STATE of the DERWENT ESTUARY 2015






A review of environmental data from 2009 to 2014

Derwent Estuary Program

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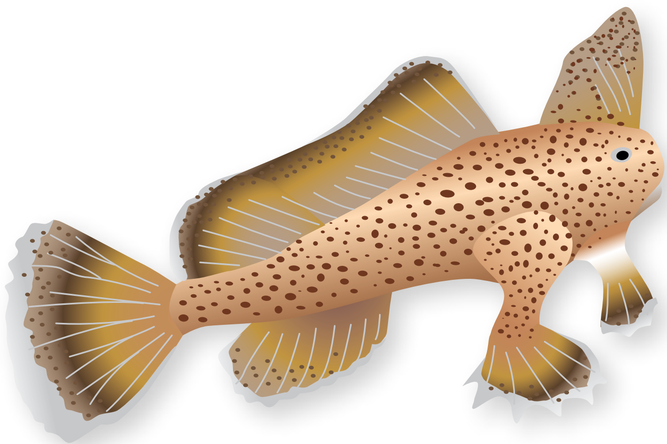

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The Derwent Estuary Program (DEP) is a regional partnership between local governments, the Tasmanian state government, businesses, scientists and the community to restore and promote our estuary.

The DEP was established in 1999 and has been nationally recognised for excellence in coordinating initiatives to reduce water pollution, conserve habitats and species, monitor river health and promote greater use and enjoyment of the foreshore. Our major sponsors include: Brighton, Clarence, Derwent Valley, Glenorchy, Hobart and Kingborough councils, the Tasmanian State Government, TasWater, Tasmanian Ports Corporation, Norske Skog Boyer, Hydro Tasmania and Nyrstar Hobart. We also work collaboratively on projects with the CSIRO Marine and Atmospheric Research, University of Tasmania, Institute of Marine and Antarctic Studies and NRM South.

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Cover photography: all photos by DEP, except bastard trumpeter (*Latridopsis forsteri*)and spotted handfish (*Brachinichthys hirsutus*), both by N Barrett, IMAS

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 2009. 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 – 210,000 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 sediments and biota by mercury, zinc, cadmium, lead, copper and arsenic;
- elevated nutrient concentrations, localised algal blooms and, in the upper estuary, seasonally depressed oxygen levels;
- loss and degradation of estuarine habitat and species;
- altered environmental flows and physical barriers to fish migration;
- intermittent faecal contamination of recreational waters;
- severe infestation by marine pests and coastal weeds.

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, catchment inputs carried by the Derwent and Jordan rivers, marine and aquaculture inputs, rubbish tips and contaminated sites, atmospheric deposition, 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, silt, litter and gross solids, and a range of toxicants including heavy metals and hydrocarbons.

Pollutant loads

From 2009 through 2013 there has been considerable inter-annual variation in estimated pollutant loads to the Derwent estuary, however cumulative loads have not changed substantially, with the exception of a further reduction in organic matter loads, associated with process changes at the Norske Skog Boyer paper mill. There has, however, been an apparent spatial shift, with higher nutrient loading in the upper estuary (associated with increased catchment, industry and WWTP loads) and decreased loading to the lower estuary (associated with lower WWTP loads). The interannual variability in suspended solids and total nitrogen loads largely reflects riverine inputs, with higher than average flows in 2009, 2011 and 2013, and lower than average flows in 2010 and 2012. Zinc loads to the estuary are difficult to quantify, as the primary sources are non-point emissions of groundwater, and it is assumed that discharges have been relatively constant during the reporting period. Cumulative inputs of faecal bacteria and litter are also difficult to quantify, but monitoring suggests that urban stormwater is the primary source. Thus, over the reporting period:

- the River Derwent contributes the majority of suspended solids and total nitrogen;
- the majority of bioavailable nutrients are derived from WWTPs, and there has been an increase in catchment inputs;
- the majority of zinc is derived from contaminated groundwater at the zinc smelter site;
- 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 35 beaches and bays during summer months and the ambient monitoring program which measures physico-chemical parameters each month at over 20 sites between New Norfolk and the Iron Pot.

Ninety percent of the Derwent's swimming areas are classified as having good or fair water quality, with little change over the past five years. Opossum Bay, Hinsby Beach and the River Derwent at New Norfolk had the best water quality, while poor water quality persists at the western end of Nutgrove and mid-Howrah beach, probably due to stormwater/sewage cross-connections. Most estuary beaches are susceptible to stormwater pollution, and swimming is not recommended in the Derwent for several days following heavy rain. Recreational water quality of Derwent's bays and coves is more variable. Over 60% of these sites have good or fair water quality, with a marked improvement over the past five years (probably due to very low summer rainfall during this period). Several sites (e.g. Sullivans Cove, Montagu Bay and Dorans Road) typically have excellent water quality, while others (e.g. Marieville Esplanade and Geilston Bay) are poor. The DEP regularly informs the community about recreational water quality via media releases, weekly water quality reports on the DEP website, and signage at beaches.

Ambient water quality indicators, such as temperature, salinity, dissolved oxygen, suspended solids and nutrients, have shown similar spatial and temporal patterns as previously reported, but have been influenced by the higher than average rainfall and river flows experienced during the past five years, together with the shift in nutrient loading towards the upper estuary. Concentrations of suspended solids and chlorophyll a have increased across the estuary as a whole, with highest values at mid estuary sites, and water clarity has also declined. Bioavailable nutrients are elevated in surface waters of the middle estuary and at depth in the mid to upper estuary, and have increased significantly over the past decade. While ambient water quality is still relatively good across much of the estuary, the recent increases in bioavailable nutrients and chlorophyll a, combined with persistently low summer oxygen levels and recent filamentous algal blooms in the upper estuary, suggest that the estuary is becoming more eutrophic, with the upper estuary at greatest risk.

Zinc levels remain elevated in the surface waters of the middle estuary and at depth in the upper estuary, but there are some indications that levels have declined across the estuary as a whole.

Sediment quality

The majority of the Derwent's sediments do not meet national sediment quality guidelines for heavy metals, particularly for mercury, lead, zinc, cadmium and arsenic. 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. A 2011 estuary-wide survey of metals in surface sediments indicates that there has been a decline in some of the extreme values previously recorded at middle estuary sites, and that there have been slight shifts in contaminant distributions, with some reductions at upper and lower estuary sites, but an apparent increase in Elwick Bay. Several recent coring investigations have shown that the contamination is largely restricted to the top one metre of sediments, with peak metal concentrations typically at a depth of 20 to 60 cm below the surface. Previous studies have shown 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. Thus managing nutrient loading to prevent associated oxygen depletion is an inportant challenge.

Seafood safety

Heavy metals in Derwent estuary oysters and mussels continue to be monitored on a regular basis, and remain well above national food safety guidelines, with no clear trend over time. Mercury levels in a broader range of recreationally targeted fish were tested during this reporting period, confirming that levels in black bream are well above national guidelines, flathead and trout are close to or slightly above, and other species are generally below the guidelines. A detailed investigation of Derwent flathead did not find a long-term trend in mercury levels and emphasized the need to consider fish size and age when interpreting monitoring results. This study also identified selenium as an important influence on mercury uptake and toxicity. There has been no change in the health advice previously issued by the Director of Public Health, which is:

- do not consume shellfish or black bream caught from the Derwent estuary and;
- limit consumption of flathead and other Derwent caught fish to no more than one meal per week, for pregnant/breastfeeding women and young children, and no more than two meals per week for the wider community.

Habitat and species

The Derwent estuary supports a wide variety of habitats, of which subtidal soft sediments are by far the most abundant (86%), followed by tidal flats (6%), seagrasses and macrophytes (3%), wetlands and saltmarshes (2%) and rocky reefs (1%). The Derwent foreshore retains 49% of its native vegetation, including 12 state-listed threatened vegetation communities and two EPBC-listed communities. There has been good progress during this reporting period in mapping the extent and condition of key habitats, including the wetlands and macrophyte beds of the upper estuary, the Lauderdale saltmarshes, and the rocky reefs of the middle and lower estuary. A Derwent Estuary Conservation Action Plan has also been prepared to better prioritise conservation actions and investments, which has highlighted the vulnerability of high value wetlands and seagrass/macrophyte communities to reclamation, water quality decline and sea-level rise.

The estuary supports a wide range of fauna, including over 150 species of fish and 120 species of birds. There is little 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 macro-invertebrates are not well known. The long-term decline in migratory shorebirds in the Derwent estuary/Pittwater area persists, and the number of ducks in the upper estuary has also fallen, however gull numbers have increased in recent years. Monitoring and conservation actions have continued for little penguins and spotted handfish, which continue to breed at a number of sites in the lower estuary. Pilot surveys have also been undertaken of Derwent estuary dolphins, endangered saltmarsh moths, and the endangered Australasian bittern. Southern right whales, and occasional humpbacks and orcas, continue to visit the Derwent, including a southern right whale and newborn calf in 2010.

Marine pests and weeds

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. There have been no system-wide surveys of marine pests in the Derwent since 2002.

A total of 71 weed species have been documented along the Derwent foreshore, including 15 weeds of national significance, with boneseed and African boxthorn the most abundant. Annual rice grass surveys have continued, with four small patches found and treated over the five year period, all in the middle estuary. A major new control program for the New Zealand weed karamu commenced in 2010, with a focus on protecting the high value wetlands in the upper estuary. This weed has been successfully reduced from 11 to 4 km of the foreshore, with further work underway.

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 2009. These include:

- Continuing site works at the Nyrstar Hobart zinc smelter to reduce heavy metal discharges, including extension of groundwater remediation systems (currently extracting over 100 tonnes of zinc per year) and completion of a major stormwater harvesting and reuse project, including a 40 ML stormwater detention dam (no significant overflows since 2012);
- Conversion to pine only processing at the Norske Skog paper mill in 2009, resulting in clearer effluent and a further 50% reduction in organic matter loads;
- Decommissioning of the Taroona wastewater treatment plant in 2014 (effluent now treated to tertiary level at Selfs Point) and construction of the 1000 ML Duckhole storage dam in 2013 to improve effluent reuse (now at about 18%);
- Construction of over 20 stormwater management projects by councils, including water sensitive urban design systems, litter and gross pollutant traps and stormwater harvesting.

Major DEP initiatives since 2009 have included the revision and endorsement of the *Derwent Estuary Environmental Management Plan* (2009), signing of a new partnership agreement in 2014, and completion of an Australian Government-supported *Water Quality Improvement Plan* to better inform management of heavy metals and nutrients. Other key projects have included:

- continued monitoring and reporting on recreational and ambient water quality, rivulets, seafood safety, including signage;
- continued development of estuarine models and decision support tools;
- initiatives to capture and treat contaminated groundwater at the zinc works site;
- initiatives to improve regional stormwater management (e.g. design and construction of four water sensitive urban design projects; guidelines and technical support for sediment and erosion control on building sites);
- planning, monitoring and investigations of key habitats (e.g. Derwent Conservation Action Plan, baseline surveys of wetlands, saltmarshes, macrophytes and seagrasses, and rocky reefs);
- monitoring and management of iconic and protected species (e.g. little penguins, spotted handfish, dolphins, saltmarsh moths and Australasian bitterns) ;
- development of a foreshore weed strategy and implementation of priority projects (e.g. rice grass and karamu control), and;
- initiatives to better understand community values, raise awareness and increase enjoyment (e.g. community survey, signage, educational projects and foreshore tracks website).

Many of these projects were implemented with support from Australian Government grants, and in collaboration with our partners. 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.

ACKNOWLEDGEMENTS

This report was produced with financial and technical support from the Derwent Estuary Program's major partners – as listed below.

- 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
- TasWater
- 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 Institute of Marine and Antarctic Studies
- CSIRO Marine and Atmospheric Research
- NRM South
- Birdlife Tasmania
- Aquenal
- Technical Advice on Water
- North Barker Ecosystem Services
- Aquatic Science

A special thanks to our colleagues at the EPA Division, Norske Skog, Nyrstar, local governments, Analytical Services Tasmania and the Public Health Laboratory, who assisted in the collection and analysis of the thousands of samples that form the basis of much of this report.

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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, seadragons and the endangered spotted handfish.

Figure 1.1 Derwent Estuary Program area

Approximately 210,000 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, in particular:

- 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 low dissolved oxygen levels in localised areas.

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. In 2010, the DEP was awarded Australia's National *Riverprize*, and in 2014 a new partnership agreement was signed to continue the partnership arrangements for a further five years.

During the period from 2009 to 2014, the DEP's partners and supporters have included:

- Tasmanian State Government
- Brighton Council
- Clarence City Council
- Derwent Valley Council
- Glenorchy City Council
- Hobart City Council
- Kingborough Council
- TasWater
- Norske Skog Boyer
- Nyrstar Hobart
- Tasmanian Ports Corporation
- Hydro Tasmania
- Australian Government
- Institute of Marine and Antarctic Studies/University of Tasmania
- CSIRO Marine Research
- NRM South

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 processing. 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.

The new State of the Derwent estuary report reviews environmental quality data collected since 2009 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. Sections 5 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, including introduced pests and weeds. Section 10 provides an overview of several integrated studies, carried out in recent years. Finally, Section 11 contains a summary and recommendations and Section 12 provides an up-to-date list of references.

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 are found in and around estuaries. In the Derwent, these include beaches and dunes, rocky foreshores, saltmarshes and other wetlands, mud and sand flats, seagrass meadows, kelp forests, and rocky reefs. Details about these habitat types are given in Section 9.1.

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 9.3.

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 2.1. Fourteen of these are land-based while the other five (Derwent River Conservation Area, Murphys Flat, Ralphs Bay, Tinderbox Marine Reserve and South Arm Conservation Area) are predominantly intertidal or subtidal. The River Derwent Conservation area is the largest reserve on the estuary (1,637 hectares) and occupies most of the wetlands and mudflats below the high water mark between New Norfolk and Dogshear Point (see Section 9.1 for more information).

Table 2.1: Conservation areas around the Derwent estuary

Classification	Municipality	Area (ha)	Date Effective	Comments
Conservation Area				
Murphys Flat Conservation Area	Derwent Valley	66	01/05/2001	Wetland
Opossum Bay Marine Conservation Area	Clarence	555	09/12/2009	Not specified
Ralphs Bay Conservation Area	Clarence	171	10/10/2006	Coastal
River Derwent Marine Conservation Area	Derwent Valley	1637	27/02/1941	River, marsh
South Arm Conservation Area	Clarence	18	29/05/1991	Wetland, migratory waders
South Arm Marine Conservation Area	Clarence	772	09/12/2009	Not specified
Truganini Conservation Area	Hobart	42	18/08/1976	Representative forest
Nature Recreation Area				
Gordons Hill Nature Recreation Area	Clarence	50	30/07/1979	Open eucalypt woodland
Knopwood Hill Nature Recreation Area	Clarence	42	27/05/1983	Dry sclerophyll forest
Meehan Range Recreation Area (includes Mt Direction)	Clarence	1257	12/03/1981	Dry sclerophyll forest
Rosny Hill Nature Recreation Area	Clarence	21	26/08/1981	Scenic
South Arm Nature Recreation Reserve	Clarence	68	06/11/1980	Coastal, recreation
Jordan Nature Reserve	Brighton	4	14/12/2011	Not specified
Tinderbox Marine Nature Reserve	Kingborough	144	18/09/1991	Marine habitat
Tinderbox Nature Reserve	Kingborough	72	27/12/2000	Representative forest
State Reserve				
Derwent Cliffs State Reserve	Derwent Valley	5	09/01/1952	Scenic
East Risdon State Reserve	Clarence	88	17/03/1971	Rare eucalypts
Iron Pot State Reserve	Clarence	2	09/11/2005	Bird breeding
Peter Murrell State Reserve	Kingborough	135	14/10/1997	Heath, rare plants
Other classification				
Goulds Lagoon – local council managed reserve	Glenorchy	8	20/05/1938	Waterfowl; private land
Green Point - now a public reserve	Brighton	22	3/05/1978	
Cape Direction Wildlife Sanctuary – now an unnamed private sanctuary	Clarence	5	2/09/1948	Muttonbird rookery

(Source – Parks and Wildlife Tasmania)

2.1.3 Human heritage values

The Derwent river valley was a major route for Tasmanian Aborigines between the coast and hinterland for around 40,000 years. The Oyster Bay Tribe on the eastern shore and the South East Tribe on the western shore inhabited the region surrounding the Derwent estuary. Both tribes utilised the Derwent as a source of food, with shellfish, such as oysters and mussels, being a major part of their diet (Ryan, 1996). The Derwent estuary shoreline contains a very high density of Aboriginal sites. These sites include shell middens, stone artefact scatters, rock shelters and quarries, which continue to be 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; reviewed/updated by Aboriginal Heritage Section, DPIPWE – Aug 2014).

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). The name '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. Some of the 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, the Shot Tower and Batchelors Grave Historic Sites, 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 fourth largest port and is an important regional centre for the 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 newsprint 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 210,000 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. During the period from 2009 to 2013, the population of the Greater Hobart region increased by 2.6%.

Figure 2.1: Uses and major reserves of the Derwent Estuary

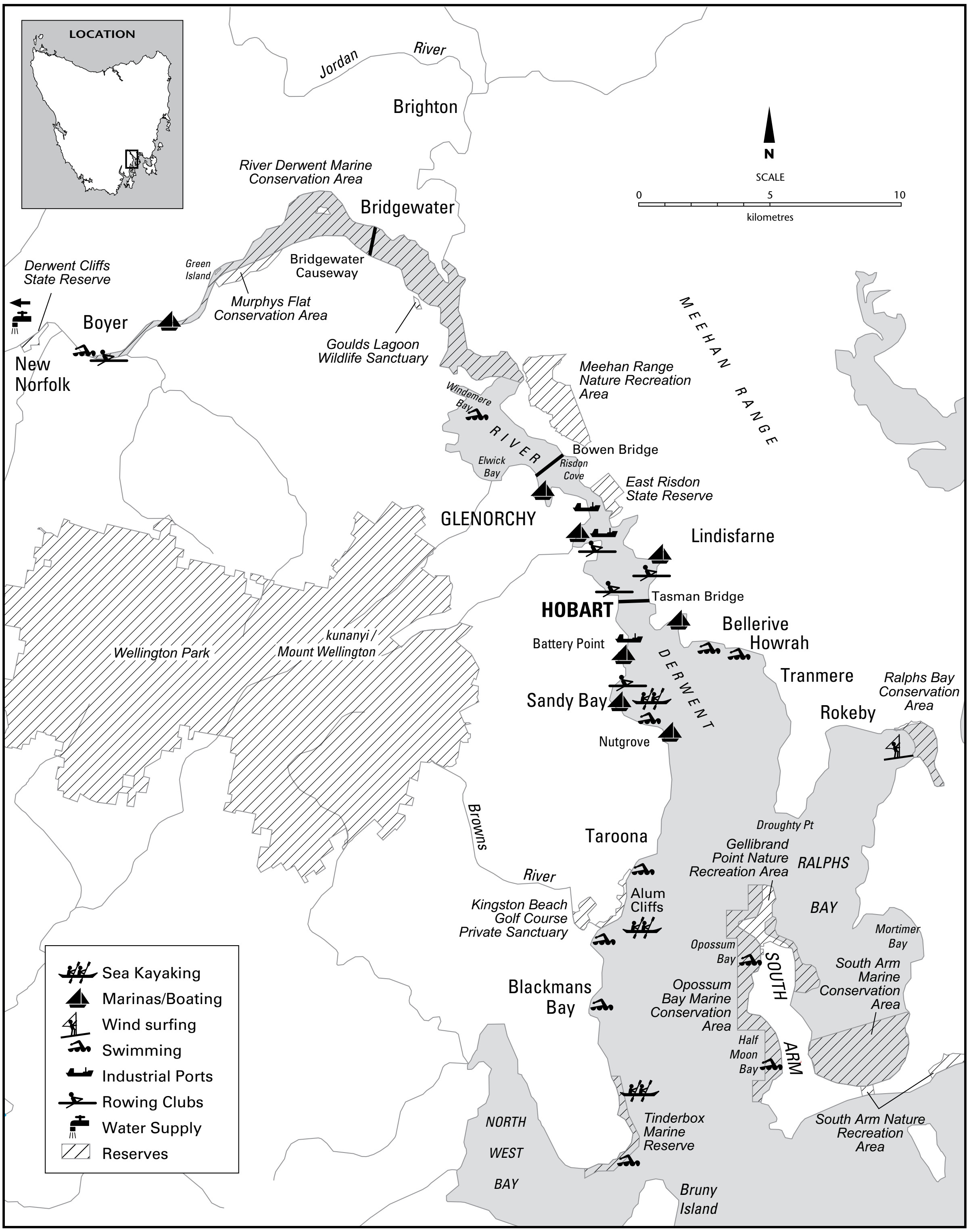


Table 2.2: Population by local government area

Local Government Area	2009	2011	2013	Annual Population Change (2012-2013)
Brighton	15,192	15,685	15,813	0.10%
Clarence	51765	52825	53582	0.90%
Derwent Valley	9,861	9,946	9,886	-0.70%
Glenorchy	44,947	45,402	45,537	0.40%
Hobart	49,917	50,482	50,473	0.30%
Kingborough	33,431	34,693	35,201	0.70%
Total Greater Hobart Area	**205,113**	**209,033**	**210,492**	**0.50%**
Tasmania	504,353	511,483	513,159	0.20%

(Source – Australian Bureau of Statistics website; www.abs.gov.au)

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 (they were 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 by the DEP, with assistance from the Department of Primary Industries, Parks, Water and Environment (DPIPWE). At that time, about 50% of the foreshore was privately owned, 30% was state owned, 10% was council owned and the remaining 10% was occupied by roads and associated corridors. Planning and development controls on 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 that are 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 over 50 kilometres of 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 precinct (construction, maintenance industries) including Incat which relies on the estuary for construction and maintenance of vessels;
- Nyrstar Hobart Smelter which relies on the estuary for shipping, water supply and 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 and refuelling of vessels;
- Impact Fertilisers which relies on the estuary for shipping;
- Domain slipway and other slipway facilities (boat maintenance and 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
- 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, and it 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 on the Derwent are jointly managed by the Tasmanian Ports Corporation and the Marine and Safety Authority of Tasmania. The Port of Hobart is the southern-most port and handles a range of shipping and various products: there were over 1.66 million tonnes of freight moved in 2013/14. Imports were around 916,000 tonnes – mostly zinc concentrates, petroleum products, phosphate rock, and calcite. Exports accounted for the remaining 745,000 tonnes – mostly sulphuric acid, zinc and zinc alloys, fertilisers and timber products.

