlines the environmental management considerations, including monitoring and compliance, required for these activities. It will be available on the DEP website www.derwentestuary.org.au when complete.

11.0 INTRODUCED SPECIES

Introduced species within the Derwent estuary include a range of terrestrial, marine, and intertidal organisms. Collectively these are having dramatic impacts on native species and natural processes within and around the estuary. The following section provides an overview on a range of introduced marine and intertidal species, and introduced foreshore plants.

11.1 Introduced marine and intertidal species

Introduced marine and intertidal species are a particularly insidious form of ecological pollution in that, once established, they can be extremely difficult – often impossible – to eradicate and can result in severe consequences to the marine environment, aquaculture, commercial and recreational fishing and public health. Some introduced marine and intertidal species are able to out-compete native flora and fauna. It is believed that introduced marine species pose a serious threat to native species found in the estuary, particularly the endangered spotted handfish, and may also affect human health (e.g., presence of introduced toxic algae) and public amenity (e.g. feral Pacific oysters on foreshore areas).

Many introduced species have flourished in the Derwent, taking advantage of the disturbed or altered environment. Physical conditions in the Derwent estuary make it somewhat susceptible to exotic marine species introductions. These include low current velocities and an abundance of sheltered habitats, which may entrap marine pest larvae and increase the likelihood of larval retention in the estuary (Aquenal 2002). The estuary contains a wide range of habitats suitable for survival and settlement of larvae, which also increases the likelihood of successful colonisation (Aquenal 2002).

Introduced marine species have been brought into Australian waters via ballast water, biofouling, deliberate introductions and aquaculture. Today ballast water and biofouling account for most overseas introductions with the significance of biofouling only being fully recognised in recent years. Once marine species have been introduced into Australian waters, all vessels and equipment used in the marine environment (including commercial and recreational fishing gear, diving equipment, kayaks) are at risk of further translocating them.

Temperate southern hemisphere estuaries such as the Derwent are susceptible to marine pest invasions from other temperate areas (e.g. northern Pacific and New Zealand) as they provide comparable conditions (e.g. temperatures) for these species to thrive, but may lack the controls (e.g. predators) to control their populations.

At least 79 introduced or cryptogenic (possibly introduced) marine species have been identified in the Derwent estuary and there are probably many more unrecorded species (Aquenal 2002, 2008a) (**Table 11.1**).

11.1.1 Review of introduced marine and intertidal species surveys

The introduced marine and intertidal species list for the Derwent estuary (**Table 11.1**) was complied on the basis of a Hobart Port Survey of the middle estuary areas in the summer of 1999-2000, and a literature review of other faunal data (Aquenal 2002). The list was also supplemented by later surveys concentrating in the Ralphs Bay area (Aquenal 2008a). A survey in 2004, of subtidal sediments in the middle and lower Derwent estuary for macroinvertebrates, identified that at least 14 of the 79 introduced marine species in the Derwent occur in soft sandy and muddy sediments (MacLeod and Helidoniotis 2005). The more recent surveys in Ralphs Bay identified previously un-recorded introduced species within the estuary , which included: the polychaete worm *Boccardia proboscidea*; barnacle *Elminius covertus*; green alga *Cladophora sericea*; brown algae *Colpomenia* sp.; *Stictyosiphon soriferus; Cutleria multifida*; *Hincksia mitchellae*; red alga *Haraldiophyllum nottii* and nudibranch *Polycera hedgpethi* (Aquenal 2008a). The nudibranch *Polycera hedgpethi* identification in the Derwent is a first for this species in Tasmania.

Of the 79 introduced species recorded in the Derwent estuary (**Table 11.1**), *Asterias amurensis* (northern Pacific seastar), *Gymnodinium catenatum* (toxic dinoflagellate), *Crassostrea gigas* (feral Pacific oyster), *Undaria pinnatifida* (Japanese seaweed 'wakame'), *Patiriella regularis* (New Zealand seastar), *Maoricolpus roseus* (New Zealand screw shell), *Petrolisthes elongatus* (New Zealand half crab), and European clam (*Varicorbula gibba*) are likely to be impacting on the ecology of the environment (Aquenal 2002, MacLeod and Helidoniotis 2005). These species are widespread or frequently reach high abundances within specific areas of the Derwent estuary. In the Ralphs Bay area, the species *Crassostrea gigas, Elminius covertus, Chiton glaucus* and *Myxicola infundibulum* are also modifying the composition of marine biological assemblages (Aquenal 2008a).A review paper on key introduced species in the Derwent estuary was recently prepared by the DEP (Whitehead 2008). Two of the most conspicuous introduced species are the northern Pacific seastar *(Asterias amurensis)* and European green crab *(Carcinus maenas).*

Table 11.1: Introduced and cryptogenic (possibly introduced) species present in the Derwent estuary