During 2013/14 Hobart was visited by 225 vessels (>35 m). Most were associated with industrial and commercial activities; however, a significant increase in the number of cruise ships certainly enhanced the ship numbers with over 100,000 passengers and crew sailing into port. Military vessels also frequent the Derwent – thus providing an important boost to tourism and the local economy. Furthermore, an increase in the number of research and Antarctic re-supply vessels, that are either based in Hobart or visit regularly, adds to the diversity of traffic on the Derwent (A. McKeand, TasPorts, 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 estuary crossings – 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. The construction of the Brighton Transport Hub in 2013 has reduced train traffic within Hobart, and increased the use of rail for the transportation of goods across Tasmania.

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 recreation with numerous parks, picnic areas, walking and cycling tracks and sports grounds on the foreshore.

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 29,449 registered pleasure boats in the state (I. Ross, MAST, pers. comm. 2014), 23% regularly use the Derwent estuary and Channel (2010 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. Marine and Safety Tasmania (MAST) manages 3 jetties, 2 boat ramps and around 822 moorings in the Derwent (which accounts for 17.7% of the state). 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 to Hobart yacht race, during which approximately 100 yachts and 10,000 people visit the Hobart waterfront over the three main days of the Sydney to 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: these include parks, picnic areas, playgrounds, playing fields, golf courses and other sporting grounds, and 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. In 2007 there were approximately 111 km of tracks along the Derwent estuary foreshore from New Norfolk to the Iron Pot lighthouse (DEP Tracks Survey 2007). This figure, which includes tracks on both the eastern and western shores of the Derwent, has increased since then as many municipalities have invested in additional tracks along the foreshore. These include the Inter 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 October 2012 an estimated 97,784 Tasmanian residents aged 5 years or older fished at least once, representing a 22% participation rate in recreational fishing. The majority of recreational fishing occurs in the south and east of the state, with the Derwent accounting for 6% of the statewide effort. An estimated 9,560 persons fished at least once in the Derwent estuary during 2012/13; key species with catch numbers (kept plus released) were flathead (53,355), barracouta (16,761), bream (13,955), Australian salmon (13,157), cod (6,027), wrasse (3,322), mullet (1,629) and trout (1,612) (Lyle et al. in press).

The Derwent is an important regional fishing port; 81 commercial fishing vessels were home-ported in Hobart in 2012/13 with a total of 18 vessels landing fish at the port of Hobart (D. Garcia, DPIPWE, 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 115.7 tonnes between 2008/09 and 2012/13; school whiting accounted for the majority of the catch (D. Garcia, DPIPWE, 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 Visitor Survey 2013/14, approximately 910,994 visitors aged 14 and over came to Tasmania in 2013/14, of which 669,064 (73%) visited and stayed overnight in the Hobart area (source – www.tourism.tas.gov.au; Date accessed, July 2014). The greater Hobart area combines a rich history, galleries, markets, restaurants and waterside pubs with a working port, providing 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, the Museum of Old and New Art (MONA), 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, 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 MONA, Wrest Point, Bellerive and further afield to Peppermint Bay, Bruny Island and New Norfolk. 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. Helicopter and seaplane tours also provide scenic flights over the Derwent estuary.

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, summer and winter MOFO festivals 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 2012/13 Hobart received 21 cruise ships over 44 visits, bringing approximately 104,700 passengers and crew (a 41% increase from the previous year). The passengers and crew from these vessels radiate out from the port of Hobart, visiting all regions of southern Tasmania (Tourism Tasmania Cruise Ship Survey 2012–2013).

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)
- Institute of Marine and Antarctic Studies (Hobart and 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, L'Astrolabe* and *Investigator*, 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.

2.2.9 Community values and uses survey

In 2013 the DEP repeated a community survey (the first occurring in 2007) of 300 Tasmanians to test awareness of the communications strategies that we had in place for the program at the time, and to measure the degree of community engagement with the Derwent estuary (Myriad 2007, 2013). The results of these surveys inform the DEPs program planning and assist us in tailoring our communications)

The 2013 Community Survey revealed that the Derwent estuary and its health are very important to the majority of people living here (83% of respondents) with many reporting that they thought that the health of the estuary had improved in the last five years (48%). People use the estuary regularly for swimming (31%), boating/rowing/sailing (31%) and fishing (29%). Walking beside the estuary was by far the most popular activity (69%). Compared with 2007 there was a large increase in the physical activity associated with the Derwent estuary.

The awareness of the DEP increased from 16% of those surveyed in 2007 to 23% in 2013. While this figure is low it is interesting that the messages that the DEP provides about swimming, seafood safety and walking opportunities around the Derwent are reaching a wide audience.

- 70% of respondents were aware of swimming advice with most people receiving this information from newspaper (51%) or beach signage (33%);
- 60% of respondents were aware of seafood safety advice with newspapers and television being their main source for this information;
- 77% of respondents were aware of information about walking tracks around the Derwent estuary. Word of mouth (23%) was a popular way to learn about walking opportunities as was the internet (11%). Local knowledge, exploration and local guide books also ranked highly as sources of track information.

The survey also provided further insight in to the community's major environmental concerns about the Derwent estuary, with commonly cited concerns including water pollution (industrial, sewage and stormwater) and litter.

3.0 PHYSICAL SETTING: ESTUARY, CATCHMENT AND CHANNEL

This section reviews the physical setting of the Derwent estuary, including estuary morphology, bathymetry and geology; estuarine circulation and coastal oceanography; and local meteorological conditions. The broader 'catchment to coast' continuum is also reviewed, including river hydrology and water quality, catchment land and water uses, and recent studies and developments in the D'Entrecasteaux Channel and Storm Bay.

3.1 Derwent estuary

3.1.1 Estuary morphology, bathymetry and geology

The Derwent estuary extends for a distance of 52 km from New Norfolk at its northern end to the Iron Pot Light at its mouth, 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.

Estuarine bathymetry is illustrated in Figure 3.1 The upper estuary extends from New Norfolk to the Bridgewater causeway, and is characterised by a narrow channel 3-6 m deep, flanked by extensive wetlands and shallow subtidal macrophyte meadows that provide valuable nutrient filtration services to the Derwent estuary (Wild-Allen et al., 2010, 2011, 2013). The middle part of the estuary - between the Bridgewater Causeway and Bowen Bridge - is 1-2 km wide, with a more convoluted shoreline with some rocky headlands and numerous small embayments. South of the Tasman Bridge the lower estuary widens and is characterised by relatively straight western and eastern shorelines, and a large (>50 km^2), shallow embayment - Ralphs Bay - on the eastern shoreline. 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.

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). This information can be accessed on The LIST website (see www.thelist.com.au).

3.1.2 Estuary circulation and coastal oceanography

The mid- to upper-estuary is generally stratified with fresh water overlying a salt-wedge, the toe of which is generally located near New Norfolk but may be pushed downstream as far as Bridgewater when flow exceeds 150 cubic meters per second (cumec) or 13,000 megalitre per day (ML/day (Davies and Kalish, 1989). The mid- to lower estuary is classified as partially- to well-mixed due principally to wind-driven and tidal mixing, and relatively large vertical mass movements occur within the water column.

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 frequently has large variations in the heights of successive tides and occasionally has only daily tide. Tidal currents are relatively weak, typically in the order of 0.1 to 0.2 m/sec. Wind and the Coriolis force deflect the main flow of fresh water from the River Derwent along the estuary's eastern shoreline, while saline bottom water travels slowly up-river. The average flushing period for the estuary is estimated to be about 12 days (M Herzfeld, CSIRO, pers. comm., Sept 2009) but bottom waters of the upper estuary may be retained for between 20 to 35 days, particularly during low flow (Davies and Kalish, 1994). Flushing times may vary considerably, depending on river flow, wind stress and other variables.

A number of hydrodynamic and biogeochemical models have been developed for the estuary, as discussed in further detail in Section 10. More detailed circulation modelling has been done in specific areas of the estuary, such as the area downstream from Norske Skog Boyer's outfall (NSR

Environmental Consultants Pty Ltd, 2001) and around existing or proposed sewage treatment plant outfalls.

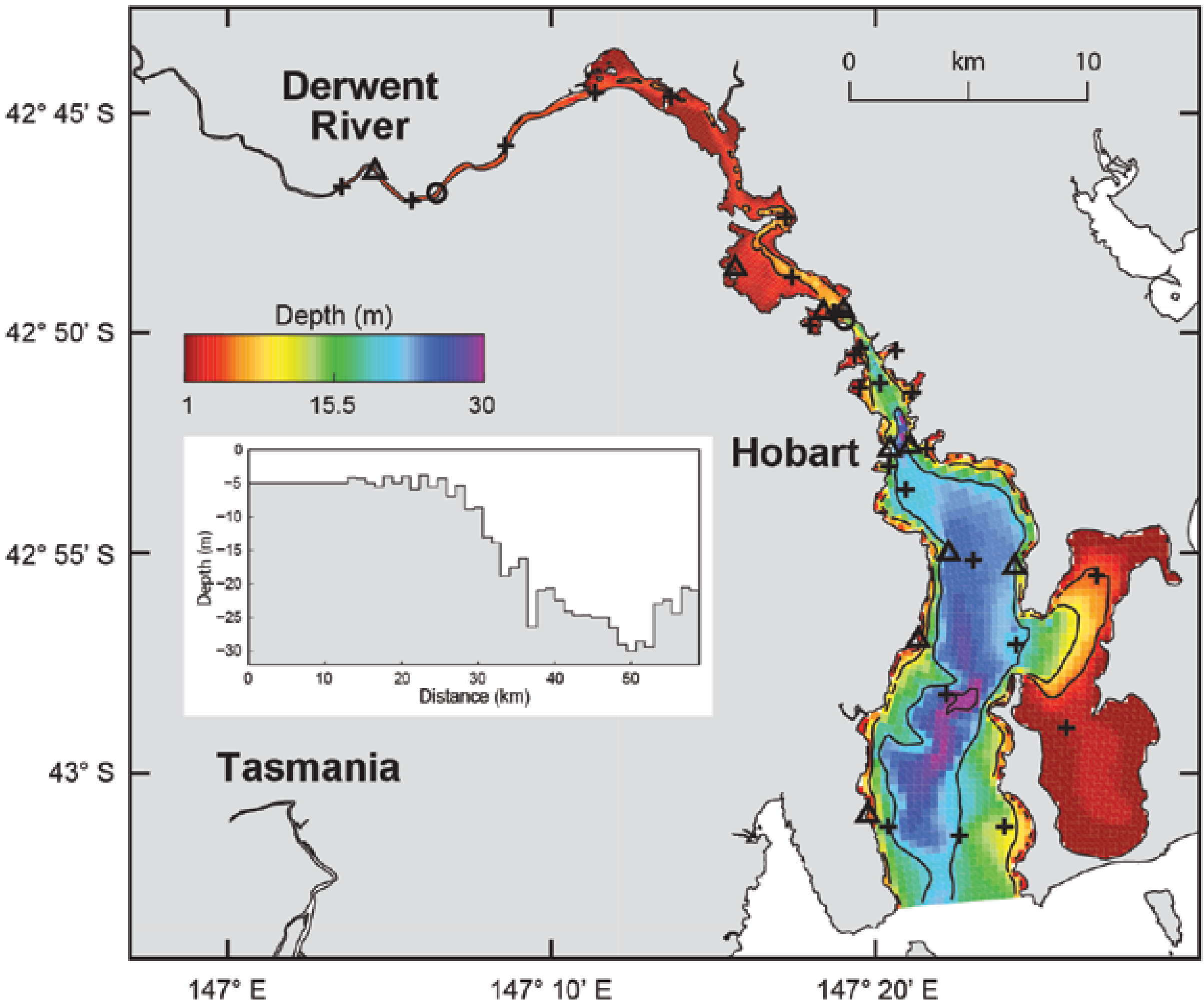
The marine waters off southeastern Tasmania are known to be an area of convergence between subtropical and sub-Antarctic water masses and the point of convergence varies seasonally and from year to year. Nutrient-poor, subtropical waters may be carried along the east coast of Tasmania in warmer seasons and these occasionally extending as far south as Storm Bay and into the mouth of the Derwent estuary. However, in cooler months 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 southeast Tasmanian coastal waters.

3.1.3 Regional climate and meteorology

The Derwent estuary region has a cool temperate climate, with a mean maximum temperature range of 12°C in July to 22°C in February. In general, due to topographic influences and the northwest-southeast orientation of the River Derwent valley, katabatic (downslope) winds prevail, blowing from the northwest. However, southerly sea breezes tend to dominate in summer afternoons.

Precipitation is monitored by the Bureau of Meteorology at a number of sites throughout the Derwent. Mean annual rainfall in the region is approximately 600 mm on the west-side of the estuary and approximately 500 mm on the east-side. Rainfall is relatively evenly distributed throughout the

Figure 3.1 Derwent estuary bathymetry (source K Wild-Allen, CSIRO)



year at between 40 mm in February and 61.7 mm in October (Figure 3.2 and Figure 3.3).

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

Figure 3.2 Monthly average rainfall 1882 to 2014 for Hobart at Ellerslie Road (www.bom.gov.au)

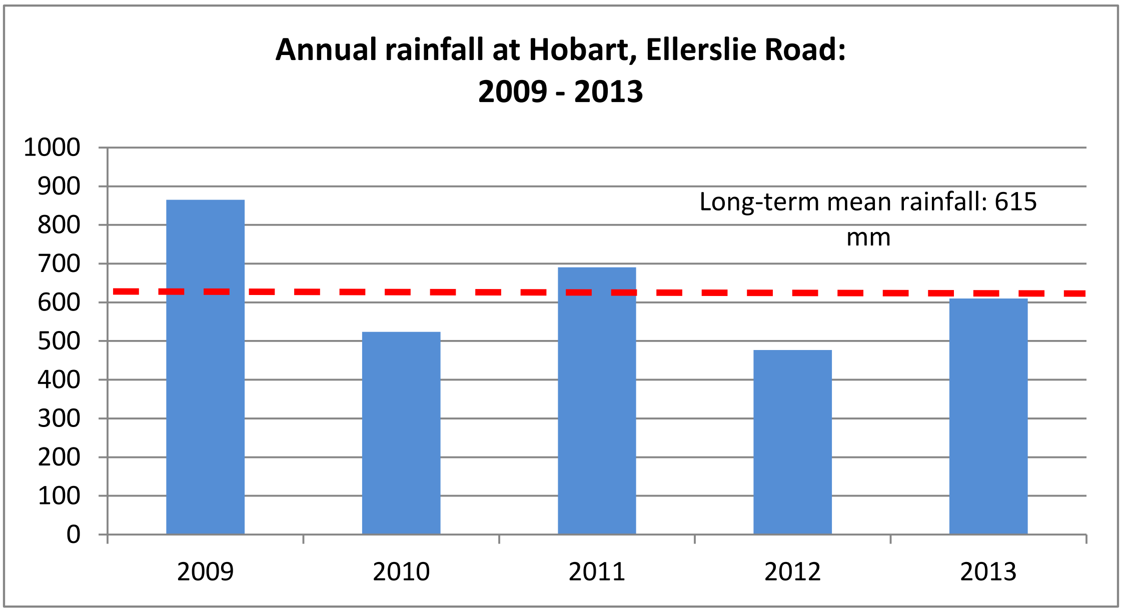


Figure 3.3 Annual rainfall 2009 to 2013 for Hobart at Ellerslie Road (www.bom.gov.au)

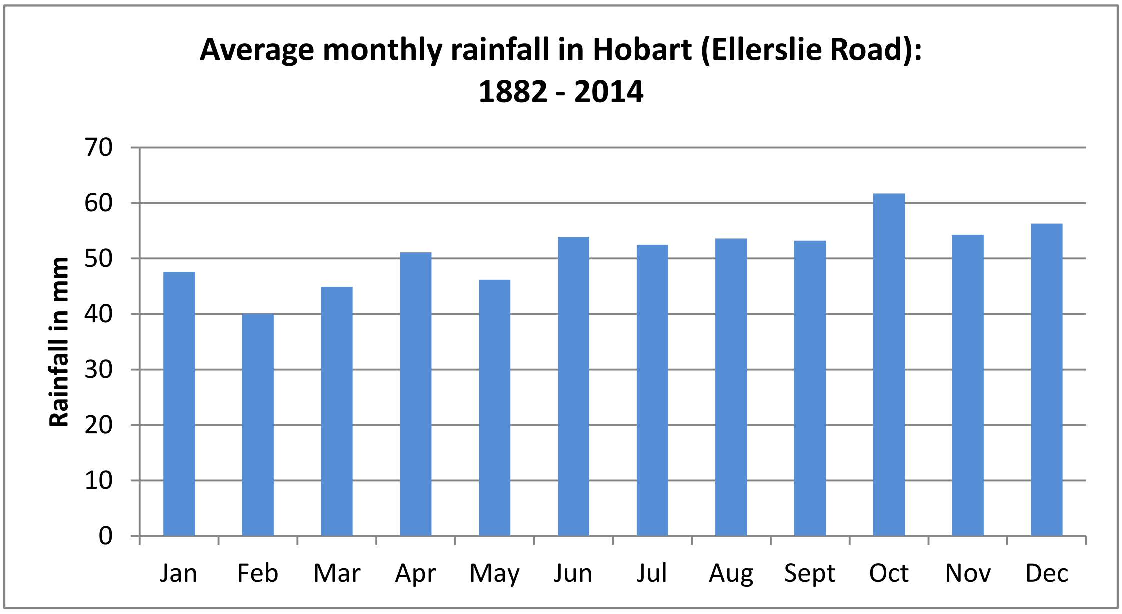


Table 3.1 Monthly rainfall in Hobart (Ellerslie Road) 2009 to 2013 (www.bom.gov.au)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2009	10.0	59.2	70.0	63.8	53.2	144.0	40.2	98.4	132.8	64.6	70.2	58.6	865.0
2010	14.4	34.8	30.4	18.2	26.6	12.4	7.4	114.0	93.4	46.2	95.2	31.0	524.0
2011	59.8	54.4	45.4	125.2	23.6	64.4	50.2	53.2	45.6	61.2	55.2	52.4	690.6
2012	56.0	22.6	30.8	22.0	92.2	33.2	18.2	57.8	68.0	29.0	24.8	22.0	476.6
2013	11.4	23.4	48.6	21.2	23.0	51.0	101.4	61.0	40.0	106.6	94.0	28.2	609.8
Long-term mean	**47.1**	**40.0**	**44.9**	**51.1**	**46.2**	**53.9**	**52.5**	**53.6**	**53.2**	**61.7**	**54.3**	**56.3**	**614.7**

3.2 Derwent catchment

The Derwent estuary's catchment covers an area of approximately 9000 km^2 in central and southeastern Tasmania (approximately one-fifth of Tasmania's land mass) and comprises the River Derwent catchment (7,500 km^2), the Jordan River catchment (1,250 km^2) and other areas immediately adjacent to the estuary (375 km^2), as indicated in Figure 3.4.

Current knowledge about the River Derwent catchment upstream of New Norfolk, with a focus on the period from 2009-14, is summarised in the following sections. For more detailed descriptions of the Derwent catchment, see Eriksen et al. (2011), Hobart Water (2006), Hydro Tasmania (2001) and Coughanowr (2001).

3.2.1 Catchment physical setting

The catchment of the River Derwent is one of the largest in the state, covering an area of about 7,500 km^2. The river originates at Lake St Clair at an elevation of 735 m and flows generally southeast through a series of dams, power stations and reservoirs until it joins the Derwent estuary at New Norfolk, 190 km downstream. This is a region of varied relief, climate and vegetation, 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. The Junee-Florentine karst (upper Tyenna and Florentine area) is also an important geologic feature.

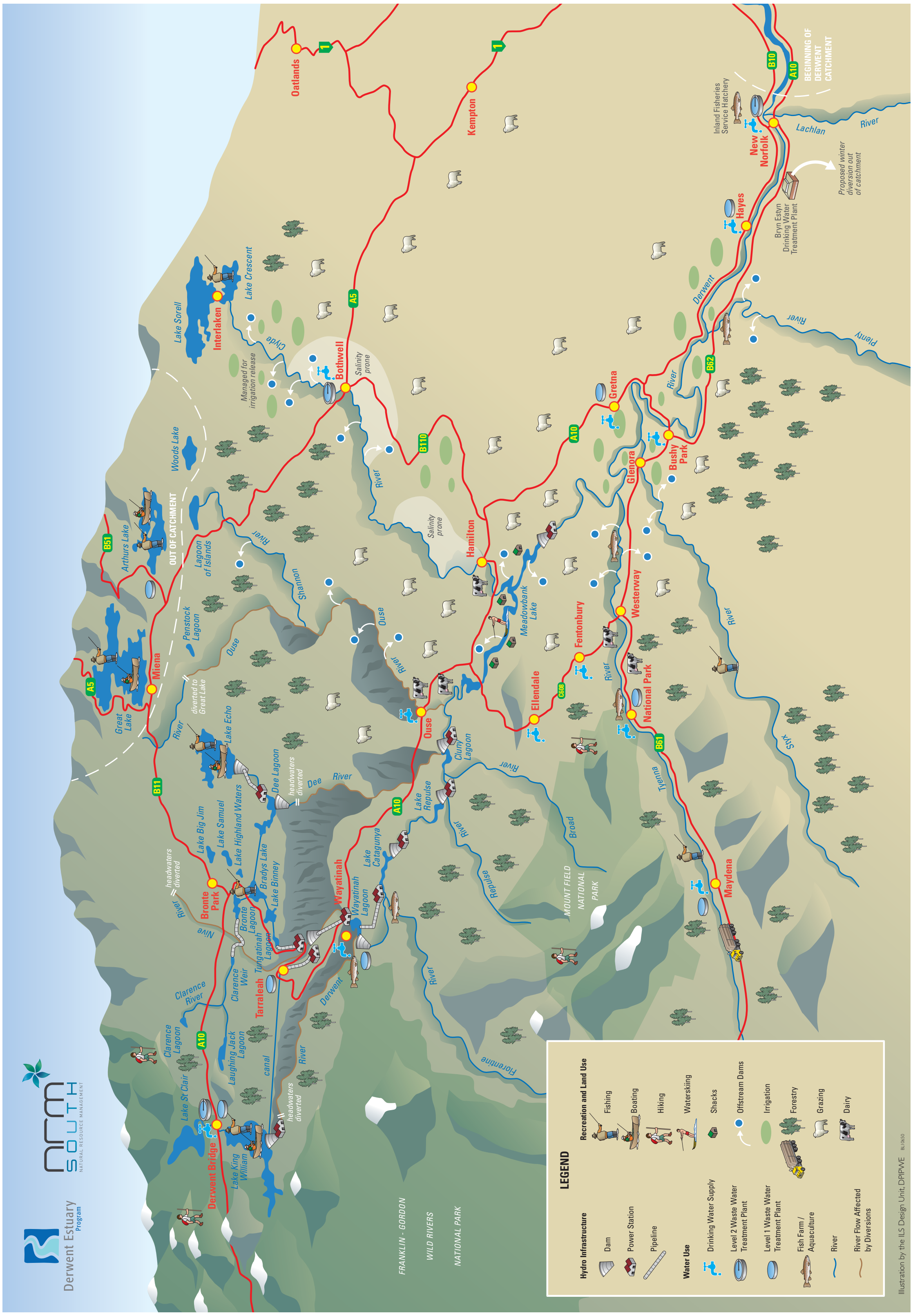
Precipitation within the catchment is variable, ranging from over 1,500 mm in the mountains and Central Plateau to 500 mm in the eastern catchment, with a general decrease in rainfall from north to south and west to east. The highest rainfall generally occurs in July and August, with lowest rainfall in January and February (Eriksen et al., 2011).

Vegetation within the Derwent catchment reflects rainfall distribution, relief and underlying geology, with the wetter western area dominated by wet eucalypt forest and rainforest. The northern catchment (Central Plateau) is characterised by alpine heathland and wet forest on the southern slopes, while further south, where there is considerably less rainfall, some remnant native grasslands and open grassy woodlands occur.

The major tributaries, water bodies and population centres in the Derwent are shown in Figure 3.5. Major subcatchments include the upper Derwent, Ouse and Clyde Rivers, and the lower Derwent. Although Great Lake is technically within the Derwent catchment, this water is generally diverted to the South Esk catchment, as is water from Lake Augusta.

Figure 3.4 The Derwent estuary catchment

Figure 3.5 Major rivers, lakes and towns and land uses within the River Derwent catchment. (from Eriksen et al., 2011)



3.2.2 River hydrology and flow regime

The River Derwent and its tributaries contribute by far the vast majority of flows into the estuary. The Jordan River contributes small and often intermittent flows to the estuary at Bridgewater, with an average annual discharge of less than 1 cubic metre per second (cumec) or 86 ML/day. Several large streams (e.g. Lachlan River and Sorell Creek; Faulkners, Humphrey, New Town and Hobart Rivulets; and Browns River) also flow year round from the well-watered mountainous slopes on the western shore of the estuary, whilst smaller, and sometimes ephemeral, streams flow to the estuary from the drier eastern shore.

Hydrology

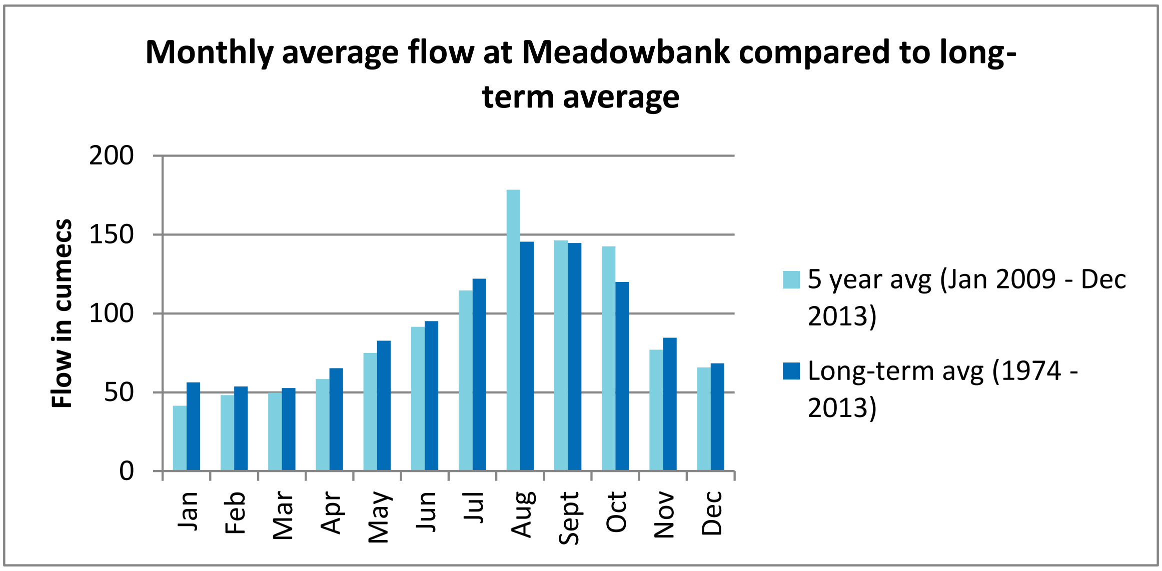
The Derwent is one of the largest rivers in Tasmania, with a long-term mean annual flow (1974-2013) of 91.1 cumec or 7,900 ML/day. The typical seasonal trend is for higher flows and greater flood frequencies in the second half of the calendar year, and lower flows during the months of January through March. Figure 3.6 shows the monthly distribution of flows below Meadowbank, including a comparison between the longer-term average flows (1974-2013), and average flows during 2009-2013. River flows during this reporting period (92.9) were considerably higher than the previous 5-year period (82.6, which included a period of drought), but were highly variable from year to year.

Figure 3.7 presents daily average river flows measured below Meadowbank from 2009 through 2013. Based on this data, three of the five years experienced above average flows and two were below average. In particular there were very low flows in 2010, with an annual average of 73 cumec. There were relatively few flood events during the five year period, with only a few events >500 cumec in 2009 and 2013, and no events >1000 cumec.

Flow regimes and environmental flow provisions

The Derwent is characterised by a highly modified flow regime, with the generation of hydro-electric power, controlled extraction and release for irrigation, land use change and the supply of water for municipal, industrial and aquaculture purposes causing significant changes to the natural flow regime. Over the past 100 years, the volume and seasonality of flows in the Derwent, as well as the pattern of low and high flow events, has been strongly affected by changes in catchment land use, flow diversion out of the catchment, impoundment and removal of water from the

Figure 3.6 Average monthly river flows measured below Meadowbank for the period 2009 to 2013, as compared to the long-term record (1974-2013) (data sourced from Hydro Tasmania)



catchment, as well as by climatic dry periods.

The cumulative effect of these impacts has resulted in an estimated 30% reduction in River Derwent flows from an annual average of 130 cumec in the 1920s (1922-1929) (Green & Coughanowr, 2004) to an approximate average of 93 cumec (2009-2013). The greatest single reduction was due to the diversion of the Great Lake outflow in 1916 (inclusive of the diversion of flow from the headwaters of the Ouse/Shannon to Great Lake via Liawenee Canal), which now flows to the north into the South Esk catchment via the Poatina Power Station.

Historical flow modifications and dam infrastructure in the Derwent catchment have affected dynamics in the estuary. The resulting impacts include changes in 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 and movement of migratory fish. Given the high value ecosystems in the upper estuary, the observed poor/declining water quality in this section and the critical importance of upper estuary to the system as a whole, one of the DEP's strategic objectives is to further investigate and encourage optimal environmental flow regimes to maintain the health of the estuary, building on the work of Davies et al. (2002).

There is currently no environmental water provision for the Derwent catchment set within a water management plan (e.g. Water Management Plan for Lakes, Sorell and Crescent, DPIPWE, 2005; Water Management Plan for Clyde River, DPIPWE, 2005), although detailed environmental flow assessments have been undertaken for the Derwent River downstream of Meadowbank Dam. At present restriction management of water diversion is based on restriction management protocols determined by a rule set to estimate flow at Bryn Estyn. This provides an estimate of flow at Bryn Estyn based on that measured at the Derwent below Meadowbank gauge and at the Tyenna River stream flow gauge (pers comm M Read, DPIPWE, 2015).

In addition, water restriction triggers for irrigation (ban on direct takes) have been set for several other rivers that flow into the Derwent below Meadowbank, as follows (Eriksen et al, 2011):

- Tyenna at Newbury 4.3 ML/day
- Plenty at Glenora 1.7 ML/day
- Lachlan River at Lyell Hwy 0.86 ML/day
- Sorell Ck u/s of Lyell Hwy 0.43 ML/day

A number of studies and investigations have been commissioned or undertaken by DPIPWE since 2001 to further inform environmental flows and sustainable water yields for the lower Derwent, as discussed below:

In 2002, Davies et al carried out an assessment of the environmental flow requirements of the lower River Derwent and upper Derwent estuary to maintain water quality and key habitats/species. A minimum flow regime

Figure 3.7 Average daily river flow (2009 – 2013) at Derwent below Meadowbank in cumecs (data sourced from Hydro Tasmania)

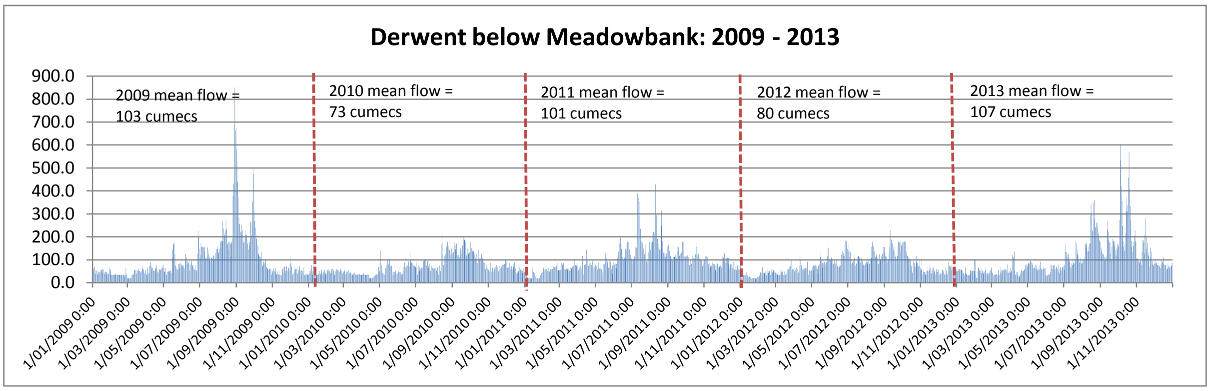


Table 3.2. Recommended minimum environmental flows to the lower river and upper estuary which provide minimal environmental risk (as mean daily flows for each month, in cumec) from Davies et al. 2002

Month	Minimal risk flows in cumec	Minimal risk flows in ML/day
Jan	50	4320
Feb	50	4320
Mar	50	4320
Apr	61	5270
May	71	6134
Jun	91	7862
Jul	102	8813
Aug	102	8813
Sept	102	8813
Oct	102	8813
Nov	82	7085
Dec	66	5702
Annual median	**76.5**	**6610**

was recommended as set out in Table 3.2,based on long-term median daily flows, and it was recommended that no further water abstractions be taken from the system in the period from Jan - April, (Davies et al. 2002). The report also recommended an annual channel maintenance high flow event of ca 400 – 450 cumec and ca 5 days' duration, and regular flushing flow events of ca 200-250 cumec and 4-5 days duration. (Note: the magnitude and duration of these higher flow elements require further investigation, and may not be operationally feasible).

In 2004, DPIPWE reviewed the allocations and environmental requirements, including new analysis on the underlying hydrology supporting the Davies assessment undertaken in 2002. It was determined that additional summer extractions could be taken without impinging on eflow requirements as described in the Davies report or risking saltwater intrusion above Lawitta, on the basis that the long-term (1981-2001) median average daily flows in the Lower Derwent were greater than the minimal environmental risk bands recommended by Davies. The difference between the current median average daily flow and the median daily environmental water provision provided a volume of water that could be abstracted from the Derwent below Meadowbank, whilst maintaining flows in the minimal risk band for each month. (pers comm., M Read, DPIPWE, 2015)

The hydrological analysis indicated that current mean daily flow at Bryn Estyn exceeded the predicted minimal risk environmental flow for each month by 10 to 23% and on that basis a volume of water could potentially be allocated from the lower Derwent while providing a flow greater than the minimal-risk environmental flow in all months of the year (pers comm., M Read, DPIPWE, 2015). A new monitoring station (river level and EC) was installed below the rapids at Lawitta to document the position of the salt wedge and provide a trigger to restrict takes, should salt levels increase. By 2006, the additional summer water allocations had been fully allocated. (Eriksen et al, 2011). Due to changes in the operation of Meadowbank Power Station resulting in greater discharges since Basslink became operational, further water could be potentially be allocated (pers comm., M Read, DPIPWE, 2015).

In 2005, the DEP commissioned further scoping of environmental flow provisions to protect estuarine assets, including water quality and key habitats (wetlands & macrophytes). This report (Davies (2005) recommended that four key elements be incorporated in an environmental flow regime for the Derwent estuary, including:

- Minimum flows
- Seasonal high flows
- Flood flow events
- Rates of water level decline

More recent hydrological studies and relevant investigations have included:

- DPIW – Surface Water Models Derwent River Catchment (Hydro Tasmania, 2007). This report developed surface water models for the Derwent catchment for three scenarios (1. no entitlements (i.e. natural flow); 2. with entitlements and 3. environmental flows plus

Table 3.3 Summary of water allocations (excluding Hydro) in the greater Derwent catchment, by category and number of allocations. Data summarised from WIST Water Entitlements database in 2011 (Eriksen et al., 2011)

Purpose	Number of allocations	Annual amount (ML)	Max daily rate (ML)	Max daily rate (cumec)	Allocation conditional?
Aquaculture	11	152,675	698.8	8.1	No, all year round
Irrigation	294	119,381	682.2	7.9	Yes, defined take period
Town water	8	81,905	331.7	3.8	No, year round
Commercial	11	41,551	762.6	8.8	No, year round
Stock & domestic	49	254	0.06	<0.01	No, year round
Recreation	2	33	-	-	No, year round
Aesthetic	1	5	-	-	No, year round
TOTAL	***376***	***395,805***	***2,475***	***28.6***	

entitlements. (Note: the summer environmental flow used in this model was 20 cumec).

- Tasmania Sustainable Yields Project (CSIRO, 2009): investigated water availability across Tasmania (including the Derwent) through to 2030 under a range of climate change scenarios (wet, medium, dry future).
- River Derwent – South East Irrigation Scheme, Environmental Water Requirements and Yield Assessment (Entura, 2012). This report evaluated potential impacts of an 11,400ML (equivalent to 60ML daily) winter take for irrigation (SEIS Stage 3) on hydrology and aquatic values below the Bryn Estyn, and concluded a very low likelihood of impact.

Given the apparent decline in water quality at New Norfolk and the upper estuary over the past 10 years, the incremental and projected increases in summer water allocations (including the SEIS-3/Sorell Irrigation Scheme which is currently under construction), as well as the changes and intensification of catchment activities, it is recommended that:

- an updated environmental flow assessment be undertaken to better understand and manage potential risks of the changing land and water uses in the catchment;
- a comprehensive monitoring program be designed and implemented in the area between Meadowbank and Bridgewater.

3.2.3. Water allocation and water uses in the Derwent catchment

In accordance with the *Water Management Act 1999*, multiple water users (abstractive and non-abstractive) are allocated water in the Derwent catchment for hydropower, irrigation, aquaculture, town and commercial water supplies, stock and domestic supply, and recreation or aesthetic purposes. Water is allocated at eight different surety levels, with Surety 1 providing the highest security of water supply. See DPIPWE website for details; www.dpipwe.tas.gov.au.

An analysis of water allocations in the greater Derwent catchment carried out in 2011 documented a total of 376 allocations adding up to 395,805 ML/year. This information was assembled from the DPIPWE WIST database, and excludes duplicated, expired and cancelled allocations. Aquaculture and irrigation accounted for 39% and 30% of the allocations, respectively, followed by town water at 21% and industrial supplies (primarily Norske Skog) at 10% (Eriksen et al., 2011). See Table 3.3 and Figure 3.8 for details. It should be noted that allocations do not necessarily reflect actual water use, which cannot be determined in the absence of metering.

Hydro-electric power generation

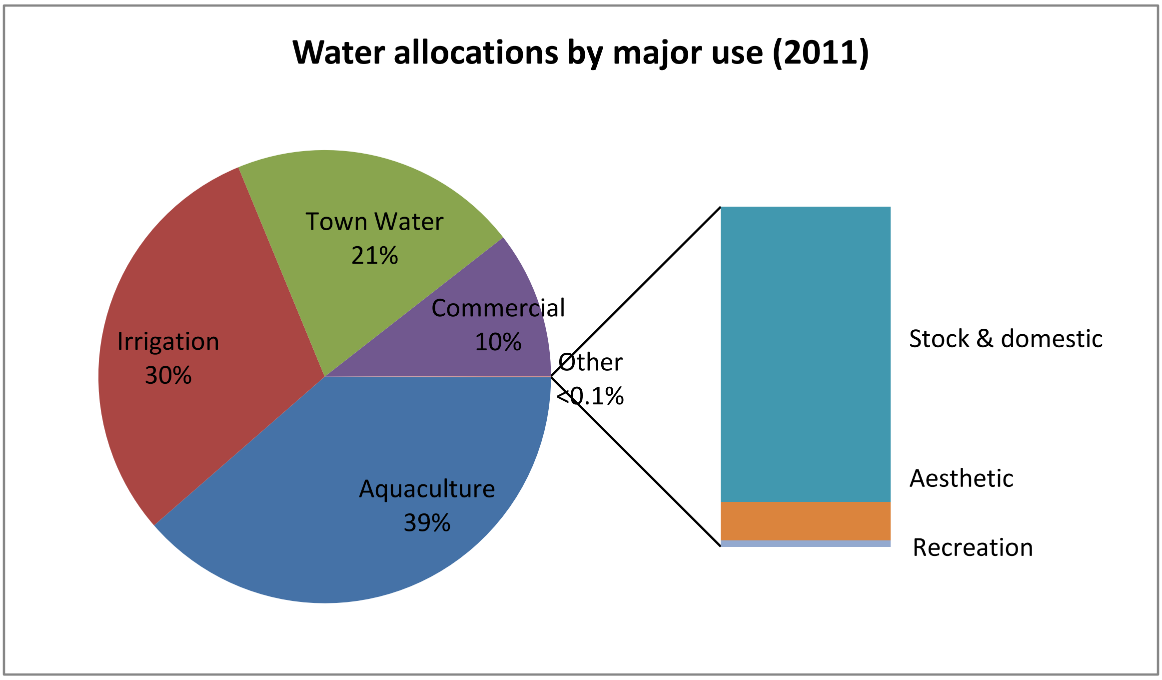
The Derwent and three of its nine tributaries have been dammed or diverted to over 20 storages for hydro-electricity generation. These include primarily run-of-the-river storages at lower altitude and several larger storages at higher altitude for manipulating winter runoff. Construction commenced with the impoundment of Great Lake in 1916 and continued until 1967– 1968 when Repulse, Cluny and Meadowbank were completed. 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 have a combined generating capacity of over 500 MW; nearly a quarter of Tasmania's hydro generating capacity. Most of the middle and lower Derwent storages are maintained at or close to full supply level, essentially passing larger flood flows. Upper storages however, such as Lake King William, have highly manipulated water levels, facilitating capture of winter flows to control delivery of flows downstream throughout the year. This markedly alters downstream peak flows during wet seasons.