Target Introduced Pests	**Common name**	**Non-target Species**	**Status**
Asterias amurensis	Northern Pacific seastar	***Fishes***	
Undaria pinnatifida	Japanese seaweed	_Salmo trutta_	Introduced
Crassostrea gigas	Pacific oyster	_Oncorhynchus mykiss_	Introduced
Corbula gibba	European clam	_Salmo salar_	Introduced
Carcinus maenas	European shore crab	_Grahamina varium_	Cryptogenic
Alexandrium catenella	toxic dinoflagellate	_Grahamina gymnota_	Cryptogenic
Alexandrium tamarense	toxic dinoflagellate	***Bryozoans***	
Gymnodinium catenatum	toxic dinoflagellate	_Watersipora subtorquata_	Introduced
Non-target Species	**Status**	_Membranipora membranacea_	Introduced
Molluscs		_Bugula neritina_	Introduced
Maoricolpus roseus	Introduced	_Bugula flabellata_	Introduced
Venerupis largillierti	Introduced	_Bowerbankia gracilis_	Introduced
Neilo australis	Introduced	_Bowerbankia imbricata_	Introduced
Theora lubrica	Introduced	_Tricellaria occidentalis_	Introduced
Raeta pulchella	Introduced	_Cryptosula pallasiana_	Introduced
Chiton glaucus	Introduced	_Conopeum seurati_	Cryptogenic
Echinoderms		***Hydroids***	
Patiriella regularis	Introduced	_Cordylophora caspia_	Introduced
Astrostole scabra	Introduced	_Ectopleura crocea_	Introduced
Crustaceans		_Ectopleura dumortieri_	Introduced
Petrolisthes elongatus	Introduced	_Bougainvillia muscus_	Introduced
Cancer novaezelandiae	Introduced	_Clytia hemisphaerica_	Cryptogenic
Halicarcinus innominatus	Introduced	_Halecium delicatulum_	Cryptogenic
Corophium acherusicum	Cryptogenic	_Obelia dichotoma_	Cryptogenic
Corophium insidiosum	Cryptogenic	_Plumularia setacea_	Cryptogenic
Caprella acanthogaster	Cryptogenic	_Sarsia eximia_	Cryptogenic
Caprella penantis	Cryptogenic	_Turritopsis nutricula_	Cryptogenic
Jassa marmorata	Cryptogenic	_Gonothyraea loveni_	Cryptogenic
Leptochelia dubia	Cryptogenic	***Algae***	
Elminius modestus	Cryptogenic	_Codium fragile tomentosoides_	Introduced
*Elminius covertus	Introduced	_Schottera nicaeensis_	Introduced
Polychaetes		_**Grateloupia turuturu_	Introduced
Euchone limnicola	Introduced	_Polysiphonia brodiaei_	Introduced
Myxicola infundibulum	Cryptogenic	_Polysiphonia senticulosa_	Introduced
*Boccardia proboscidea	Introduced	_Polysiphonia subtilissima_	Cryptogenic
Ascidians		_Ulva lactuca_	Cryptogenic
Ascidiella aspersa	Introduced	_Ulva rigida_	Cryptogenic
Ciona intestinalis	Introduced	_Ulva stenophylla_	Cryptogenic
Botrylloides leachi	Introduced	_Bryopsis plumose_	Cryptogenic
Botryllus schlosseri	Introduced	_Antithamnionella ternifolia_	Cryptogenic
Dictyota dichotoma	Cryptogenic	_*Cladophora sericea_	Introduced
Enteromorpha compressa	Cryptogenic	_‘*Colpomenia sp.,’_	Introduced
Hincksia sandriana	Cryptogenic	_*Stictyosiphon soriferus_	Introduced
Nudibranch		_*Cutleria multifida_	Introduced
*Polycera hedgpethi	Introduced	_*Hincksia mitchellae_	Introduced

* species identified in Aquenal (2008a)
** Alastair Morton (DPIPWE) _pers. comm._ 21 Aug 2009 – Blackmans Bay
Data sourced from literature review and field surveys (Aquenal 2002, 2008a).

Northern Pacific seastars

The northern Pacific seastar (*Asterias amurensis*) is thought to have been introduced to the Derwent estuary via ballast water in the 1980s. In Tasmania the highest densities are found in the Derwent estuary, and they have more recently spread to other areas outside of the Derwent. The Derwent is not a closed waterway, so some spread may be natural, but other vectors for translocation include ship ballast and biofouling.

The impact of *Asterias* on soft sediment habitats in Tasmania has been the subject of extensive research (Ross *et al*. 2002, 2003a, 2003b, 2004, 2006), and includes large impacts on bivalve populations (e.g. mussels and cockles). At high densities, *Asterias* has the potential to impact a large variety of taxa, with significant and broad effects on soft sediment communities. The impacts of *Asterias* on infaunal bivalves may be exacerbated when combined with bivalve larvae predation by other introduced species such as European green crabs (*Carcinus maenas*) (Ross *et al*. 2004). While *Asterias* also occurs on sheltered rocky reef habitats, its impacts on these communities remain poorly understood.

Asterias has also been implicated as a contributing factor to the decline of the endangered spotted handfish in the Derwent estuary (Bruce and Green 1998). Northern Pacific seastars have been observed feeding on stalked ascidians, which are commonly used as a spawning substrate, (*Sycozoa* sp.) and it is possible that predatory loss of the ascidian may impact spotted handfish by reducing the available spawning substrate (Bruce and Green 1998). Furthermore, *Asterias* predatory behaviour suggests that it also may feed on the slow-moving young of the handfish, and eats the handfish large benthic egg masses (which *Asterias* will eat in captivity) (Bruce *et al*. 1997). The impact of *Asterias* on other rare echinoderm species in the Derwent estuary (e.g. small five armed seastar *Marginaster littoralis* (possibly extinct) and the holothurian *Psolidium ravum*), remains poorly known (Gowlett-Holmes 1999).

The distribution of *Asterias* in the lower Derwent estuary (south of the Tasman Bridge) was mapped using underwater video transects at depths >3 m during September and October 1999 (Ling 2000). This survey indicated that the estuary *Asterias* population was approximately three million, with the highest abundance occurring around wharf structures (>2 individuals m^2), where there is an increased availability of food (principally mussels dislodged from wharf pylons due to wave action) (Ling 2000). Based on this survey, it was estimated that about 10% of the Derwent estuary *Asterias* population aggregate around the wharf areas, within approximately 0.1% of the total estuary area, and it has been suggested that *Asterias* around the wharfs are potentially responsible for 90% of the zygote production in the estuary (Ling 2000). It has been hypothesised that, by reducing the high density *Asterias* populations found around wharves in the Derwent estuary, the reproductive output and overall population abundance could be reduced (Ling 2000). However, the effectiveness of this technique depends on the link between larval abundance and the number of larvae that recruit to the adult population (Bax *et al*. 2006), which is currently unknown (*Asterias* NCP 2008). This knowledge gap needs to be addressed before the effectiveness of seastar control around wharfs, and other artificial marine structures, can be fully assessed (*Asterias* NCP 2008). If eradication of *Asterias* from the Derwent is not technically or financially feasible, clear objectives for a Derwent estuary *Asterias* management program need to be developed, to guide ongoing control activities. The objectives and potential control options should be informed from scientific advice and the *Asterias National Control Plan* developed in 2008.

European green crab

The introduced European green crab, *Carcinus maenas* was first recorded in Port Phillip Bay, Victoria, in the late 1800s, apparently introduced in the dry ballast of wooden vessels from Europe (Hobday *et al*. 2008). In 1993, it was discovered in north-eastern Tasmania (Gardner *et al*. 1994), where its pelagic larval form may have been transported to Tasmania via a strengthening East Australian Current due to climate change. It is thought that in 2002 *Carcinus* spread to populate the entire east coast of Tasmania (Hobday *et al*. 2008) and is now prevalent in the Derwent estuary, where it may cause significant impact on native benthic organisms (Walton *et al*. 2002). *Carcinus maenas* is an aggressive inshore predator and the spread may cause a decline in the abundance of native bivalves in subtidal areas, and virtual elimination of many native Tasmanian inshore crabs species (Walton *et al*. 2002).

11.1.2 National and state management framework and initiatives

In recognition that an integrated and coordinated approach is required to tackle the marine pest problem, a national system has been developed for the prevention and management of marine pest incursions. The national system has three major components:

1) Prevention: systems to reduce the risk of introduction and translocation of marine pests (including management arrangements for ballast water and biofouling).
2) Emergency response: a coordinated emergency response to new incursions and translocations.

3) Ongoing control and management: managing introduced marine pests already in Australia, where eradication is not feasible.

The National Introduced Marine Pest Coordinating Group (NIMPCG) is the group responsible for implementing the National System chaired by the Australian Governments Department of Agriculture, Fisheries and Forestry (DAFF). NIMPCG includes representatives from the Australian Government, State and Northern Territory Governments, marine researchers, industry and conservation. In Tasmania, the Department of Primary Industries, Parks, Water and Environment (DPIPWE) is the lead agency for the management of marine pests. An overview of the National System and implications for management of the Derwent estuary is provided in Whitehead (2008).

In 2001, the Australia Government introduced mandatory ballast water management requirements for all vessels entering Australian waters. International vessels must exchange ballast water at sea in accordance with these requirements before entering Australian waters. Under the national system, a risk-based system to manage domestic ballast water is currently being developed. A National Monitoring Network is also being developed to provide timely detection of marine pest incursions and to feed into the ballast water risk tables. Hobart is the only location in Tasmania included in the National Monitoring Network.

In 2008 *National Control Plans* for six agreed marine pests were endorsed by NIMPCG. Four of these species (the northern Pacific seastar *(Asterias amurensis*), European green crab (*Carcinus maenas*), Japanese seaweed (*Undaria pinnatifida*), and European clam (*Varicorbula gibba*) are found in the Derwent estuary. The control plans contain a comprehensive review of impacts (environmental, economic, and social), distribution, vectors for translocation, recommendations for the prevention of new infestations, and options for emergency and ongoing management (based on a review of research and previous control measures). Management frameworks are also outlined, and in some instance management costs have been estimated. *National Control Plans* have also been endorsed for the European fan worm (*Sabella spallanzanii*) and Asian bag mussel (*Musculista senhousia*); however, these species have not been recorded within the Derwent estuary.

11.1.3 Derwent Estuary Program management priorities

The DEP undertook a workshop with local experts and managers of introduced marine and intertidal species in November 2008. The workshop was attended by representatives from CSIRO, University of Tasmania, Tasmanian Aquaculture and Fisheries Institute (TAFI), State Government, Aquenal Pty Ltd and DAFF. Based on the workshop outcomes, several key management priorities were identified, as described below:

Priority 1. Eradicate rice grass from the Derwent

Rice grass *Spartina anglica* is a vigorous salt marsh plant that typically inhabits the upper intertidal zone of temperate estuaries. Rice grass was introduced to the Tamar estuary in 1947 with the goal of stabilising mudflats, reclaiming intertidal lands and improving navigation. The plant spread rapidly throughout the estuary, and subsequently to other parts of the state (largely due to deliberate introduction through the 1940s to 1970s) including the Derwent estuary. In 1995, DPIWE staff documented approximately two hectares of *Spartina* in the middle and upper reaches of the Derwent and noted that rice grass has the potential to invade 180 ha of intertidal habitat in the Derwent estuary region. Infestations have the potential to dramatically alter the ecological and natural heritage of the estuary by modifying the distribution and habits of a range of resident flora and fauna, including shorebirds, fish, invertebrates, seagrasses and saltmarsh. Infestations progressively invade the immediate and surrounding area of intertidal zones altering estuarine sediment dynamics, affecting navigation and tourism. Rice grass may also inhibit coastal access and use, and detrimentally affect recreational fishing and boating.

Regular surveys and treatment (spraying with Fusilade Forte) of Derwent estuary rice grass has been carried out for over a decade by staff from Department of Primary Industries and Water (DPIW) with assistance from the DEP. By January 2009 this effort had reduced the known area to about 4 m^2 distributed over several sites in the middle to upper estuary. *Spartina angelica* seed can remain viable for up to six years after flowering, and as a consequence a long term monitoring program is required until any occurrences can be declared 'successfully eradicated'. The first survey of habitats up-river of the Bridgewater causeway was carried out by the DEP in 2008 and no *Spartina* was observed. *Spartina* eradication from the estuary is an achievable management objective in the Derwent estuary, and has been identified as a high priority by the DEP. Recent control has been undertake in partnership with DPIPWE and has been supported by Natural Heritage Trust funding. Further control efforts until 2011 will be coordinated by the DEP, with the support of Australian Government Community Coastcare funding.

Priority 2. Prevent new introductions into and out of the Derwent estuary.

Although the Derwent estuary already has at least 79 introduced species, there is the potential for many more species to be accidentally introduced to the estuary from shipping ballast water, hull fouling, unclean or wet fishing gear, dive gear, or boating equipment. The Derwent estuary also poses a high risk to other areas within Tasmania. For example, boating traffic from the Derwent (heavily infested with marine pests), could inadvertently translocate these species to pristine areas such as Port Davey and Bathhurst Harbour.

Multiple approaches are required to reduce the risk of new species introduction into, and out of, the Derwent estuary. They include:

- Education and awareness raising (e.g. even wet diving equipment poses a risk of transporting microscopic larvae of introduced species to new sites).
- Monitoring for new introductions and triggering a quick control response if new species are found. In particular the introduced species: Asian bag mussels (*Musculista senhousia*), European fan worm (*Sabella spallanzanii*) and Eastern mosquito fish (*Gambusia holbrooki*), are found in northern Tasmania but are absent from the Derwent estuary. These species may pose a high risk of potential introduction. Monitoring should also include the ecological impacts arising from current introduced species.
- Providing physical management options to collect and dispose of biofouling wastes at slipways, marinas (e.g. boat cleaning and disposal facilities) and commercial sites (e.g. aquaculture net maintenance areas) in the Derwent.

Priority 3. Control Pacific oyster populations at strategic locations.