During 2009–14, Hydro Tasmania has been progressively implementing oil management plans at power stations across the state to minimise the risk of oil loss from their infrastructure, and any impacts as a result of a spill. A major refurbishment of the 40-year-old Kaplan turbine at Meadowbank Power Station (on the River Derwent above New Norfolk) is currently underway and will be upgraded to an innovative oil-less design which will significantly reduce the risk of an oil spill. Other oil management improvements include improved bunding around transformers; an upgrade of site specific equipment to support oil spill response; and replacing aged or inadequate oil pipe supports, valves or fittings to reduce failure risk.

Town and commercial water supply

The River Derwent and its tributaries are an important source of town and industrial water supplies. The majority of Hobart's municipal water supply is taken from the River Derwent 3.5 km upstream of New Norfolk, and purified at the Bryn Estyn water treatment plant to meet drinking water standards prior to distribution. In addition there are a

Figure 3.8 Summary of allocations by major use (excluding Hydro) as percentage of total allocations for whole catchment (Eriksen et al., 2011)



number of smaller drinking water offtakes that supply towns within the catchment. The largest of these is Lake Fenton and is also linked to the Hobart municipal supply.

Bryn Estyn treats and distributes about 80 to 90 ML/day (equivalent to 1 cumec of river flow) on average of drinking water from the Derwent (to a maximum of 180 ML/day or 2.1 cumec), which is approximately 60% of the total annual average demand. In summer, when demand may rise to 240 ML/day, mountain supplies (Lake Fenton and Mt. Wellington) supply the remainder. The Bryn Estyn plant also supplies an increasing amount of treated off-peak water to the South East Irrigation Scheme (up to 1,975 ML for Stage 2, and 3,000 ML for Stage 3 starting in 2015–16).

The Norske Skog 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 treated to remove solids and biochemical oxygen demand (BOD) prior to being discharged back into the river downstream of the mill. Between 2009 and 2013, the annual quantity of water drawn from and discharged to the river has ranged from 20,000 ML to 23,000 ML (P. Kearney, Norske Skog, pers. comm.). See Section 4.2.2 for further information on Norske Skog.

Irrigation

A 2011 review of water allocations in the Derwent catchment (Eriksen et al., 2011) determined that there were 294 registered allocations for irrigation, totaling 119,381 ML/yr (an average of 682 ML/day or 7.9 cumec). This accounts for 30% of allocated use. The majority of allocations are located in the lower catchment, followed by the Clyde catchment. Irrigation water is typically stored in off-stream dams; in 2011 there were 135 licensed dams within the catchment greater than 1 ML in size, with an additional 52 proposed; again the majority of these are in the lower Derwent and Clyde River catchments. However, not all dams are required to be registered under current Tasmanian law, provided they are not on a watercourse, hold less than 1 ML of water storage and are only used for stock and domestic purposes.

Major irrigation areas/projects within the Derwent catchment include the following:

- Clyde River: this scheme uses water released from lakes Crescent and Sorell in accordance with the *River Clyde Water Management Plan (2005)*. Water levels in these lakes are currently managed in compliance with the requirements of the Inland Fisheries Service to control the breeding and movement of carp. The Shannon Clyde Water Company (previously the Clyde Water Trust) have been granted 10,000 ML from Lake Crescent (Surety 5/Surety 6), plus an additional 10,000 ML from Lake Meadowbank. There are also options for additional takes, under specific conditions and/or Ministerial request (see Eriksen et al., 2011 for details).
- Southeast Irrigation Scheme (SEIS): this scheme has been developed in a number of stages, as described below (see Tasmanian Irrigation website for further details www.tasmanianirrigation.com.au):
    - Stage 1: based on the Coal River and Craigbourne Dam, this project (completed in 1986) is located outside of the catchment.
    - Stage 2: commenced in 1991 to supply up to 1,975 ML of water via a piped system to the Richmond/ Cambridge area. The water was initially supplied from Craigbourne Dam, however in 2000 the Daisy Banks Dam was constructed to augment this scheme using treated off-peak water supplied by Tas Water.
    - Stage 3: a piped irrigation system that crosses the Derwent just above Bridgewater Causeway, and includes a pump station/boost pumps and a 250 ML holding dam at Rekuna. This could eventually supply a total of 9,600 ML/yr of River Derwent water (4,800 ML in summer, 4,800 ML in winter) to the Teatree/ Sorell/Forcett areas. The initial offer is for 3,000 ML summer allocation of treated off peak water from Bryn Estyn; this is currently under construction with a planned start in 2015/16.

Information about the scheme has been sourced from the

- Southern Highlands Scheme (proposed): this scheme would pump winter flows from the Shannon River (with possible supplementation from Great Lake) to a piped irrigation system in the Clyde catchment around Bothwell via pump stations and an off-river dam near Hermitage. The project is currently under investigation, with development and construction dependent on funding (Tasmanian Irrigation website; pers. comm. P Rand, Tas Irrigation, Jan 2015)

Aquaculture

There are seven fish hatcheries/grow-out facilities located within the Derwent catchment, as listed in Table 3.4. The largest operations are located on the Derwent at Wayatinah, on the Florentine River, on the Tyenna River at National Park and on the Derwent below Meadowbank. Smaller hatcheries are present on the Tyenna River (Karanja), Plenty River (Salmon Ponds) and the Derwent at New Norfolk. An eighth hatchery has been licensed, but not yet built, on the Broad River near Cluny. The main species cultured is Atlantic salmon, with smaller amounts of trout. Fish hatcheries have the greatest annual allocation of water in the Derwent catchment, at 152,675 ML or 39 % of the total allocation. This water use is considered to be a non-consumptive use, as water is diverted through the farm and returned some distance downstream. However, most hatcheries have limited water quality treatment, with the exception of the new operation at New Norfolk which has installed recirculation systems (Eriksen et al., 2011).

Tassal conducts quarterly water quality monitoring at the Russell Falls hatchery at three sites:

1. upstream
2. downstream
3. discharge from the hatchery

In addition, Tassal has conducted a freshwater macro invertebrate survey in the Tyenna River adjacent to the Russell Falls hatchery, which suggested that hatchery operations at this site were not having a detrimental effect on invertebrate communities within the Tyenna River (Tassal Sustainability Report, 2013). More detailed monitoring data were not available at the time of this report.

3.2.4 Land use and recent developments

The most recent available land use mapping for the Derwent catchment is derived from a statewide mapping project based on data collected during the summer of 2009/10, through a collaboration between the three NRM regions and DPIPWE. More recent land use mapping – based on 2013 conditions – is currently underway by DPIPWE, but these maps and derived products have not yet been released.

Secondary land use maps for the Derwent and Jordan River catchments for 2009/10 are presented in Figures 3.9 and 3.10, while the relative proportion of major land use categories are presented as pie charts (Figures 3.11 and 3.12). Based on these maps, the major land uses across the Derwent catchment consist predominantly of nature conservation and other substantively natural areas (54%),

Table 3.4 Fish hatcheries in the Derwent catchment

Location	Species	Discharge point	System
Wayatinah	Atlantic salmon	Wayatinah Lagoon-Derwent (Saltas)	Hatchery, flow-through
National Park Russell Falls	Atlantic salmon	Tyenna River (Tassal)	Hatchery, flow-through
Florentine	Atlantic salmon	Florentine River (Saltas)	Hatchery, flow-through
Karanja	Atlantic salmon	Tyenna River (Tassal)	Hatchery, flow-through
Salmon Ponds	Trout	Plenty River (IFS)	Hatchery, flow-through
Broadmeadow	Atlantic salmon	Derwent River below Meadowbank (HAC)	Hatchery, flow-through/ recirculation
New Norfolk	Trout	Derwent River (IFS)	Hatchery, recirculation

Figure 3.9 Secondary land use map for the Derwent catchment (source: NRM South)

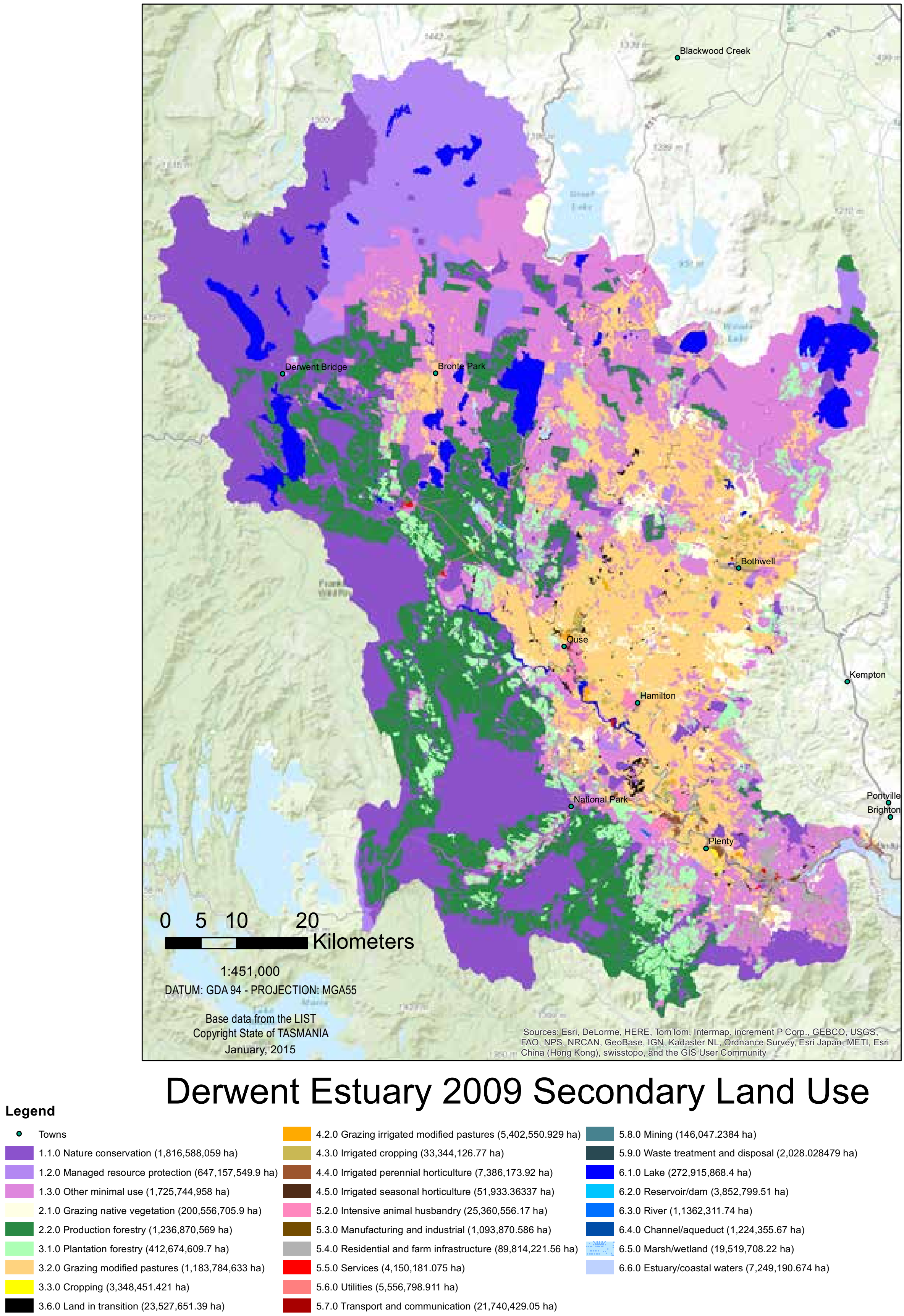
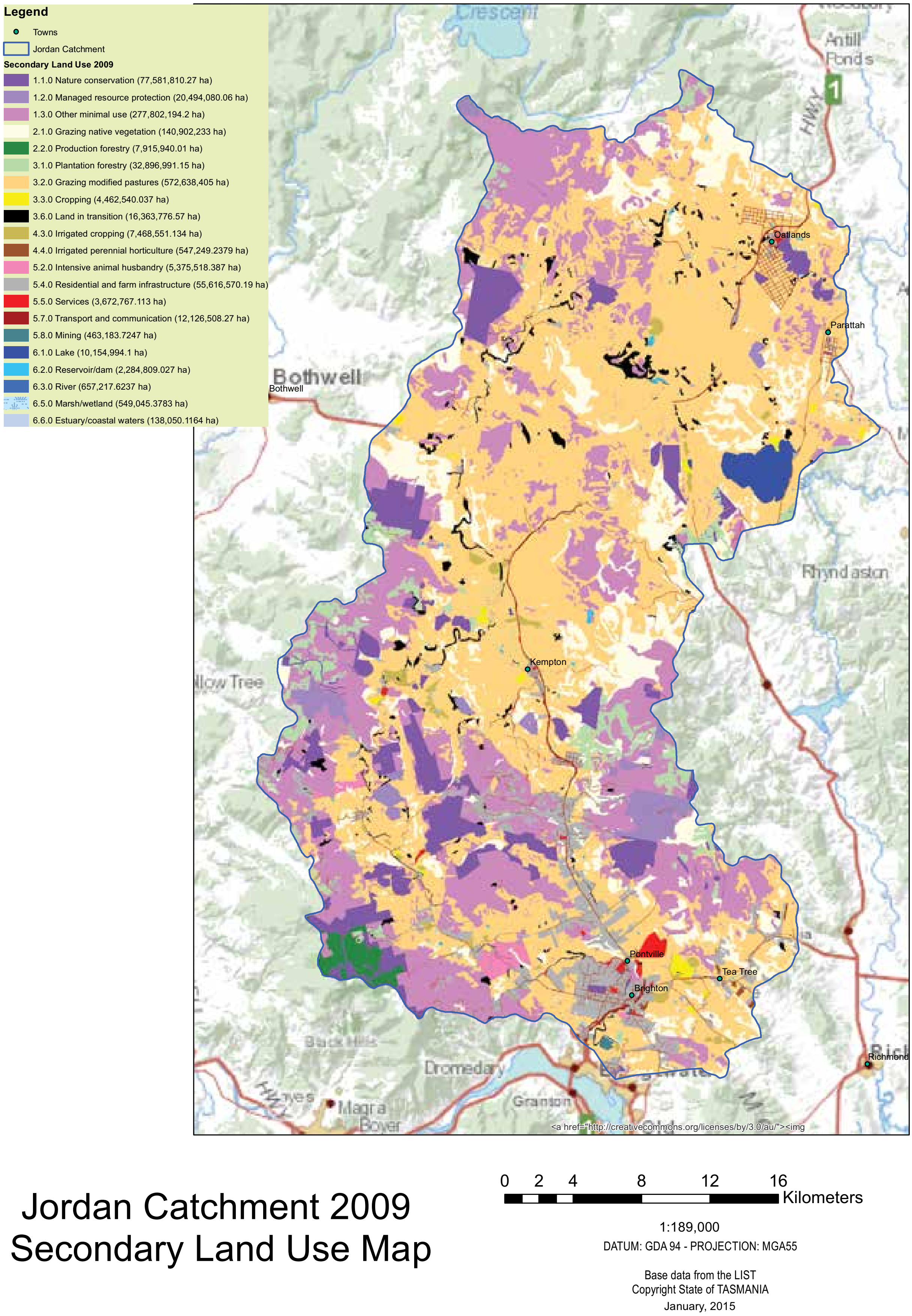


Figure 3.10 Secondary land use map for Jordan River (source: NRM South)



followed by forestry (21%), agriculture (primarily grazing 19.1%), lakes/waterbodies (4.1%) and residential/services/etc (1.6%).

In contrast, agriculture (primarily grazing) is the predominant land use in the Jordan River catchment at 64%, followed by conservation and other minimal use at 28%, with minor areas of forestry (3%), residential/services/etc (4%) and water (1%) making up the remainder.

Further discussion of major land use activities, including recent and planned developments, is provided below.

Figure 3.11 Secondary land use in the Derwent catchment by category (2009/10) (Source: NRM South)

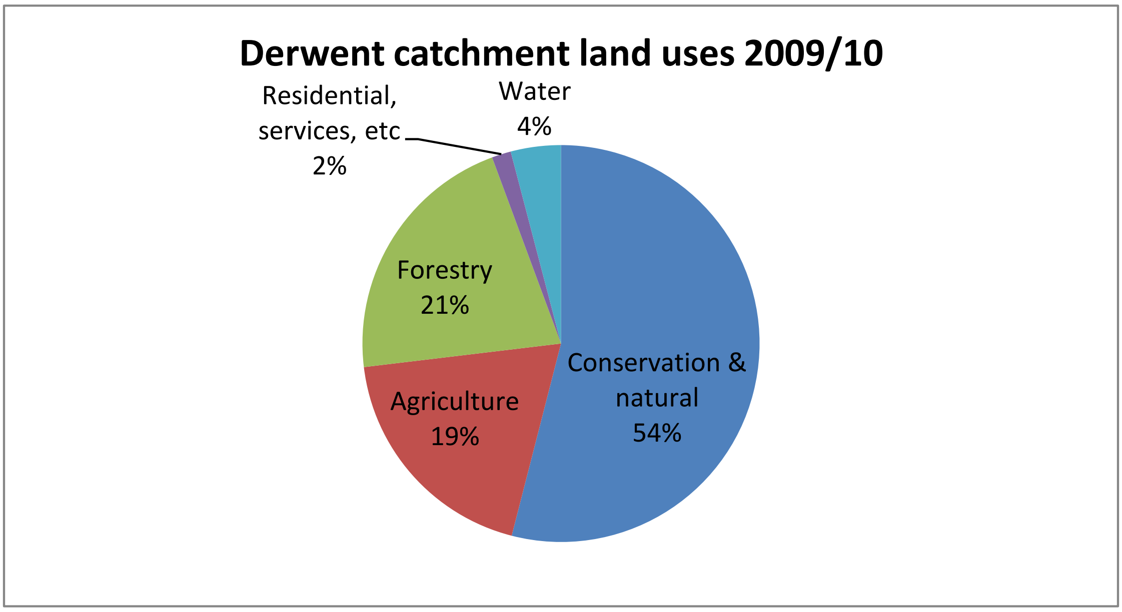
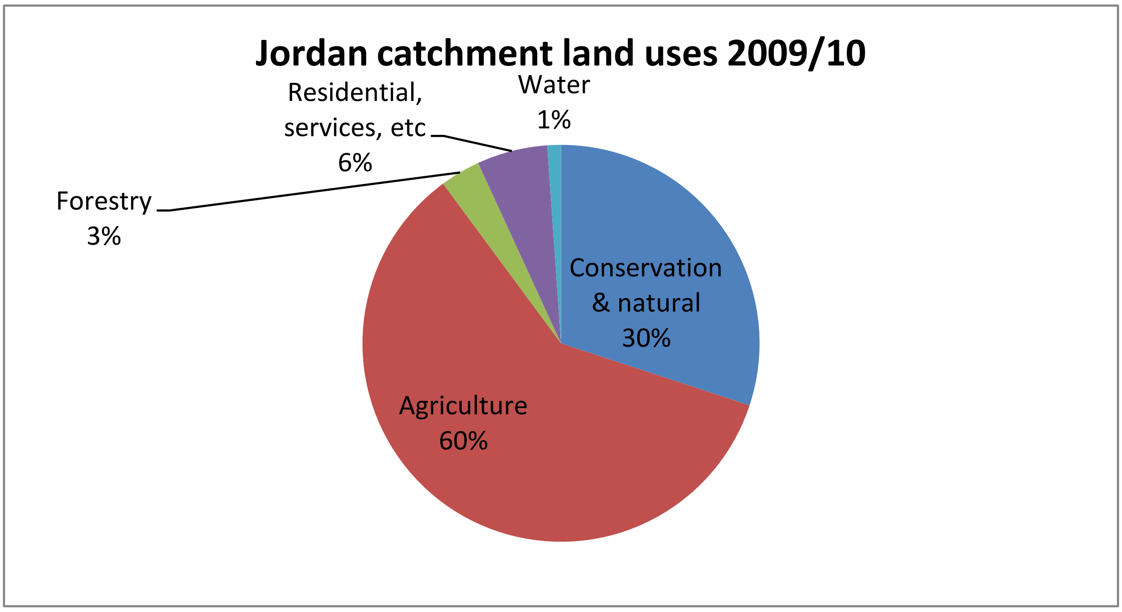


Figure 3.12 Second land use in the Jordan catchment by category (2009/10) (Source: NRM South)



Conservation and other natural environments

Approximately 1,817 km^2, or 23%, of the Derwent catchment is protected as nature conservation areas, including 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. An additional 647 km^2 (8%) is classified as being 'managed resource protection' (primarily associated with hydro operations), together with 1,726 km^2 (22%) classified as 'other minimal use'. These substantively natural areas include both public and private lands, and are located primarily in the far northern and southern ends of the catchment.