The Pacific oyster *Crassostrea gigas* was deliberately introduced to southern Tasmania in 1947 to establish the oyster aquaculture industry, following the collapse of the wild native oyster (*Ostrea angasi*) fishery (Mitchell *et al*. 2000). Initial introduction to Tasmania was trialled in Pittwater, east of the Derwent estuary, however, this population did not grow successfully. Later introductions were made in North West Bay, northern d'Entrecasteaux Channel in 1963 (Mitchell *et al*. 2000), and may have initiated the spread into the adjacent Derwent estuary. Although the commercial introduction of the Pacific oyster has had important economic benefits for southern Australia, the adverse effects of the oysters include: loss of coastal aesthetic and amenity value due to large and often dense intertidal settlements, organic enrichment of sediments (due to oyster faeces), risk of injury to coastal marine users, and damage to property (due to sharp edges of oysters).

A survey was undertaken during spring-summer 1999-2000 around mainland Tasmania (including the Derwent estuary) to record baseline data on the distribution and abundance of feral Pacific oysters and to describe the environmental conditions that they inhabit. A photographic record was taken of each site and estimates of oyster densities and size ranges were recorded (Mitchell *et al*. 2000). In the Derwent, boat ramps and jetties, rocky shore diving and snorkelling sites, and rocky shore dog walking areas are some examples of amenities impacted by Pacific oyster growth. Derwent estuary control of Pacific oyster has been largely community driven through the efforts of groups such as the Tranmere-Clarence Plains Land and Coastcare group. This and similar groups could be encouraged to target control in those areas with high natural, social and aesthetic value. It may be possible to compare areas of high public amenity and high environmental values at risk from Pacific oysters, with the 1999-2000 oyster distribution map to gauge priority areas for potential management. The importance of community involvement in Pacific oyster monitoring was also noted by the first state-wide survey organisers, Mitchell *et al*. (2000). This state-wide survey included the development of community based monitoring field sheets and a training session for Fishcare volunteers. The Southern Coastcare Association of Tasmania has recently received a Tasmanian Community Fund Grant to support further Pacific oyster control projects in the region.

11.2 Derwent estuary foreshore weeds

The Derwent estuary foreshore supports a wide variety of environmental weeds that have invaded and threaten the survival of native plants and animals, and have negative effects on social, economic and conservation values. Weeds found around the foreshore include Weeds of National Significance (WoNS), many state-listed declared weed species and the invasive intertidal rice grass (*Spartina anglica*), which poses a serious risk to tidal flat communities and protected wading birds (**Section 9.0**).

Foreshore vegetation surveys around the estuary have identified 44 species of environmental weeds within a 100 m zone landward of the high watermark (**Table 11.2**). Weeds are present in 10.7 km^2 of the 23.2 km^2 total area surveyed (100 m swath from high water mark) and absent from 10.9 km^2 (1.58 km^2 was not surveyed for weeds). Some of the more common weeds found include:

Table 11.2: Environmental and declared weeds recorded along the Derwent estuary foreshore

Common Name	**Scientific name**	**Declared or environmental weed**	**Area of weeds present (km^2)**
african boxthorn	*Lycium ferocissimum*	Declared weed	4.81
banana passionfruit	*Passiflora tarminiana*	Environmental weed	0.04
blackberry	*Rubus fruticosus aggregate*	Declared weed (WoNS)	2.85
blue butterfly bush	*Psoralea pinnata*	Environmental weed	0.02
boneseed	*Chrysanthemoides monilifer subsp. monilifera*	Declared weed (WoNS)	3.48
briar rose	*Rosa rubiginosa*	Environmental weed	1.72
bridal creeper	*Asparagus asparagoides*	Declared weed (WoNS)	n/a
californian thistle	*Cirsium arvense*	Declared weed	0.03
cape ivy	*Delairea odorata*	Environmental weed	0.07
Cape Leeuwin wattle	*Paraserianthes lophantha*	Environmental weed	0.19
Chilean needle grass	*Nassella neesiana*	Declared weed (WoNS)	n/a
coast teatree	*Leptospermum laevigatum*	Environmental weed	0.02
cootamundra wattle	*Acacia baileyana*	Environmental weed	0.13
cotoneaster	*Cotoneaster sp.*	Environmental weed	0.71
crack willow	*Salix fragilis*	Declared weed (WoNS)	1.04
cumbungi	*Typha latifolia*	Environmental weed	0.04
english broom	*Cytisus scoparius*	Declared weed	0.03
fennel	*Foeniculum vulgare*	Declared weed	3.27
fuchsia	*Fuchsia magellanica*	Environmental weed	0.05
gorse	*Ulex europaeus*	Declared weed (WoNS)	0.29
hawthorn	*Crataegus monogyna*	Environmental weed	0.55
horehound	*Marrubium vulgare*	Declared weed	0.01
ivy	*Hedera helix*	Environmental weed	0.08
Japanese honeysuckle	*Lonicera japonica*	Environmental weed	0.02
marram grass	*Ammophila arenaria*	Environmental weed	1.47
mirror bush	*Coprosma repens*	Environmental weed	0.70
montbretia	*Crocosmia xcrocosmiiflora*	Environmental weed	0.02
montpellier broom	*Genista monspessulana*	Declared weed	0.65
myrtle-leaf milkwort	*Polygala myrtifolia*	Environmental weed	0.05
pampas grass	*Cortaderia selloana*	Environmental weed	0.01
passion fruit	*Passiflora sp*	Environmental weed	0.01
periwinkle	*Vinca major*	Environmental weed	0.22
radiata pine	*Pinus radiata*	Environmental weed	2.02
red valerian	*Centranthus ruber*	Environmental weed	0.05
rice grass	*Spartina anglica*	Environmental weed	0.004
scrambling groundsel	*Senecio angulatus*	Environmental weed	0.05
serrated tussock	*Nassella trichotoma*	Declared weed (WoNS)	0.05
spanish heath	*Erica lusitanica*	Declared weed	0.12
sweet pittosporum	*Pittosporum undulatum*	Environmental weed	0.29
trailing daisy	*Osteospermum fruticosum*	Environmental weed	0.56
tree lucerne	*Chamaecytisus palmensis*	Environmental weed	0.17
wandering jew	*Tradescantia fluminensis*	Environmental weed	0.03
white weed	*Cardaria draba*	Declared weed	0.01
willow (see also cracked willow)	Salix species	Declared (WoNS)/ Environmental weed	0.15

African boxthorn, blackberry, boneseed, briar rose, crack willow, fennel, marram grass and radiata pine.

There are 15 declared weeds species along the Derwent foreshore, as listed under the *Tasmanian Weed Management Act 1999*. The legal status of declared weeds requires landowners and managers to eradicate or control them, depending on the zoning for each particular weed under the Act. Seven of the declared weeds are also WoNS, as listed in the Australian Weed Strategy (Australian Weeds Committee, revised 2008): blackberry, boneseed, gorse, serrated tussock, willow, Chilean needle grass and bridal creeper. There are a total of 20 declared WoNS in Australia and these are considered to be the country's worst invasive plants. Each WoNS has a national strategy with actions to improve their management.

Several nationally strategic WoNS projects are being implemented in the Derwent estuary that focus on the management of bridal creeper, boneseed, Chilean needle grass, serrated tussock, seeding willows and gorse at key locations. Programs for boneseed, bridal creeper and serrated tussock run until November 2009 and programs for seeding willows and Chilean needle grass ended in June 2009. An eradication program for bridal creeper is in its second year, as is the boneseed program, which focuses on eradication of outlier patches, protecting the Derwent estuary (New Norfolk area) and the Pittwater and Orielton Lagoon area, and setting and progressing national containment lines. The Chilean needle grass program treated all known infestations during 2008-09 and carried out some additional surveying and mapping. In partnership with the DPIPWE and the National Chilean needle grass coordinator, foreshore signage is also under development for the Montagu Bay foreshore area.

Various Coastcare community groups have also conducted weed management works along the foreshore, with several groups involved in on-going maintenance for more effective control.

A number of State weed-specific strategies have been produced as have regional, local government and site-specific weed plans that have assisted weed management in the Derwent estuary. For example, the *Southern Tasmanian Weed Strategy 2005-2010* (Schrammeyer 2005) provides a framework to identify and consolidate weed management issues in the southern Natural Resource Management (NRM South) region including the Derwent estuary, and sets strategic actions and outcomes. Through this Strategy, available data on 30 priority weeds has been compiled and maps produced for the NRM South region to facilitate the monitoring and evaluation of future management activities.

A Derwent-specific weed strategy will be developed in 2009-10 to support the various management activities taking place at sites around the foreshore. It will compile and integrate existing information to produce a Derwent foreshore weed strategy focusing on eradication of key weeds (e.g. rice grass) and management of weeds affecting high conservation value areas. Key outcomes include a prioritised weed management action list and recommendations for weed management in high conservation value areas.

12.0 CLIMATE CHANGE

Future climate change will impact upon the natural environment, infrastructure and heritage values of the Derwent estuary. In 2007, the United Nations Intergovernmental Panel on Climate Change (IPCC) issued their *Fourth Assessment Report* to better inform the global community of the expected consequences of anthropogenic greenhouse gas emissions (IPCC 2007). The IPCC report defined a range of future emissions scenarios and used global climate computer models to project impacts associated with each scenario. A number of scientists have noted, however, that recent greenhouse gas emission levels already exceed all of the IPCC future scenarios (Garnaut 2008), and as such the climate change projections carried out to date may underestimate the impacts to the Derwent estuary.

In 2008, the Derwent Estuary Program (DEP) prepared a discussion paper on climate change impacts on the Derwent estuary. The paper reviewed recent studies and initiatives with a focus on climate change impacts to natural habitats, species and water quality in the estuary (Whitehead 2008). This section summarises the paper's main findings and the full paper is available on the DEP website at www.derwentestuary.org.au (go to 'Monitoring and Science').

12.1 Regional climate change projections

Several high resolution models have recently been developed at national and regional scales that provide insights into possible future climate change impacts on the Derwent estuary, as summarised below:

- Australian climate change projections have been modelled on a coarse resolution grid spacing of approximately 300 km x 300 km (CSIRO 2007), enabling a regional Hobart assessment that is relevant to 2030 and 2070 based upon three IPCC scenarios: a 'medium' 2030 prediction (A1B), as well as 'low' (B1) and 'high' (A1FI) 2070 predictions.
- A higher resolution Tasmanian climate change modelling study at 14 km grid squares was undertaken by Hydro Tasmania, the Tasmanian Partnership for Advanced Computing (TPAC) and CSIRO (reported in McIntosh *et al*. (2005)). This study applied the IPCC A2 greenhouse gas emission scenario and was projected to 2040, which is comparable to the 'medium' greenhouse gas emissions scenario A1B over this same time period.
- More recently, the Hobart-based Antarctic Climate Ecosystem Co-operative Research Centre (ACE CRC) has initiated a Climate Futures for Tasmania project that will build on previous Tasmanian climate modelling research to produce local scale climate projections for Tasmania under a range of accepted greenhouse gas emission scenarios. Analyses will be undertaken at fine scale 10-15 km grid cell resolution and will focus on future: a) water status in catchments and reservoirs; b) normal, average climate conditions; and c) extreme events, including high winds, flooding, and coastal inundation.

12.2 Projected climate change impacts on the Derwent estuary

The studies described above project a number of climate-change impacts on the Derwent estuary, including changes in air and water temperatures, rainfall and river flow, wind and storm events, marine currents, as well as sea level rise and shoreline erosion. To increase the resilience of the Derwent estuary's natural environment to climate change, there is a need to reduce anthropogenic causes of environmental stress. In areas of conflict between the protection of social, economic and natural values, we must increase our knowledge and understanding of the risks posed and the management options available.

12.2.1 Meteorology and river flow

Based on recent high-resolution modelling (McIntosh *et al*. 2005) which assumes a 'medium' greenhouse gas emissions scenario, it is predicted that by 2040 the Derwent region will experience a general trend of increasing rainfall intensity during storm events that may also become more frequent. The models also predict an increase in average wind speeds and increased frequency of high wind events. Climate change influences on the net flow of the River Derwent are difficult to predict, and further research is required in this area. However, it is possible that increased water use (e.g. irrigation of drier agricultural areas, in part a consequence of climate change) could contribute to a net reduced River Derwent flow to the estuary.

The model also predicts climate change-related variations in seasonal conditions by 2040, as summarised below:

- ***Autumn*** **–** decreased rainfall. In areas of less cloud development, an increase in surface water solar irradiation is also predicted.
- ***Winter and early spring*** **–** strong winds and an increase in minimum (overnight) temperature. An increase in rainfall in late winter (peaking in August), continuing into the spring is predicted.

- ***Early summer*** **–** strong winds and an increase in minimum (overnight) temperature.
- ***Summer*** **–** warmer water and lower nutrient levels are predicted at the entrance of the estuary due to a strengthened East Australian Current (EAC). Development of water stratification will depend on wind condition in summer and autumn. A decrease in rainfall is also predicted and in areas of less cloud development there will also be an increase in surface water solar irradiation.