Forestry

Forestry is a significant land use, particularly in the western and northern areas of the catchment, with 16% (1237 km^2) of the catchment occupied by production forestry and another 5% (413 km^2) in plantation forestry (NRM South mapping). Most production forests are dominated by *Eucalyptus delegatensis* (gum-top stringybark), *E. obliqua* (brown top) and *Eucalyptus regnans* (swamp gum). *E. regnans* is the tallest growing flowering tree in the world, with significant old growth forests found in the Styx and Upper Florentine Valley, and along the River Derwent near Wayatinah. Native forest harvesting is undertaken by a variety of methods dependent upon forest type. All native forest is regenerated back to native forest. A number of plantations, consisting mainly of *E. nitens* and *Pinus radiata* (radiata pine), have also been established on both public and private lands. These plantations are more broadly distributed across the catchment.

Forestry Tasmania manages the Derwent Forest District, much of which falls within the Derwent River catchment. Three year Wood Production Plans are published each year, identifying coups to be harvested as well as any proposed roads; more detailed Forestry Practices Plan are also available for individual coupes (see www.forestrytas.com.au/forest-management/3yp/derwent-district for details). There are also substantial areas of private forests and plantations within the catchment.

There were relatively few changes in forestry activities in the Derwent Forest District during the 2009 through 2013 period, however since the signing of the Tasmanian Forest Agreement in late 2012 and the associated legislative and tenure changes that have occurred since, a reduction in harvesting has occured, e.g. in the Styx and Butlers Gorge areas. Water quality monitoring activities have largely focused on pesticide and herbicide applications, using risk-based monitoring systems (NRM South and use maps, 2010/11; Forestry Tasmania website and Three year Production Plans; pers. comm. D White Forestry Tasmania, Jan 2015).

Agriculture

Agricultural land in the Derwent catchment covers an area of approximately 3,300 km^2, and is predominantly located in the catchments of the 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.

There have been a number of new developments since 2009, including expansion of irrigated agriculture, as well as the expansion of dairy operations. New and proposed irrigations schemes, including SEIS-3, will also increase irrigated agriculture, though much of this will be in adjacent catchments but using River Derwent water (see Section 3.2.3). There are currently about 5000 cows on nine farms in the catchment, with a 3–5 year target of an additional 3000 cows that could be hosted in the catchment, or an estimated 1000 ha of land converted to dairy, at a stocking rate of 3 cows/ha (pers. comm. Dairy Tas).

Residential, commercial and other intensive land uses

The Derwent catchment lies principally within the Central Highlands municipality, with a smaller area in the Derwent Valley council. The total population of the catchment above New Norfolk is relatively small (<3,000); with larger population centres at Bothwell, Maydena, Ouse and Hamilton. Commercial, and industrial activities are also relatively small scale and include petrol stations, landfills and waste transfer stations, sawmills/treated pine facilities, quarries and mines, and other small forestry and agricultural operations. There are 13 small (Level 1) wastewater treatment plants (WWTPs) and two Level 2 plants (Bothwell and Lake St Clair), as well as about 30 other Level 2 premises regulated by the EPA. The majority of these are quarries and gravel pits (Eriksen et al., 2011).

3.2.5 Water quality

Derwent Catchment Review, 2011

In 2010, the DEP and NRM South commissioned a detailed review of the Derwent catchment, with support from DPIPWE, Southern Water and Hydro Tasmania. A key focus of this report (Eriksen et al., 2011) was to collect, compile and analyse water quality data collected in the catchment over the previous decade, report on conditions and trends, and identify existing and potential threats to water quality. The following discussion has been extracted from the report's Executive Summary

Analysis of water quality was divided into five regions, largely based on the grouping of waterways within the power generation scheme, as this is one of the most significant influences on water movement through the catchment. These regions and their general water quality characteristics were described as follows:

- The Upper Derwent headwaters of the Central Plateau which have been developed into the Upper Derwent Power Scheme. This group includes the upper Derwent (Lake St Clair through to Tungatinah), the Clarence, Nive and upper Dee rivers, which flow to Tungatinah, and Lake Liapootah. This region was found to have overall good water quality with issues generally associated with flow regulation and lake level changes;
- The Lower Derwent Power Scheme Lakes, downstream of Lake Liapootah, including Wayatinah and Cluny lagoons, and Lakes Catagunya, Repulse, and Meadowbank. These lakes are generally a 'throughput' for the water from the upper catchment overprinted by local land use impacts, point source inputs and seasonal changes within the lakes;
- Western inflows to the Derwent River (Florentine, Broad, Tyenna, Styx and Plenty rivers). These unregulated rivers have generally good water quality, with aquaculture, agriculture and forestry activities common in the catchments;
- Eastern inflows to the Derwent (Dee, Ouse and Clyde rivers). These rivers have highly modified flow regimes due to water diversions and regulation for irrigation. Land use impacts are most intensive in these catchments with turbidity, elevated nutrients and salinity identified water quality risks;
- Derwent below Meadowbank to New Norfolk Bridge, including the intake for the Bryn Estyn Drinking Water Treatment Plant. Similar to the lower Derwent lakes, this part of the Derwent is dominated by power station releases with water quality affected by local land-use.

A conceptual model for the catchment was developed (Figure 3.13) and a number of stressors and risks were identified, including climate change, blue-green algae blooms, changes in land and water use, hydropower operations, aquaculture and recreational pressures.

The report found that monitoring programs within the catchment have been temporally and spatially fragmented, making catchment scale integration and comparison of data extremely difficult, particularly with respect to longer-term trends and catchment loads. A long-term broad-scale monitoring program was recommended to better assess catchment health and identify emerging threats.

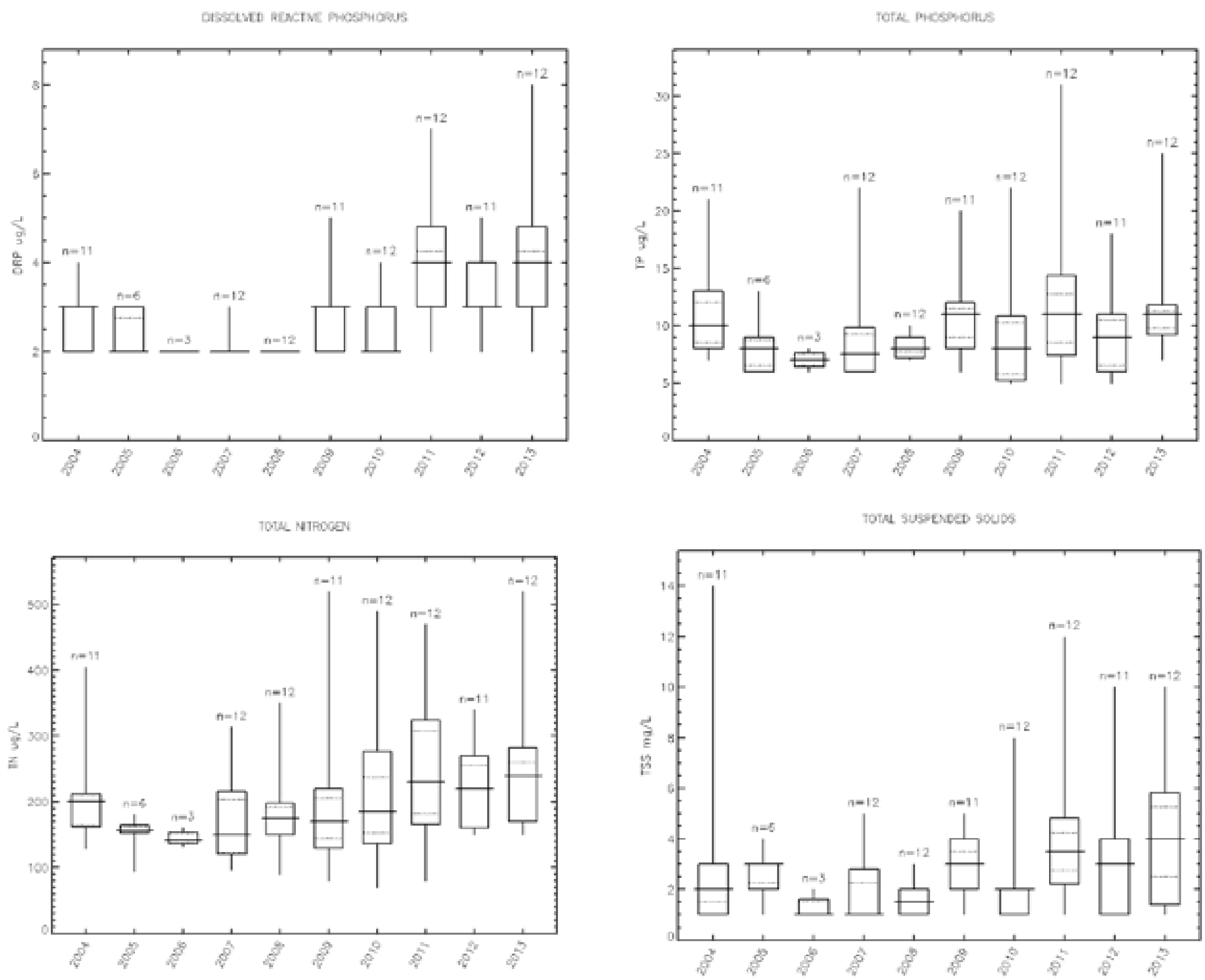
In response to these recommendations, the DEP has established a Derwent Catchment Working Group, which includes representatives from DPIPWE, NRM South, Tas Water, Hydro Tasmania, Tassal and Derwent Catchment NRM. This group meets regularly to share information and collaborate on water quality issues, including monitoring activities in the catchment.

Water quality trends at New Norfolk

As part of the review of ambient water quality carried out for this report (see Section 5), the DEP analysed long term water quality records at New Norfolk. This site has been monitored by Norske Skog Boyer since 1999 as part of the DEP monitoring program, and previously as part of their license conditions with the EPA. Some previous data is also available, collected in 1993/94 as part of the Derwent Estuary Nutrient Program (Coughanowr, 1995), as well as higher frequency data collected upstream at Bryn Estyn in 1996–98 as part of the Derwent Catchment Study (Coughanowr, 2001, Wild-Allen et al, 2014).

A review of this data suggests that there has been an overall decline in water quality since the early 1990s, particularly with respect to dissolved reactive phosphorus, total nitrogen, total phosphorus, total suspended solids and total organic carbon (see Figure 3.13). The variations in water quality may be related to a number of factors including changes in catchment yields due to climatic variation, changes in land use and land-based activities such as increased irrigation and aquaculture development, dairy expansion, and loss or degradation of riparian vegetation. While water quality is currently still relatively good by national standards, it is important to understand and manage the causes of water quality changes to prevent potential problems in the upper estuary, such as toxic blue-green algal blooms, seagrass loss, and exacerbation of already low dissolved oxygen (DO) levels. See Section 5 for further discussion.

Figure 3.13 Water quality trends at New Norfolk 2004 to 2013



3.2.6 *Water management and planning*

There is no overarching catchment management legislation in Tasmania, and no single body with planning or management responsibility for the Derwent catchment. Key legislation, policies, regional plans and recent projects are outlined below.

State Government

The *Water Management Act 1999* regulates water use through the allocation and licensing of direct or stored water extractions. The Act also enables development of catchment-based Water Management Plans. No new Water Management Plans relevant to the area have been completed since the River Clyde, and Lakes Sorell and Crescent Water Management Plans took effect in 2005, nor are any new plans in progress.

Water quality is managed through the State Policy on *Water Quality Management, 1997*. Protected Environmental Values (PEVs) were set for the Derwent estuary and catchment in 2003, and Water Quality Objectives (WQOs) have been drafted and are pending EPA Board review and approval. See epa.tas.gov.au/epa/derwent-estuary-catchment-and-derwent-estuary for details.

Local Government

Local government – specifically the Central Highlands and Derwent Valley councils – is responsible for managing uses and development on private lands through their respective planning schemes. Both councils also support regional NRM officers and catchment groups, including the development and implementation of the Derwent Catchment NRM plan and various weed strategies.

The *Southern Tasmania Regional Land Use Strategy 2010-2035* was developed through the Southern Tasmanian Councils Authority (STCA) to provide a foundation for the development of new planning schemes. This strategy was designed to facilitate sustainable development, protect and improve amenity and quality of life, and provide greater certainty and direction to the community and industry with respect to land use, development and infrastructure investment decisions (STCA, 2011). A number of these strategies have important implications for water quality.

Other organisations

Greening Australia has developed/implemented a number of projects within the catchment, including a *River Derwent Conservation Action Plan* for the area between Lake Cluny and New Norfolk; Strategic restoration of key tributaries, (Greening Australia, 2013); *Lake Meadowbank Riparian Management Action Plan 2011* (with support from Hydro Tasmania) and the *Plenty Rivercare Plan* (2010). Most of these projects have included weed control, fencing/managed stock access and revegetation with native species.

Derwent Catchment Committee (previously Derwent Catchment NRM) has an existing catchment management plan (*Derwent Catchment Natural Resource Management Plan 2002*, currently under review) and has prepared and implemented a number of weed management projects, including the Upper Derwent Highland Lakes World Heritage Area Weeds Buffer Project, with a number of other partners.

NRM South developed The Natural Resource Management Strategy for Southern Tasmania 2010-15 (NRM South, 2010). This strategy identified the management of waterways and wetlands to maintain or improve water quality and ecosystem health as a key issue, as well as the need for ongoing monitoring to inform decision making and effective natural resource management planning. This strategy is currently under review and due for release prior to end 2015. NRM South also developed the Southern Tasmanian Weed Strategy (2005–10) in collaboration with STCA, along with subsequent updates.

Forestry Tasmania developed the *Three year Wood Production Plan* (2014–15 to 2016–17) and Forestry Practice Plans for individual coupes. See www.forestrytas.com.au/forest-management/3yp/derwent-district

Hydro Tasmania has developed the Derwent Environmental Review, 2001.

TasWater, Southern Water or Hobart Water have developed a number of planning documents, such as the Derwent River Drinking Water Catchment Management Plan (Hobart

Water, 2007) and Background Paper (Hobart Water, 2006). An updated Drinking Water Risk Assessment is currently in progress.

3.2.7 Catchment stressors, risks and recommendations

The Derwent Catchment Review (Eriksen et al., 2011) and subsequent information have identified a number of stressors and risks that could adversely affect downstream users and the health of the Derwent estuary more broadly. These include:

- Changing water quality, as described in Section 5;
- Changing flow regime associated with hydropower operations, increasing water allocations and climate change;
- Changes/intensification of land and water uses, including aquaculture, irrigation and dairy;
- Management and monitoring of potential toxicants, including blue-green algae and herbicides/pesticides;
- Lack of a coordinated whole-of-catchment management and monitoring system.

With respect to monitoring, Eriksen et al. 2011 recommended the following:

- The goals of existing monitoring programs within the greater catchment are not universal and necessarily reflect the management responsibilities, budget and interests of each organisation. Most water quality monitoring was found to be 'reactive' in response to an incident or set of conditions, or involve ongoing monitoring of a routine set of parameters for a specific purpose (e.g. drinking water intake). Monitoring programs are spatially and temporally fragmented, with rationalisation of some key longer term sites and programs occurring recently. This variation in spatial and temporal monitoring, along with variation in parameters, makes catchment scale integration of information or comparison extremely difficult.
- The primary recommendation arising from the review is that a long-term broad-scale monitoring program be instigated for the purpose of assessing catchment health in the Derwent catchment, and identifying emerging threats. A multi-stakeholder approach, modelled on the Derwent Estuary Program, would provide a template for coordinated monitoring, data management, sharing and review. A collaborative approach to monitoring and reporting will improve communication of existing and emerging issues between stakeholders, provide a basis for whole of catchment reporting, and improve opportunities for management of often complex or widespread natural resource issues.
- An integrated monitoring program also requires a better understanding of actual water usage in the catchment. This could be provided by the metering of water allocations with the information made available for interpretation of the water quality monitoring results.
- Some of the suggested monitoring already occurs, but the results are difficult to access efficiently due to data formats or other logistical constraints. Improved data storage and sharing between catchment users would increase the usefulness of this already existing information.

3.3 D'Entrecasteaux Channel and Storm Bay

3.3.1 Overview

The D'Entrecasteaux Channel and Storm Bay play an important role with respect to the overall circulation and water quality in the Derwent estuary. Marine water from Storm Bay travels up the bottom of the estuary as far as New Norfolk and gradually mixes with over-lying freshwater from the River Derwent. Previous modelling has also indicated that there is a net transport of water from the Channel into the Derwent (Herzfeld et al., 2005). Thus changes in water quality in these adjacent coastal areas may have widespread implications for the Derwent estuary. In particular, changes in oceanographic currents associated with climate change and increasing aquaculture production may influence estuary nutrient and algal dynamics.

3.3.2 The D'Entrecasteaux and Huon Collaboration

This collaborative project was established in 2011 as an initiative of Kingborough Council, and has been supported by the DEP, NRM South, Tassal, Huon Aquaculture, Tas Water and Huon Valley Council. The partners have agreed to work together to facilitate and report on actions to sustain a healthy waterway, track waterway conditions, trends and inputs, and increase public awareness and engagement in caring for the waterway.

Recent outputs have included the 2012 State of the Channel Report, a Joint Action Plan and a number of community engagement activities (see www.ourwaterway.com.au/ for details).

3.3.3 State of the D'Entrecasteaux Channel and the lower Huon Estuary 2012

This report, together with an associated inventory of scientific information (Parsons, 2012) was the first major publication of the D'Entrecasteaux Channel Initiative. The report reviews and updates available scientific data from 1999 to 2012, and is an excellent source of information: it includes a general overview, anthropogenic inputs, water and sediment quality, seafood safety, nutrient sources and modelled impacts, foreshore environment, natural values, habitats and species, introduced species and climate change. The report also identifies a number of key management issues and data gaps for further investigation.

3.3.4 BEMP monitoring and review

Another major report completed during the current reporting period was the Evaluation of Broadscale Environmental Monitoring Program (BEMP) Data from 2009-2012 (Ross & McLeod, 2013). This report reviewed and analysed water and sediment quality data collected at 15 sites within the D'Entrecasteaux Channel and Huon River/Port Esperance Marine Farm Development Plan (MFDP) areas.

The report also evaluates the data in the context of major system drivers, previous environmental data sets and broader ecosystem performance measures. Catchment inputs, fish farms and oceanic inputs were found to be the major sources of nutrients, but vary in the form and timing of nitrogen they input to the system.