Understanding how rainfall parameters (amount and intensity, spatial and seasonal distribution, and evaporation) will change is important for managing urban stormwater runoff. There is potential for increased urban stormwater infrastructure problems if there is an increased frequency of intense rainfall events, especially if current infrastructure has been designed for different storm intensity and frequency to that expected in the future. Urban streams and waterways, which are drainage conduits for urban runoff, could experience increased high intensity flow events and sediment erosion. Increased sediment loading may then occur in some Derwent estuary bays that receive water from urban streams and water ways. Sediment is often bound to various water pollutants, which can be released under certain depositional conditions. Wet weather around Hobart typically brings high amounts of freshwater surface runoff, increased turbidity from silt, faecal bacteria, nutrients, oil, heavy metals and litter to the estuary (**Section 4**).

12.2.2 Ocean temperature and currents

Pronounced impacts are predicted in the marine and coastal environment due to climate change. A 60 year record of water temperature near Maria Island, off the East Coast of Tasmania, already shows significant warming of 0.15°C per decade at both the sea surface and at 50 m depth. The largest increases (0.3°C per decade) were during the months of November to May, when the EAC extends into Tasmanian waters (Ridgeway and Godfrey 1997). These observations are consistent with climate models projections, which suggest a strengthening of the EAC, with warmer water penetrating down the East Coast of Tasmanian (Hobday *et al*. 2006a, 2006b, 2006c) that can also influence conditions in Storm Bay and the Derwent estuary. Climate models project a 1°C to 2°C rise in sea surface temperature off the Tasmanian East Coast by 2070, if 'medium to high' green house gas emissions occur (Hobday *et al*. 2006a).

The warming waters off eastern Tasmanian and the strengthening southward movement of the EAC is causing a southward shift or range extension amongst many marine species – both native and introduced – with potentially serious implications for regional marine ecosystems, fisheries and aquaculture. For example:

- The algal dinoflagellate *Noctiluca scintillans* was first observed in Tasmanian waters in 1994 having been transported here by the EAC from the mainland. Since 2003 it can be found all year round in the water column in southern Tasmania (Ajani *et al*. 2001, Albinsson *et al*. 2006), including the Derwent estuary, where it causes pink algal blooms on the water surface.
- The European green crab, *Carcinus maenas* – a serious marine pest – is thought to have recently spread down the East Coast of Tasmania as pelagic larvae carried by the EAC, and is now present in the Derwent estuary where it has the potential to cause serious impacts on native benthic organisms (Walton *et al*. 2002). See **Section 11.1.1** for details.

12.2.3 Sea-level rise

A range of global sea-level increases have been projected for different greenhouse gas emission scenarios. For example the IPCC 2007 'high' emissions scenario (A1Fl) is predicted to cause a global sea-level rise of about 0.8 m by 2100. However, as noted previously, greenhouse gas emissions trends already exceed the A1Fl scenario levels and some scientists predict considerably greater rates of global sea-level rise. For example, recent publications suggests that a rise of up to 1.4 m is possible by 2100 (Church *et al*. 2008), or even as much as 2 m (Pfeffer *et al*. 2008). Global sea-level rise is also influenced by localised conditions arising from tides, storm surges, rain-runoff/flooding and wind waves, some of which may also be modified by climate change.

A number of recent studies have been carried out to better quantify future sea-level inundation risks in Tasmania, with a focus on major population centres and associated infrastructure, these include:

- Projections of future sea-level rise under different greenhouse gas emission scenarios have been undertaken by Sharples (2006) and Hunter (2008). Their projections are based on the combination of global sea-level rise in combination with episodic and localised extreme rises in sea-level associated with storm surges. Storm surges occur when a number of different factors may combine, such as: low atmospheric pressure, onshore winds, high tide, and high rainfall runoff from the land into the coastal zone (DPIW 2008).
- The Sharples (2006) 2100 sea-level and storm surge predictions have been used to undertake a GIS map-based assessment of the amount of coastal area in Tasmania (in hectares), and the different asset types that may be impacted by sea-level rise. This assessment includes all of the municipalities bordering the Derwent estuary (DPIW 2008).

- The Hunter (2008) report provides further detail on sea-level extremes for Hobart, from 2000 to 2040 and 2100. A summary and practical guide has been created for planners and managers by staff of the former Department of Primary Industries and Water (DPIW 2008), based on the Hunter (2008) study.
- The sea-level rise projections in Hunter (2008) could be used to undertake further assessment of inundation risk if combined with recently produced high resolution coastal topographic data. This topographic data has been made available for the greater Hobart area to an elevation of up to 10 m above sea-level (with +/- 0.25 m vertical and horizontal accuracy), collected for the State Emergency Service using light detection and ranging (LIDAR) techniques.

It is important to note that the sea-level heights projected in Hunter (2008) and Sharples (2006), are based on still-water conditions, and have not incorporated localised wave information. Changes in wind climate, shoreline topography and nearshore bathymetry can have dramatic impacts on wave conditions, which can exacerbate impacts from sea-level rise. This may increase inundation risk, as well as coastal erosion in susceptible areas. Several recent studies have investigated coastal erosion risks, as described below:

- The vulnerability of the Derwent estuary coastline to climate change has been coarsely mapped (see Foreshore climate change vulnerability NRM South – on the LIST website http://www.thelist.tas.gov.au/).
- Detailed inundation and coastal erosion risk projections have been undertaken under a greenhouse future for several locations within the Clarence municipality bordering the Derwent estuary (Carley *et al*. 2008, Clarence City Council 2008).
- The University of Tasmania and ACE-CRC have initiated the *TAsmanian Shoreline Monitoring and ARChiving* (TASMARC) project, which provides training and equipment to volunteer community groups to survey the profile of beach and dunes in areas that are vulnerable to coastal erosion (Hennecke *et al*. 2004, http://www.tasmarc.info). A number of sites in the Lauderdale and South Arm areas are being surveyed as part of this project.

In undeveloped areas, some coastal and shallow estuarine habitats may be able to adjust to rising sea-level by moving up-river or inland, as current habitat areas become inundated. In coastal areas where human development and land use prevents this transgressive movement, these habitats may become reduced in area and eventually lost. This phenomenon has been called 'coastal squeeze' (Doody 2004), and may potentially affect a range of habitats around the Derwent estuary, such as wetlands, saltmarshes, intertidal sand and mudflats, beaches, penguin rookeries and rocky shores. In particular, there are approximately 156 hectares of saltmarsh and approximately 488 hectares of wetland around the margins of the Derwent estuary that may be susceptible to sea-level rise and coastal squeeze. Some areas of particular concern are described below:

- The saltmarsh at Lauderdale provides habitat for the Tasmanian endemic saltmarsh looper moth *Dasybela achroa*, which is listed as vulnerable under the Tasmanian *Threatened Species Protection Act 1995*. Only three occurrences of this moth have been observed outside of the Lauderdale saltmarsh, and as such this saltmarsh is a critical location for this species. The Lauderdale saltmarsh is projected to be increasingly inundated by the sea in the future (Clarence City Council 2008), and it is unclear if appropriate new saltmarsh habitat will establish nearby to sustain this species.
- The extent of intertidal sand and mudflat habitat in the estuary may also decline in the future due to climate change, unless deposition rates keep pace with sea-level rise. There are currently about 1,000 hectares of intertidal sand flats in Ralphs Bay that provide important habitat for wading shorebirds, as discussed in **Section 9.0**. The extent and suitability of future wading bird habitat in the Derwent estuary is as yet unknown.

12.3 State and regional management initiatives

All levels of government are working towards strategies to address the causes of climate change and to mitigate the impacts. These initiatives are reviewed in the DEP Climate Change paper (Whitehead 2008). Further detail on local government initiatives, including DEP council partners, can be found at the Local Government Association of Tasmania (LGAT) website: http://www.lgat.tas.gov.au.

13.0 SUMMARY AND RECOMMENDATIONS

The Derwent estuary, together with Mt Wellington, provide an idyllic natural setting for the city of Hobart, Tasmania's capital city. The estuary is heavily used for recreation, marine transportation, boating and fishing, and is internationally known as the venue for the Sydney-to-Hobart yacht race. The Derwent is Tasmania's fourth largest port, and has been an important centre for industrial development. Despite a long history of environmental degradation, the Derwent estuary is still an important and productive ecosystem, which requires careful and committed management if its natural values are to be enhanced and maintained in perpetuity.

The environmental quality of the Derwent estuary is a function of its physical setting together with historic and recent inputs of pollutants. The physical features play an important and often controlling role in the ultimate fate and distribution of contaminants. The Derwent is a relatively deep, micro-tidal estuary, which is highly stratified in its upper reaches, and well mixed in its broad lower reaches. Estuarine circulation is characterised by a relatively short residence time (approximately 12 days), and a large and consistent freshwater input from the River Derwent. Net freshwater surface flows are downstream, while saline bottom water travels slowly upstream. The Derwent is affected by strong seasonal influences – temperatures, coastal currents, winds and other factors – that ultimately affect water quality. The catchment of the River Derwent is large and sparsely populated, with generally good water quality. However, flows are strongly regulated for hydroelectric power generation and overall yields have decreased in recent years.

Since Hobart was established at Sullivans Cove in 1804, the Derwent estuary has received the majority of the city's urban and industrial wastewater, much of which was untreated or poorly treated until the 1980s and 1990s. Contaminants associated with wastewater discharges have included pathogens, nutrients, organic matter, suspended sediments, heavy metals, resin acids, hydrocarbons and other organic compounds. There have been significant decreases in most end-of-pipe emissions over the past 10 to 20 years, particularly as a result of sewage treatment plant upgrades, effluent reuse and improved treatment of wastewater from major industries.

Six years on from the publication of the previous *State of the Derwent Estuary* report, there have been a number of major advances in monitoring, reporting and system understanding, as well as on-ground actions that have significantly reduced pollutant loads. The following sections summarise major advances associated with monitoring, reporting and system understanding and identify some key areas where further information and understanding is recommended. Further discussion of key issues and recommended management actions is provided in the *Derwent Estuary Environmental Management Plan* (2009).

General recommendations for monitoring, investigations and reporting include the following:
- Review, enhance and rationalise current monitoring of pollutant discharges associated with wastewater treatment plants, industries (including monitoring and trade waste audits for small and medium-sized premises) and landfills.
- Review and enhance monitoring of the River Derwent between Meadowbank Dam and New Norfolk to better quantify flows and inputs to the estuary.
- Recommence regional rivulet and stormwater monitoring and incorporate event monitoring.
- Integrate monitoring, modeling and reporting across the Derwent catchment, estuary and D'Entrecasteaux Channel/Storm Bay system.
- Maintain and enhance existing water quality programs in the Derwent estuary (ambient and recreational water quality).
- Carry out a whole-of-estuary sediment survey to evaluate changes in sediment quality since the last full survey in 2000.

13.1 Recreational water quality

The Derwent Estuary Program (DEP) recreational water quality monitoring program was one of the first in Australia to adapt to new guidelines and reporting standards as set out in the *Guidelines for Managing Risks in Recreational Water* (NH&MRC 2005). The DEP modified the Derwent monitoring program to incorporate new indicators, methods and reporting systems that are consistent with both the NH&MRC and the *Tasmanian Recreational Water Quality Guidelines*. Improvements to recreational water quality reporting and awareness-raising include weekly *Beach Watch* snapshots published in *The Mercury* newspaper and DEP website, innovative signage and community service announcements. Despite more stringent guidelines, water quality has improved at most Derwent swimming beaches since 2003, although this may be related to dry weather conditions in recent years.

Recommendations for further monitoring, investigations and reporting include:
- Site specific investigations at key swimming beaches (e.g. Howrah east) and bays (e.g. Cornelian Bay and Marieville Esplanade) to identify and address sources of faecal contamination.

- Rainfall response monitoring and predictive modeling to improve understanding of stormwater influences on recreational water quality.
- Stormwater and sewage infrastructure monitoring, to identify potential sources of contamination, including the use of tracers.
- Monitor the effectiveness of new urban stormwater systems in the treatment and removal of faecal contamination and other pollutants.
- Update and enhance recreational water quality signage, web and newspaper reporting.

13.2 Heavy metals and other toxicants

The Derwent Estuary Water Quality Improvement Plan (WQIP) for Heavy Metals and other related investigations have resulted in major improvements in our understanding of heavy metal sources, sinks and impacts. In particular, studies of sediment processes, sediment toxicity and benthic community structure have been particularly valuable in understanding heavy metal contamination in the estuary. Furthermore, the potential risk of remobilisation of heavy metals from sediments has been identified, which may result from low dissolved oxygen levels within bottom waters, as well as oxidation of sediment-bound heavy metals due to sediment disturbance. Detailed hydrodynamic, sediment, and zinc transport models developed by CSIRO have also enhanced predictive capacity and underpin system-wide decision support systems.