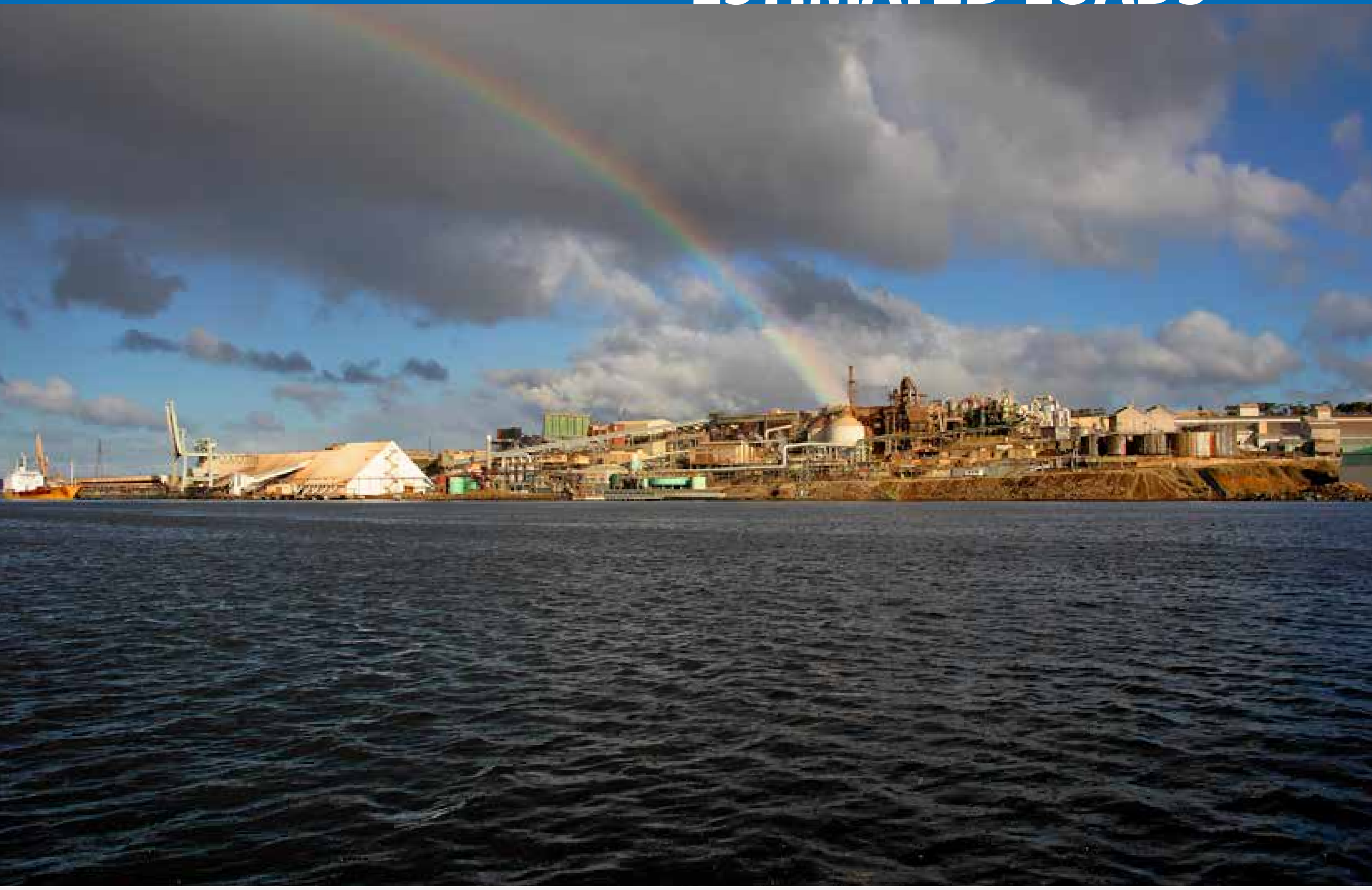
Comparison of previous data sets with the BEMP data indicated a high degree of natural variability, as well as some system changes consistent with increased inputs of organic matter and nutrients associated with expansion of marine farming. These include an increase in ammonium concentrations in bottom and surface waters and a decrease in oxygen concentrations in bottom waters of the Huon Estuary. Evaluation of longer-term changes in Channel water quality was not possible due to a lack of comparable pre-BEMP ammonium and dissolved oxygen data. There was no clear evidence of a change in water column productivity (i.e. phytoplankton biomass), but some indication of a change in phytoplankton composition. There was also no evidence of major broad scale changes in sediment condition and infaunal community composition. The full report can be accessed at dpipwe.tas.gov.au/Documents/Ross---Macleod-BEMP-Data-Review-2009-2012-.pdf

3.3.5 Storm Bay research and recent/proposed developments

There have been several recent projects undertaken or currently underway in Storm Bay to better understand and characterise water quality in this area. One such project commenced in 2009 and conducted baseline monthly water quality surveys at 5 to 6 sites to better understand effects of climate change and climate variability on fisheries and aquaculture in the region, including changing currents and primary productivity (Crawford et al., 2011). This information is being used to inform the development of climate change adaptive management strategies for commercial and recreational fisheries and for the potential expansion of salmon aquaculture into Storm Bay. The data has also been used to support modelling of the bay's water circulation and ecosystem dynamics.

There is considerable interest in the expansion of salmon aquaculture within Storm Bay, for example along the shoreline of North Bruny Island (HAC, 2014). The potential for impacts of aquaculture expansion in Storm Bay on Derwent estuary water quality would depend on the size and proximity of these farms to the mouth of the Derwent. This has not yet been investigated.

4.0 POLLUTION SOURCES AND ESTIMATED LOADS



Contaminants enter the Derwent estuary from a variety of sources. During the 2009 to 2013 reporting period, point sources included twelve wastewater treatment plants (WWTPs), and two large industries (the Norske Skog paper mill and Nyrstar Hobart smelter) as shown in Figure 4.1. Diffuse sources included 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 boating, marinas and port facilities. 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, and a range of toxicants including heavy metals and hydrocarbons.

4.1 Wastewater treatment plants

In many urban areas sewage effluent is a major source of nutrients to aquatic systems. Nutrients may trigger algal blooms, seagrass die-off and other ecosystem changes, while pathogens found in wastewater (as indicated by faecal indicator bacteria) represent a risk to human health. Other wastewater contaminants include commercial, industrial and household chemical wastes, as well as disinfection by-products.

In Tasmania, wastewater treatment plants (WWTPs) are regulated by the Environment Protection Authority (EPA), under the provisions of the *Environmental Management and Pollution Control Act 1994.*

The *State Policy on Water Quality Management 1997* provides the overarching policy framework for water management. It forms the foundation for the prioritisation of effluent reuse wherever feasible; sets discharge limits in line with published *Emission Limit Guidelines* for WWTPs or discharge limits based on site-specific considerations; and allows for the setting of mixing zones where required.

Annual environmental reports are required for all WWTPs regulated by the EPA.

Prior to 1 July 2009 the provision of water and sewerage services was mainly the responsibility of individual councils. Following the establishment of three regional water corporations under the *Water and Sewerage Corporation Act 2008*, Southern Water became the water and wastewater service provider for southern Tasmania. As of 1 July 2013, the regional water corporations were amalgamated into a single state-wide entity, TasWater.

During the period 2009 to 2013, there were 11 wastewater outfalls discharging to the Derwent estuary at the locations shown in Figure 4.1. These outfalls serviced 12 WWTPs (the Green Point/Bridgewater outfall services two WWTPs).

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 Lauderdale, 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 may have localised effects on water quality.

Some sewage and wastewater is also discharged directly to the Derwent from recreational and commercial vessels, many of which lack holding tanks. In December 2013, the EPA published the *Boat Sewage Management Directive*, which differentiates between small and large vessels and sets a number of guidelines and other criteria for the discharge of boat sewage into marine waters. Boats carrying 16 or more people are not permitted to discharge within one nautical mile of land, while discharges from smaller boats are allowed in accordance with specific criteria. In the Derwent, no sewage discharge is permitted upstream of the Bridgewater Causeway. See EPA website below, and associated map for further details:
epa.tas.gov.au/epa/boat-sewage-management-directive

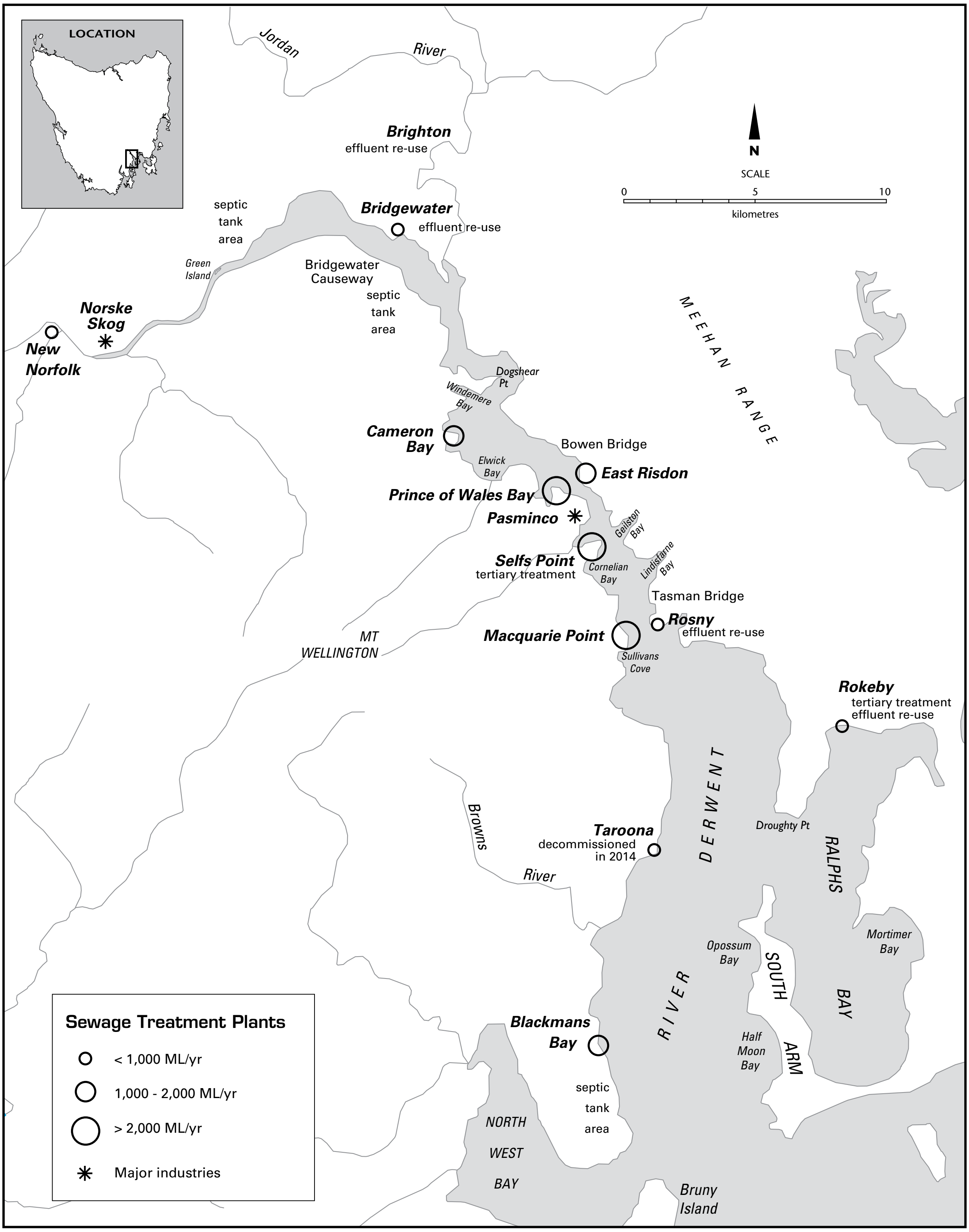
Accidental spillage of raw sewage from WWTPs, pump stations and other infrastructure malfunctions occurs from time to time and is typically related to stormwater infiltration during wet weather, electricity outages or blockages due to tree-root intrusions during dry weather. Localised impacts from these sources can be significant, but are typically short-lived.

4.1.1 Effluent quantity, quality and recent trends

The type and degree of wastewater treatment, and thus effluent quality, varies from plant to plant. Nine of the plants that discharge to the Derwent 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). In addition, effluent from a number of plants is reused for irrigation, reducing flows and associated loads, as described in Section 4.1.2. (Note: the Taroona WWTP was decommissioned in 2014, and no longer discharges to the Derwent.)

The majority of Derwent estuary WWTPs receive a combination of domestic and commercial wastewater generated within their respective catchments, while some WWTPs also receive large quantities of industrial trade

Figure 4.1 Wastewater treatment plants and major industries



wastes (e.g. Macquarie Point, Cameron Bay, Prince of Wales Bay and Selfs Point). In addition, some WWTPs receive tankered waste, particularly Prince of Wales Bay and Macquarie Point.

Effluent is monitored at all WWTPs on at least a monthly basis for total suspended solids (TSS), biochemical oxygen demand (BOD), nutrients (dissolved and total phosphorus, ammonium, nitrate + nitrite, total nitrogen (TN)) and faecal bacteria (thermotolerant coliforms and enterococci).

Continuous monitoring of flow volume is also carried out at all plants. Additional parameters are analysed at some plants, depending on the characteristics of the catchment, and all effluent is disinfected prior to discharge. Chlorine is the most commonly used disinfectant. This data is reported to the EPA and has been analysed here to give an indication of typical effluent quality and to calculate approximate pollutant loads discharged to the estuary.

A summary of monitoring results for each of the 12 Derwent

Figure 4.2 Derwent wastewater treatment plants – relative contributions of contaminants in 2013/14, after reuse

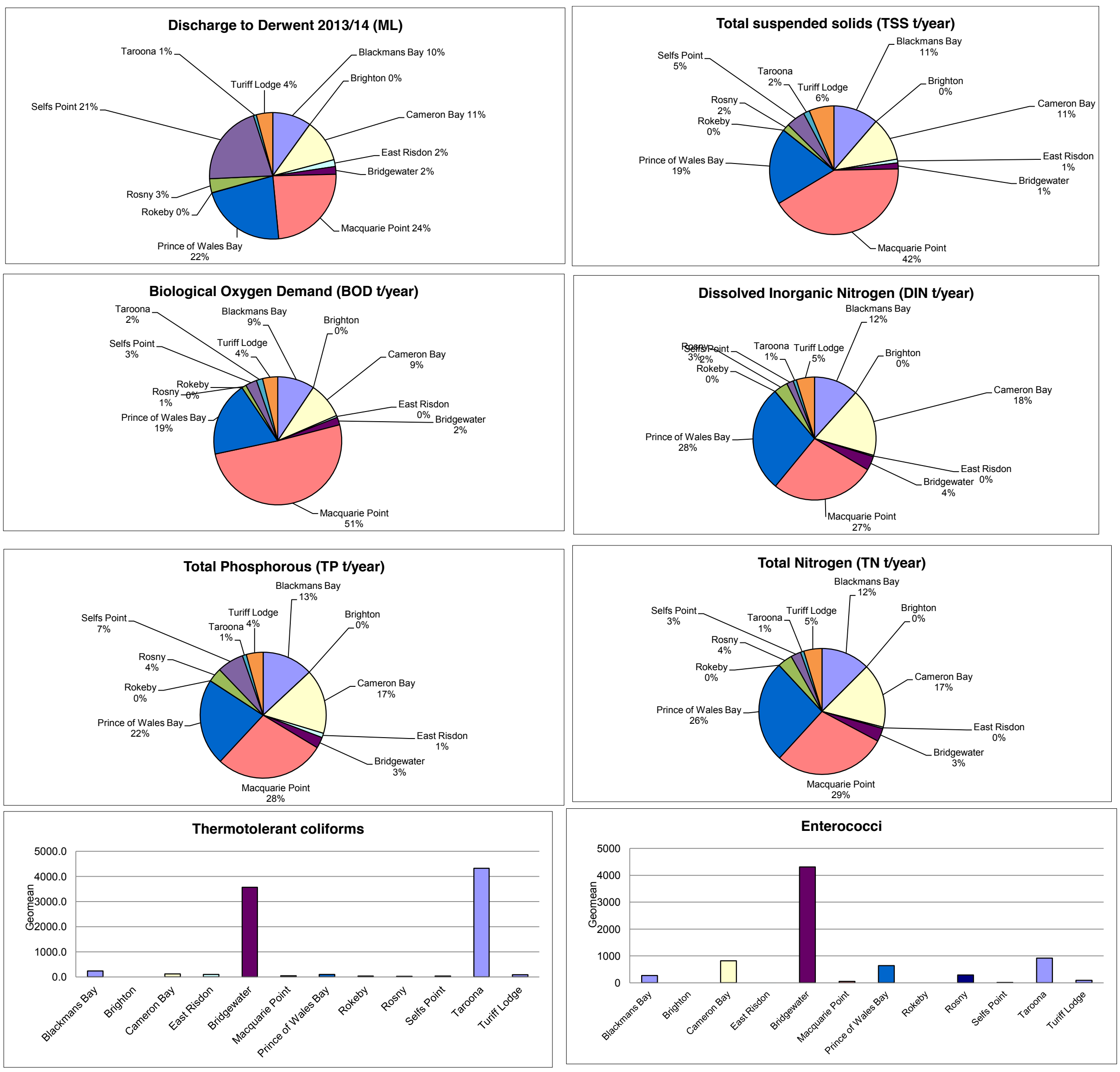


Table 4.1 Derwent wastewater treatment plants – average annual flows, mean concentrations and annual inputs, after reuse

Treatment plant	Discharge	TSS		BOD		Ammonia		NOx		DIN		Total Phosphorous		Total Nitrogen		Therm coli *	Enterococci	vol effluent reused	% effluent reused
	Total (ML)	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			
Blackmans Bay	1544	19.8	32.3	20.0	37.1	23.7	38.3	4.6	8.1	28.3	46.4	7.8	11.5	35.6	61.5	236	273	0	0
Brighton	0		0.0		0.0		0.0		0.0		0.0		0.0		0.0			281	100%
Cameron Bay	1698	14.9	31.0	15.5	36.3	10.2	28.8	20.5	42.0	30.7	70.8	7.5	14.6	37.4	81.3	121	814	46.5	3%
East Risdon	271	10.3	2.7	7.0	1.9	3.0	0.8	1.6	0.6	4.6	1.4	3.4	1.0	5.8	1.9	101	5	0.0	0
Bridgewater	308	12.5	4.3	19.0	7.7	25.6	9.9	18.6	4.8	44.2	14.7	8.1	2.5	54.8	16.7	3570	4313	539	64%
Macquarie Point	3711	31.5	118.7	44.5	200.9	18.1	74.4	9.5	35.1	27.6	109.5	7.2	24.9	35.8	142.8	53	46	102.0	3%
Prince of Wales Bay	3431	7.1	55.0	18.5	74.8	32.5	98.9	3.4	12.5	35.9	111.4	6.0	19.6	40.8	129.5	97	643	0.0	0
Rokeby	10	6.0	0.1	2.5	0.0	1.0	0.0	1.8	0.1	2.8	0.1	1.5	0.0	4.3	0.1	36	0	620.0	98%
Rosny	556	11.0	5.0	9.0	4.5	16.0	9.5	7.6	5.0	23.6	14.5	6.1	3.2	33.3	18.6	22	288	1685	75%
Selfs Point	3225	4.1	13.5	2.5	11.4	0.4	3.8	0.4	3.3	0.8	7.1	1.3	6.0	3.0	12.7	42	14	14.5	0.5%
Taroona	117	39.0	4.4	46.0	6.3	25.0	2.8	6.9	0.7	31.9	3.5	8.3	0.9	41.7	4.3	4324	920	4.5	4%
Turiff Lodge	653	16.2	17.8	19.0	15.1	22.0	13.6	5.8	5.4	27.8	19.0	6.1	3.8	36.3	23.0	90	95	0.0	0
Total loads																			
2013/14	15524	285		396		281		118		398		88		492					
2012/13	15619	263		330		340		85		425		90		502					
2011/12	18566	412		481		324		93		417		100		480					
2010/11	19673	418		406		322		86		409		105		502					
% change 2010//11-13/14	**21%**	**32%**		**2%**		**13%**		**-36%**		**2%**		**16%**		**2%**					

Notes:

- Total discharge has been adjusted for reuse schemes
- Discharge values derived from TasWater Annual Environmental Reports, Section C
- Concentrations are median values for 12 month period, with the exception of thermotolerant coliform and enterococci, which are based on geomean values
- Data presented for most WWTPs is derived from one effluent sample per month, annual loadings should be viewed as "best estimate only"
- Macquarie Point measured carbonaceous biochemical oxygen demand up until Nov 2012 and normal BOD thereafter; this may have resulted in an apparent increase in BOD loads

WWTPs is presented in Table 4.1, including total annual flows, median concentrations of key parameters and estimated loads. The combined total flow from all WWTPs discharging to the Derwent in 2013/14, after reuse, was 15,524 ML or 42,532 kL/day. Cumulative loads of TSS, BOD and nutrients for all plants in 2013/14 are also provided, as are comparative loads for the previous three years.

Figure 4.2 illustrates proportional contributions of key parameters from each WWTP. The three largest WWTPs in terms of flows are Macquarie Point, Selfs Point and Prince of Wales Bay – these contributed 67% of treated effluent to the estuary in 2013/14. Four plants contributed over 80% of sewage-derived TSS, BOD and nutrients (Macquarie Point, Prince of Wales Bay, Cameron Bay and Blackmans Bay). Of these, Macquarie Point is by far the largest contributor, followed by Prince of Wales Bay.

Due to difficulties in calculating mass emissions of faecal bacteria, cumulative loads have not been calculated; instead the geomean values for each plant are provided. In 2013/14, thermotolerant coliform counts at WWTPs were generally within license conditions (200 for cfu/100 ml for freshwater and 750 cfu/100 ml for bays and estuaries), but with elevated counts reported at Taroona and Green Point (geometric mean: 4324 and 3570 respectively). Enterococci levels were more variable between plants and did not necessarily correspond to thermotolerant coliform levels.

Figure 4.3 Summary of combined annual loads from wastewater treatment plants 2010/11 to 2013/14

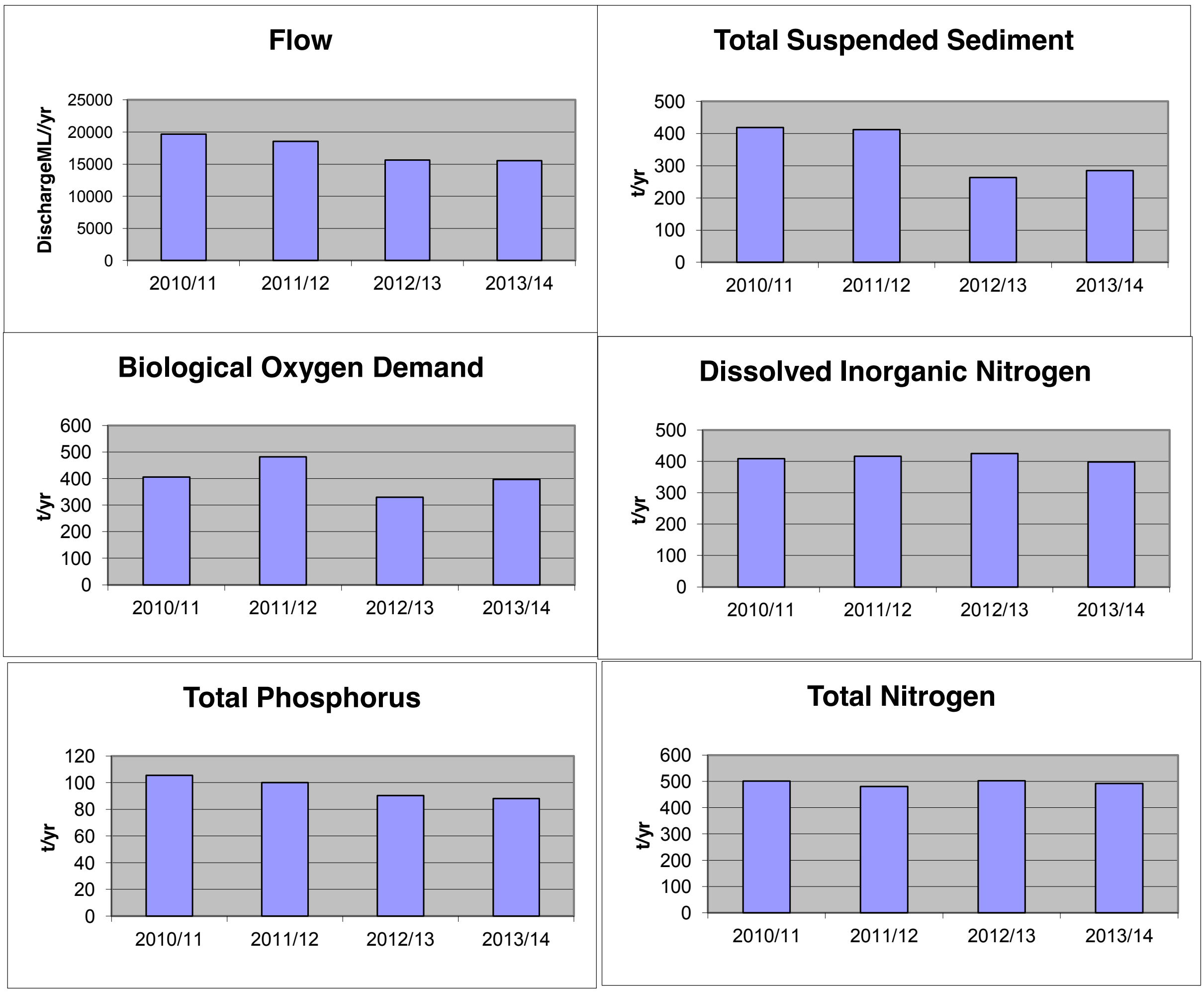


Figure 4.3 shows how cumulative loads from all plants combined have changed over the past four years (2010/11 through 2013/14). The total volume of effluent discharged to the estuary has decreased markedly in recent years, due in large part to the installation of water meters. For example, 2013/14 flows were about 20% lower than in 2010/11 flows. However, as this resulted in a higher concentration effluent, cumulative loads of most parameters did not decrease correspondingly. There have been reductions in some parameters – in particular TSS and TP have decreased by 32% and 16% respectively, however BOD, dissolved inorganic nitrogen (DIN) and TN have not declined appreciably.

4.1.2 Effluent reuse

Treated effluent is currently used from several wastewater treatment plants in the Hobart metropolitan area, particularly from Rosny, Rokeby and Brighton/Bridgewater (for agricultural uses), and to a lesser degree from Cameron Bay (Claremont Golf Course), Selfs Point (sports and regatta grounds) and several other plants (internal uses). There is also some wastewater reuse associated with the Collinsvale reuse scheme in Glenorchy. The volume of effluent reused from these various schemes varies from year to year, depending on climatic conditions, user demand, storage capacity and effluent quality (e.g. occasional high salt levels in Rosny effluent). The volumes and sources of effluent reused since 2009 are presented in Figure 4.4. The total volume of effluent reused in 2013/14 was about 3,300 ML. This represents about 18% of the sewage generated in the Hobart metropolitan area, and nearly doubles reuse since 2009/10). The recent increase in reuse has been due in part to improved storage capacity, with the commissioning of the Duck Hole storage dam in June 2013.

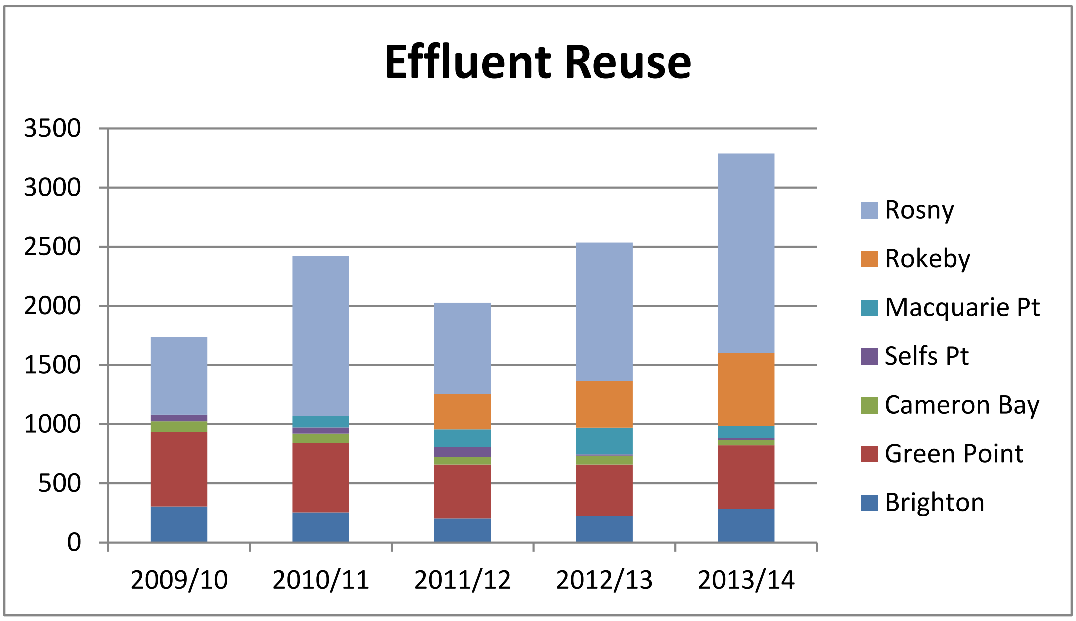
4.1.3 Management actions and new initiatives

Since 2009, a number of strategic reviews, investigations, infrastructure upgrades and other initiatives have been implemented by TasWater, including the following:

Strategic reviews, planning and design

- Kingborough WWTP rationalisation (investigation and planning)
- Turriff Lodge ambient monitoring and discharge management plan development
- Brighton development and expansion plus Green Point process improvements

Figure 4.4 Volume of effluent reused from WWTPs in the Derwent estuary region



- Central Hobart Area WWTP strategy
- Effluent reuse feasibility studies

Monitoring, modelling and investigations

- Derwent Estuary Environmental Assessment project (2010–14), 3 stages, including:
  - Stage 1 – GHD nearfield modeling; diver outfall surveys; risk assessment of 8 outfalls (completed 2011)
  - Stage 2 – CSIRO R&D partnership: real-time nutrient sensors at Bryn Estyn intake and estuary entrance plus towed sensor trials (Wild-Allen and Raynor, 2014); modeling & scenario-testing (completed in 2014/15)
  - Stage 3 – extended monitoring of water, sediment and biota associated with 8 outfalls (commenced in May 2014 for 12 month period);
- Turriff Lodge: outfall relocation studies, mixing zone modelling and ambient monitoring (2012–14);
- Blackmans Bay: new outfall investigations and pre/post construction monitoring of water & infauna (2007–2013).

Infrastructure

- Replacement and extension of the Blackmans Bay outfall (2010);
- Relining of Geilston Bay main (Sept 2010) and section of Sandy Bay foreshore (2011);
- Investigation, planning and upgrade of Salamanca sewerage pumping systems (2012);
- Water metering, resulted in reduced sewage flows (completed 2013);
- Duckhole reuse dam: 1000ML dam to complement on-farm storage (2013);
- Taroona WWTP decommissioned, including construction of new main to Sandy Bay and pumping of effluent to Selfs Point WWTP for tertiary treatment (May 2014);
- Lauderdale Stage 2: replacement of 240 septic systems with reticulated sewerage, pressurised pumping to Rokeby (May 2014).

TasWater is currently developing a long-term strategic plan for Derwent estuary WWTPs, with the objective of rationalising existing plants and improving overall treatment. Following on from the monitoring, modelling and strategic planning activities described above, it is anticipated that major infrastructure projects will be designed and constructed in the next five years.

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 runoff, groundwater seepage and spills.

At present, there are over 50 state-regulated (Level 2) industrial premises and hundreds of local council-regulated (Level 1) premises situated within the greater Hobart catchment. 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).

4.2.1 Nyrstar Hobart Smelter

The Nyrstar Hobart zinc smelter is situated at Lutana on the western shore of the middle Derwent. Nyrstar is a Level 2 industrial premises, operating under an Environmental Protection Notice regulated by the Environmental Protection Authority (EPA). The plant has been operating since 1917 and is one of the world's largest producers of zinc metals and alloys, with an annual production capacity of 280,000 tonnes. Other products and residues produced at the smelter include sulphuric acid, paragoethite, copper sulphate, lead-silver product and cadmium metal.

Contaminants associated with the zinc refinery include heavy metals, arsenic, fluoride, particulates, sulphur oxides/sulphate and some nutrients. These contaminants enter the Derwent via the foreshore outfall/diffuser, groundwater, surface runoff during occasional storm events and air/dust emissions.
In recent years, the majority of heavy metals entering the

Derwent estuary from the Nyrstar site have been associated with diffuse, rather than point sources, and thus annual loads are difficult to estimate with accuracy. During the period 2009–13, it is estimated that groundwater contributed the largest proportion of heavy metals, followed by air emissions, the effluent treatment plant, as well as stormwater runoff when site storage capacity was exceeded. See Figure 4.5 for proportional inputs from these sources in 2012/13.

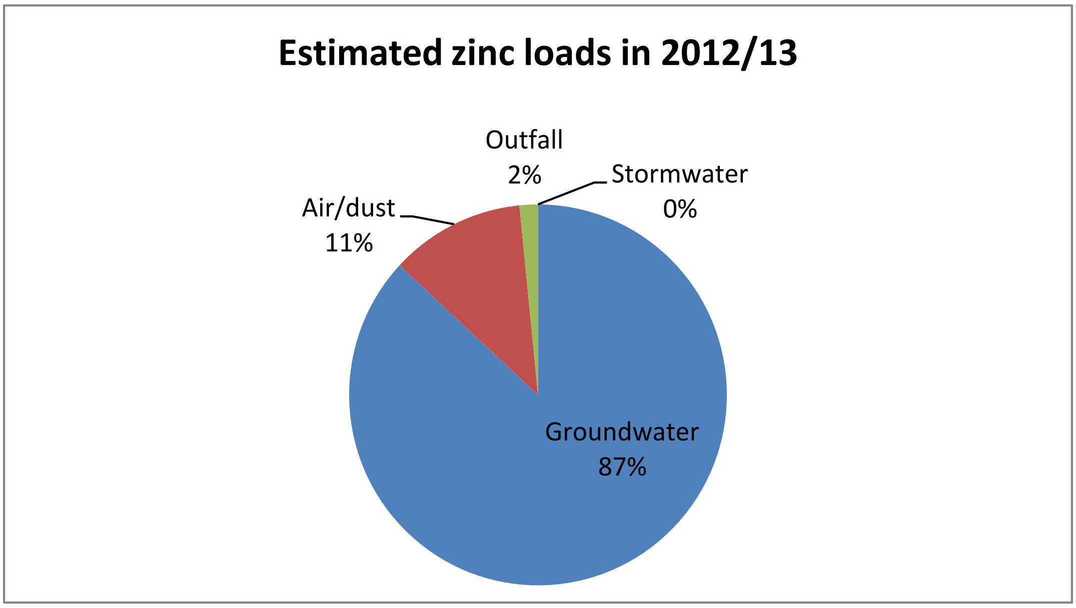
Emission sources from the Nyrstar site are monitored on a regular basis in accordance with EPA license conditions. In addition, ambient water quality monitoring is carried out in the middle Derwent, as is water and sediment quality monitoring in New Town Bay (see Section 5). A long-term fish and shellfish monitoring program is also conducted throughout the estuary (see Section 8). Information in this section was derived from *Nyrstar's 2013/14 Annual Environmental Review, 2014/17 Environmental Management Plan, 2012 Groundwater Management Strategy*, National Pollutant Inventory reporting (2012/13) and other sources, as noted.

Effluent stream

Nyrstar discharges about 60,000 to 100,000 KL/day of aqueous effluent at a monitored outfall point. Approximately 95% of this effluent consists of saltwater taken from the Derwent and passed through a scrubbing system to remove residual sulphur dioxide from tail gas exiting the acid plants. The remaining 5% (about 4,000 to 6,000 KL/day) is treated wastewater, groundwater and stormwater discharged from the Effluent Treatment Plant (ETP), which forms part of the combined effluent stream.

This combined effluent stream is monitored at the foreshore outfall on a daily basis for pH, cadmium, copper, mercury, lead, zinc, and sulphate. In addition, a minimum of two samples per year are further analysed for arsenic, TSS, fluoride, iron + manganese, N as ammonia, TN & TP, beryllium, cobalt and nickel for EPA and/or NPI reporting. Additional monitoring is also conducted at key points within system, such as the ETP outflow and seawater intake. Figure 4.6 presents estimated annual heavy metal loads discharged to the estuary from the main outfall for the period from 2009 through 2013. Annual loads ranged from 1.8 to 6.5 tonnes, with the vast majority made up of zinc.

Figure 4.5 Proportional zinc loads from Nyrstar in 2012/13



Stormwater

The *Nyrstar Stormwater Management Strategy* seeks to capture and treat all stormwater generated on site, through the progressive development of a closed drainage system which directs stormwater to the Contaminated Water Pond or to one of several retention basins on site. Stormwater is then processed in the ETP to remove metals, before being discharged to the Derwent. Significant recent investment in infrastructure – including additional retention ponds, diversion pipes, constructed wetlands, and filtration cells – has allowed the site to withstand increasingly larger storm events without resulting in overflow. In the event of overflow, the least contaminated overflow points are activated first. Any overflows are monitored, with results reported to the EPA (NH, 2013).

During the period from 2009/10 through 2013/14, there has been a major reduction in the frequency and extent of stormwater discharges from the site, as shown in Table 4.2. No overflows have occurred since May 2012.

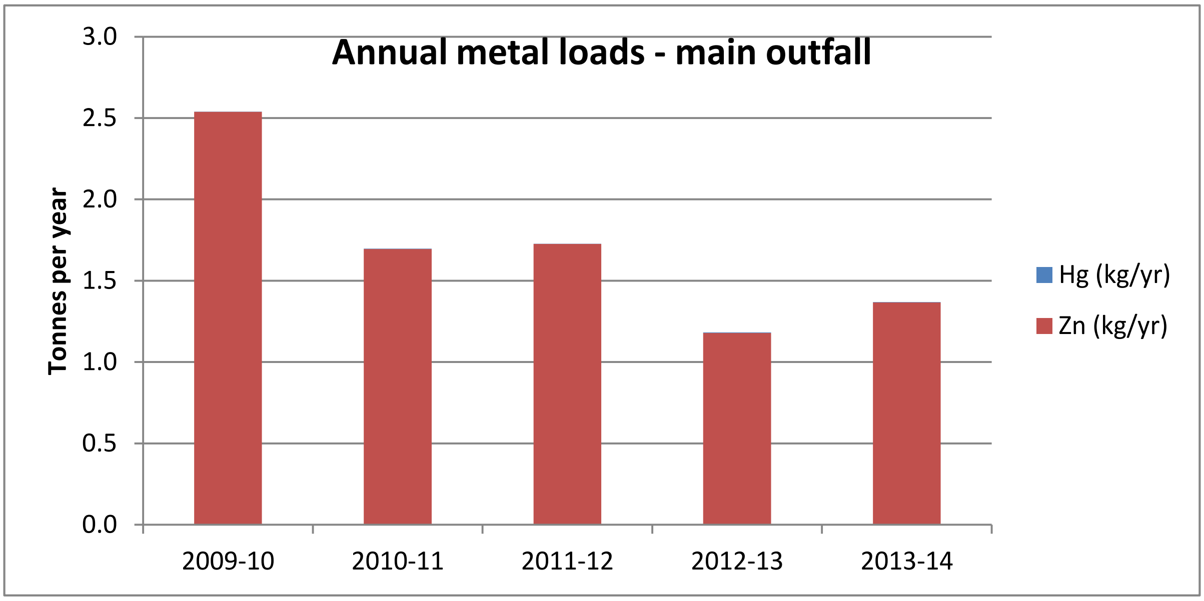
Table 4.2 Monitored heavy metal discharges – annual stormwater loads

Year	# events	Zinc (kg)	Cadmium (kg)	Lead (kg)	Copper (kg)
2009/10	3	374	8	7	2
2010/11	2	1119	57	32	8
2011/12	2	214	3	31	4
2012/13	0	0	0	0	0
2013/14	0	0	0	0	0

Actions undertaken by Nyrstar from 2009 to 2014 to improve the treatment and management of stormwater at the site include the following:

- Construction of an additional 2 ML stormwater detention pond at the southern wharf foreshore area;
- Installation of car park biofiltration cells, allowing primary treatment of contaminated runoff;
- Completion of a major stormwater harvesting and reuse project, with funding from the government's *National Urban Water and Desalination Plan*. As part of this, a 40 ML stormwater detention pond was completed in 2014 in the Loogana area, while the installation of a

Figure 4.6 Annual estimated zinc emissions from Nyrstar outfall (2009/10 – 20012/13)



reverse osmosis (RO) treatment plant is scheduled for 2015. This project will allow reuse of up to 2.4 ML/day of collected stormwater on site (which will reduce pressures on potable water supplies) and will also further reduce metal levels discharged via the ETP (NH, 2013).

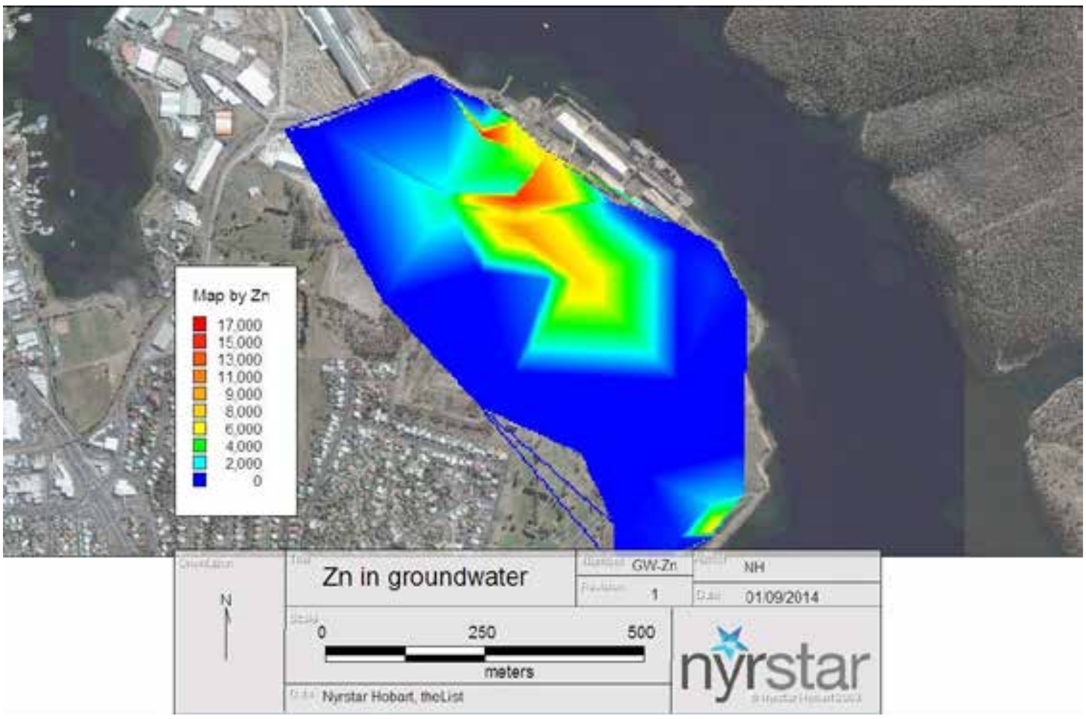
Groundwater

Groundwater beneath the NH site is highly contaminated with heavy metals, particularly zinc, cadmium and copper. Groundwater is contained in a dual layered aquifer system, with the shallowest aquifer being more contaminated (NH, 2013). This is a significant issue for both NH and the Derwent estuary, with previous estimates assigning 85% of the zinc load into the estuary as originating from NH groundwater (DEP, 2009). As a result, considerable efforts have been made to reduce the flow of groundwater into the Derwent, as well as to minimise the introduction of additional contaminants into groundwater.