Seafood safety studies have been extended to include a wider range of recreationally targeted fish. Improved public awareness of heavy metal levels in shellfish and fish has been achieved through brochures, web-based information, and community service announcements.

On-ground works to reduce heavy metal loads to the Derwent have included construction of a 15 ML stormwater collection/treatment system at the Nyrstar Hobart zinc smelter and extension of the groundwater extraction system to intercept major contaminant plumes.

Recommendations for further monitoring, investigations and reporting include:

- Greater focus on mercury bioaccumulation with respect to seafood safety and food-chain pathway investigations.
- Extension of recreational fishing surveys to assess heavy metal contamination in different species and across a greater geographical range, using larger population samples.
- Update public information on seafood safety on a regular basis and as new information emerges.
- Investigate further options to capture and treat contaminated ground and surface water at the Nyrstar smelter site.
- Develop a priority list for site specific investigations of historic foreshore tips, contaminated sites and fuel storage areas as potential sources of heavy metals and other toxicants.

13.3 Nutrients and organic matter

The stage 2 WQIP greatly extended our understanding of nutrient sources, sinks and processes in the Derwent, and the associated biogeochemical model has greatly improved our capacity to predict how alternative management scenarios may affect the estuary. Key findings include the relative importance of both catchment and marine sources of nutrients (including aquaculture), and the potential for these sources to offset recent reductions in sewage-derived loads if not carefully managed. Also identified, is the critical role played by denitrification in maintaining estuarine health, the strong influence of changing river flows and as well as the links between nutrient loading, dissolved oxygen levels and the stability of sediment-bound heavy metals.

Since 2003, on-ground works to reduce nutrient loads to the Derwent have primarily been the result of effluent reuse schemes in Clarence. Improvements to the Norske Skog effluent treatment plant have also resulted in a > 80% reduction in organic loads to the upper estuary, starting in October 2007.

Recommendations for further monitoring, investigations and reporting include:

- Investigate the role of sediments in nutrient processing, including identification of areas with high nutrient removal capacity.
- Investigate how river flows influence nutrient status, including testing a wider range of river flow and pollutant loading scenarios.
- Investigate catchment-estuary-channel links in relation to nutrient sources, transport and cycling.
- Investigate further opportunities for effluent reuse, including long-term viability.

13.4 Estuarine habitats and species

A number of important surveys and investigations into Derwent estuary habitats and species have been conducted since 2003 or are currently underway, including detailed mapping of foreshore vegetation, wetlands, saltmarshes, seagrasses and rocky reef communities. Much of this information has been compiled into a *Derwent Estuary Habitat Atlas*, and is available via the LIST website. Other key studies and investigations have included surveys of benthic invertebrate communities, various studies of Ralphs Bay flora and fauna, and investigations or surveys of key species (e.g. little penguins and spotted handfish).

Recommendations for further monitoring, investigations and reporting include:

- Develop and monitor a representative suite of biological indicators of estuarine health, including both habitat and species indicators.
- Monitor the extent and condition of key habitat types (e.g. seagrass and aquatic macrophytes, rocky reefs, soft sediments), and progressively refine monitoring methods.
- Commence regular monitoring of primary production (e.g. phytoplankton, microphytobenthos, macroalgae and epiphytes) for temporal and spatial changes in species composition and biomass.
- Investigate conditions required to sustain key habitat types and coverage (e.g. upper Derwent aquatic macrophyte beds and wetlands).
- Monitor populations and breeding success of key species (e.g. little penguins, spotted handfish, migratory fish, waterfowl, wading birds).
- Investigate conditions required for breeding success of key species (e.g. black bream).
- Assess impacts of river and stream barriers to migratory fish and develop a strategy to improve migration and breeding success.
- Monitor the impact of introduced species (e.g. marine pests and foreshore weeds) and assist in developing management objectives and plans where appropriate.
- Continue monitoring and treatment of rice grass.
- Education and awareness – improve community and environmental managers' understanding of native species and habitats.
- Promote community awareness and understanding to help prevent translocation of current, and the introduction of new introduced species.

13.5 Climate change and sea-level rise

A number of recent studies have provided baseline information including light detection and ranging (LIDAR) mapping, shoreline vulnerability assessment, and development of sea-level rise curves. Recent work undertaken in the Clarence municipality provides an excellent model for risk assessment associated with sea-level rise.

Recommendations for further monitoring, investigations and reporting include:

- Extend the Clarence municipality climate study approach to the rest of the Derwent estuary.
- Assess coastal inundation and erosion risk to sewage and stormwater infrastructure, which may impact upon Derwent estuary water quality.
- Monitor shoreline position along highly vulnerable shorelines.
- Investigate risks to key habitat types and identify mitigation options. In particular, identify and assess areas where future habitats may colonise or be sustained (e.g. wetlands and saltmarshes) as the impacts of climate change and sea-level rise on current habitats increases.
- Use LIDAR, and other techniques, to assess changes within critical habitats (e.g. changes in wetland elevation (erosion and deposition).

13.6 Recommendations from the 2009 Derwent Science – Management Symposium

The Derwent Estuary Science – Management Symposium (November 2009) concluded with a panel session that explored current and emerging management issues facing the Derwent estuary and identified critical information gaps needed to address these. The panel discussion is summarised in the Conference Proceedings (see www.derwentestuary.org.au) for details, however the key 'take home messages' are also reproduced here:

- It was proposed that we need a substantial community debate and a long-term vision for the Derwent, but that this debate needs to be grounded on good scientific understanding. What kind of Derwent do we want? What can we reasonably expect to have?
- The panel and audience emphasised that we cannot fully replace ecosystems or the services they provide (e.g. wetlands, tidal flats, nutrient processing and denitrification). A strategic approach is needed to manage and conserve these assets and services for future generations.
- Things keep changing. We need to plan for population growth, climate change and natural variability and anticipate this variability within our planning and management systems.
- Catchment and marine issues should to play a more central role in the DEP priorities, including environmental flows, fire management and aquaculture development.
- We need to develop a better understanding of the role of sediments within the estuary, and system links between water, sediments and ecology.
- It was recognised that strong partnerships have been a key factor in the DEP's success and it was recommended that these partnerships be extended to include new partners and adjacent regions.

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