Nyrstar operates an extensive groundwater monitoring and management program. Water levels are measured across 88 onsite bores on a 6-monthly basis, while samples are taken every two years for metals, sulphates, conductivity and pH. Groundwater monitoring across the site was last conducted in November 2013, with contaminant levels found to be comparable to the previous monitoring campaign. Interpolation of these results is used to identify and target contamination hotspots for further remediation, as illustrated in Figure 4.7.

Groundwater is currently recovered at seven sites across the smelter that target known contamination hotspots, and the extracted groundwater is processed in the ETP to remove heavy metals prior to discharge (NH, 2013). Over the past five years, annual loads of zinc and cadmium recovered from groundwater ranged from 83 to 132 tpa (tonnes per annum), as illustrated in Figure 4.8. Over 90% of this is collected from the site's two horizontal extraction systems plus the Loogana-Inshallah system.

Figure 4.7 Zinc in groundwater beneath the NH site, interpolated from 2013 groundwater monitoring data (source: Nyrstar Hobart, 2014)



In 2012, Nyrstar commissioned an updated groundwater review and management plan, including temporal and spatial analyses of contaminant plumes, review of existing remediation systems, revised estimates of metal loads entering the Derwent, monitoring gap analysis and a conceptual long-term remediation plan (GHD, 2012).

Key findings of the review included the following:

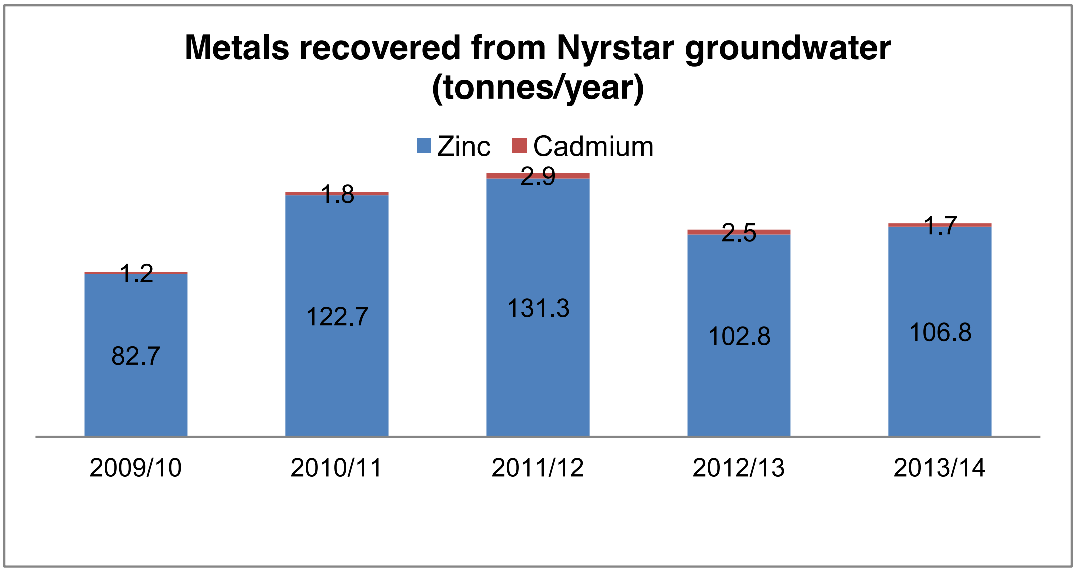
- The primary contaminant plume is located down-gradient of the Electrolysis plant. While remediation systems were capturing an estimated 60% of the zinc load from this plume, it was still the most important target area for further remediation activities.
- An estimated load of 83.4 tonnes of zinc and 1.3 tonnes of cadmium was being exported to the Derwent from groundwater at the site each year.
- Horizontal groundwater remediation systems were determined to be by far the most cost effective way to capture and treat contaminated groundwater at the site.
- The conceptual long-term strategy for the site suggested a combination of recharge controls, improvements to existing systems and installation of a series of horizontal bores along the foreshore, which would eventually isolate the site from the river environment.

Work on several major groundwater projects has been undertaken since 2009, as listed below. These projects were co-funded through Australian Government grants, some of which were sourced in partnership with the DEP:

- Installation of a series of 13 horizontal groundwater interception bores down-gradient of the Electrolysis department plus pumping/transportation system to ETP (2009);
- Installation of a vertical bore targeting contaminated groundwater in the old quarry area (2011);
- Further groundwater investigations in the Old Acid Plant area, followed by construction of a 240 m long horizontal bore to remove contaminated groundwater along the northeastern foreshore (2013/14);
- Installation of an additional 240 m groundwater interception trench at Loogana as part of the Stormwater Harvesting & Reuse Project (2014).

Combined with these improvements has been the ongoing project of sealing the Electrolysis Department basement to prevent further groundwater contamination. The project began in 2008 and approximately 70% of the area to be sealed has been completed (pers. comm. T Milne, Feb 2015)

Figure 4.8 Annual heavy metal load recovered from groundwater at Nyrstar



Note: Load estimates prior to 2010/11 do not include Loogana-Inshallah)

Atmospheric emissions, including dust

Over fifteen stacks are located on the Nyrstar Hobart site, and a number of methods are used to capture airborne contaminants to reduce adverse effects on human health and the environment. These include wet scrubbing, baghouses, chemical absorption towers and electrostatic precipitators. Stacks relying on such gas cleaning processes to meet air quality standards are monitored in accordance with the EPN, with requirements varying from continuous automatic monitoring to six-monthly testing.

Ambient monitoring of SO2 also occurs in surrounding areas. Monitored parameters include gaseous SO2, SO3, NOx, and airborne particulates, toxic metals (Pb, As, Sb, Cd and Hg) and other contaminants. Based on NPI reporting, Nyrstar's air and fugitive emissions account for the second largest proportion of heavy metal loads from the site (as compared to groundwater), as well as significant amounts of SO2 (320 tonnes/year), NOx (200 tonnes/year) and particulate matter (24 tonnes/year PM10) to the local airshed (2012/13 NPI Report). NPI values should be treated with some caution as the methods used may potentially over- or under- estimate certain parameters.

Dust management remains an important management issue for the site, particularly during the loading and unloading of ships with bulk concentrates and residues, from open areas during high winds, and from vehicle movements on roadways. NH has placed significant effort into an annually updated Dust Management Plan, which has resulted in improved understanding of dust sources, additional monitoring and alerts, alterations to procedure, and staff training (NH, 2013).

An estimate of loads falling into the Derwent estuary from air emissions (stacks and dust) has not been determined.

Land and buffer zone management

Nyrstar carries out a range of activities that fall under this heading, including management and removal of legacy stockpiles, removal/demolition of redundant plant and equipment, and rehabilitation and revegetation of land. Key areas of activity from 2009 to 2014 have included:

- Loogana-Inshallah contaminated site remediation: this area was used as a storage area for contaminated residues (HPL1 and jarosite) from 1940 to 1997 and has been in progressive stages of rehabilitation since 2002. Key activities have included installation of a cut-off trench between the site and New Town Bay; development of a secure landfill to contain jarosite wastes; covering and subsequent removal/reprocessing of the HLP1 stockpile; construction of an aquifer and stormwater detention ponds to collect contaminated water; and extensive revegetation using native plants. In 2014 the final stages of the rehabilitation were completed as part of the NH Stormwater Harvesting and Reuse Project, including construction of a 40 ML stormwater detention dam, additional groundwater interception, capping and revegetation. This project was awarded the 2014 Tasmanian Engineering Excellence Award (Environment Category).
- "Smelter in the Park": this project incorporates site revegetation and demolishing redundant plant and equipment to improve the aesthetics of the site. Key activities since 2009 have included extensive perimeter plantings; revegetation of the Old Leach area and car park rain gardens; demolition of the Old Research Building and development of an interpretive site; demolition of unused storage tanks; and monitoring of foreshore erosion
- Quarry management: monitoring and site assessment of the old quarry area where significant stockpiles of contaminated soil, asphalt and timber wastes are currently stored

Proposed management actions 2014–17

Management actions proposed to further reduce pollutant loads to the Derwent include the following:

- Construction of the reverse osmosis (RO) plant. This will allow for full recycling of collected stormwater and further reduce metal loads discharged via the ETP;
- Final design and construction of the wharf stormwater project (an area that is not fully included in the closed drainage network);
- Completion of Electrolysis basement sealing;

- Continued implementation of the NH Groundwater Management Strategy, including:
  - Intensive investigation in areas identified within the strategy
  - Development and installation of targeted remediation systems
- Old quarry investigations and management plan;
- Continued implementation of the revegetation plan (Smelter in the Park).

4.2.2 Norske Skog paper mill

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, specialty newsprint and lightweight coated papers, with a paper production capability nearing 300,000 air-dried tonnes per year. Since October 2009 paper has been made from 100% thermo-mechanical pine pulp of which >95% comes from Forest Stewardship Council (FSC) certified forests. (Prior to October 2009, paper was manufactured 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. No bleach or dioxin-forming chemicals are currently used or have historically been used at the mill.

The mill operates an on-site water treatment plant, a wastewater treatment plant and small sewage treatment plant. A coal-fired boiler supplies most of the energy to the site, and solid wastes (e.g. wood wastes, water and wastewater treatment plant biomass, and ash from the coal-fired boiler) are either reused, recycled or disposed of at the Boyer Mill solid waste landfill.

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 boiler. The majority of these contaminants enter the Derwent estuary via a combined effluent stream (CES), but other potential sources include the water treatment plant settling ponds, sewage treatment plant effluent, stormwater runoff, landfill leachate, groundwater and air/dust emissions. Emission sources from the site are monitored on a regular basis, in accordance with EPA license conditions. 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 5).

A number of surveys, investigations and modeling were carried out as part of an Ecological Risk Assessment (NSR, 2001) and a follow-up macroinvertebrate survey was carried out in 2003 (Aquenal, 2003). During the period 2007 to 2011, a project was carried out 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 DEP. One task in this project was to investigate estuarine responses associated with the introduction of secondary treatment at the Norske Skog mill (see Section 10 for details).

The following sections review emissions associated with different areas of the plant. Much of the information in this section was derived from the most recent annual review for the site (Norske Skog, 2014) and/or from previous DEP Annual Technical Reports.

Liquid emissions – combined effluent stream (CES)

Liquid emissions from the site consist predominantly of pulp and paper processing effluent, together with cooling water used in the process, discharged via the CES. There have been a number of major changes in the nature and treatment of this effluent stream since 2007, as outlined below:

- During the period 1989 to 2007, this effluent was treated to primary level (i.e. removal of most solids and some resin acids);
- Starting in October 2007, the treatment plant was upgraded to provide secondary treatment, with further removal of particulate and dissolved organic matter, and resin acids. The secondary treatment system consists of a primary clarifier, an integrated biofilm activated sludge plant and a secondary clarifier;

- In October 2009, the mill ceased processing eucalyptus (cold caustic soda process) and shifted to pine only (thermo-mechanical process), resulting in a much clearer effluent and further reduction in organic matter loads.

The new secondary effluent treatment plant (SETP) has been very successful in reducing BOD and resin acids loads (99% reduction), TSS (86% reduction), and also has lower temperatures and more stable pH. However, there has been an increase in nutrient levels – as the secondary treatment process requires addition of some nutrients in order to sustain the biological secondary treatment process. A key objective of the Boyer SETP operation is to minimise TSS emissions. An essential tool in achieving this is correct nutrient doses. Phosphorous levels were deliberately altered during 2011 and 2012 to achieve continued TSS reduction. Having achieved consistent TSS reductions, the target is to manage the nutrient dose to optimise performance without any adverse impact on TSS.

The CES is the primary source of emissions to the Derwent from the site. This treated process effluent is warm (average 29°C) and is monitored for flow, temperature, pH, TSS, BOD, TOC, resin acids, nutrients (TN, TP, NOx, NH4 and DRP), TPH (previously oil and grease) and thermotolerant coliforms, in accordance with EPA license conditions (EPN).

Following the commencement of secondary effluent treatment, the effluent was also tested quarterly for whole effluent toxicity (Microtox), for twelve months after commissioning, with no significant toxicity recorded. Average annual flows and estimated loads from the CES for the period from 2006–13 are provided in Figure 4.9. This time period is presented to illustrate how loads have changed in response to major treatment upgrades and process changes. All monthly thermotolerant counts during this period were <10 cells/100 ML.

Liquid emissions – water treatment plant (for process water)

The mill's water treatment plant processes approximately 12,000 ML/year of River Derwent water (pumped via a water intake at Lawitta) for use in paper manufacturing. Liquid emissions from the water treatment plant are discharged to settling ponds and wetlands in the Western Settlement Area, where they are monitored for pH, TSS, TPH, sulfur and aluminum, as well as zinc and other metals. Since 2008, the alum sludge produced by this plant has been treated using Geobags (geotextile filtration systems) before it is discharged into the settling ponds. These have significantly enhanced sludge retention and dewatering. Elevated aluminum and sulphur levels are related to the use of aluminium sulphate as a coagulant in the water treatment process.

Liquid emissions – stormwater, groundwater and landfill leachate

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

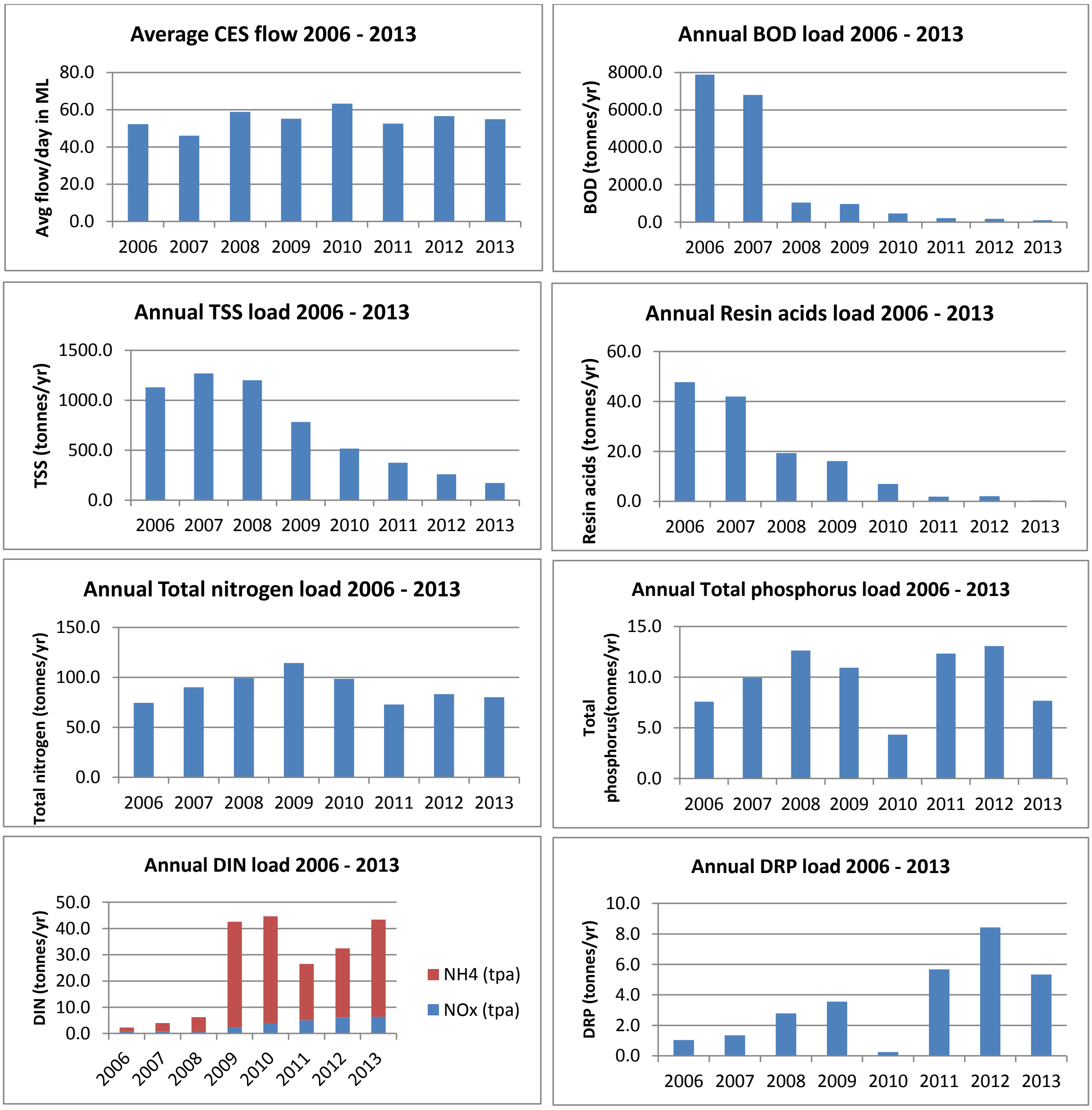
- **Stormwater** quality is monitored up to twice yearly at nine sites (4 around the general mill area; 5 around the landfill area) for a wide range of parameters, following a >10 mm storm event. Stormwater quality is variable, with occasionally elevated levels of TSS, total petroleum hydrocarbons, zinc, aluminum, barium and adsorbable organically bound halogens (AOX) at some sites.
- **Groundwater** Thirteen bores located in three focal areas (general mill, western settlement and landfill) are monitored six-monthly for a base set of parameters, and once every three years for an extended parameter list. Investigations carried out in the 1990s documented some degree of historical contamination at the site, with key contaminants of interest being barium, copper, mercury, zinc and sulphide, but suggested there was little offsite migration to the estuary.
- **Leachate** from the landfill and ash dump is also monitored twice yearly. Analyses indicate elevated levels of barium, AOX and sulphur. Since 2001, leachate from the landfill has been collected and treated at the effluent treatment plant.

Atmospheric emissions

Air emissions are predominantly associated with the site's coal-fired boiler, which is the largest in southern Tasmania, burning typically about 90,000 tonnes of coal/year. This boiler is fitted with an electrostatic precipitator to control particulate emissions and is monitored continuously for opacity and twice yearly for gasses (SO_2 and NO_X) and particulates.

Combined selected total metals concentrations (Pb, As, Sb, Cd and Hg) are also periodically monitored. Mass emissions, as reported as part of the National Pollution Inventory, include SO_2 (1400 tonnes/year), NO_X (530 tonnes/year), particulate matter (16 tonnes/year PM10), and fluoride (6.7 tonnes/year) to the local airshed (2012/13 NPI Report). NPI

Figure 4.9 Norske Skog Boyer Combined Effluent Stream – estimated annual discharges to the Derwent 2006–13 (sources: Combined Effluent Stream (CES) monitoring reports (Norske Skog) & *National Pollutant Inventory (nutrients prior to 2008))



Note: starting in 2007, when the SETP was commissioned, daily flows include both treated effluent as well as cooling water values should be treated with some caution, as the methods used may potentially over- or under- estimate certain parameters.

New developments and management actions proposed

A major new development at the Norske Skog Boyer mill has been the commissioning of the new lightweight coated paper project to convert current newsprint operations to coated grades suitable for catalogues (April 2014).

Focus areas for further improvements in coming years include achievement of European Commission Best Available Technologies emission targets.

4.2.3 Impact Fertilisers

Impact Fertilisers is situated immediately to the northwest of the Nyrstar Hobart Smelter at Lutana, and is operated as a Level 2 industrial premises regulated by the EPA. The plant has been operating since 1924 and has typically produced between 150,000 and 210,000 tonnes/year of superphosphate fertilisers through a process that combines phosphate rock with sulphuric acid (produced by Nyrstar). Production in recent years has been lower (e.g. 93,096 tonnes in 2014), due to adverse global influences together with a fire that interrupted production for four months in 2014 (Impact, 2015). Contaminants associated with the fertiliser plant include nutrients (particularly phosphorus), particulates, fluoride and some heavy metals. These contaminants enter the Derwent via airborne dust emissions, stormwater runoff and groundwater.

Liquid processing wastes generated at the plant are re-used within the production process. A stormwater retention pond, with 1.76 ML capacity, was constructed on the site in 2004 to capture runoff 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 particularly during plant closures this pond may overflow to the Derwent estuary, resulting in discharges of nutrients (primarily phosphorus) and heavy metals (primarily zinc). In 2010, a filter press was installed to process accumulated stormwater, significantly reducing overflow events. Volumes and concentrations discharged are monitored by Impact and reported to the EPA, and estimated annual stormwater loads are provided in Table 4.3. Other recent and proposed management actions to reduce stormwater discharges include maintenance of silt traps, site cleaning and improved operation of the filter press and pond levels.

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 been installed to further evaluate this situation.

Atmospheric emissions (largely hydrogen fluoride) include particulates and fluoride associated with the manufacturing process. A four-stage scrubbing plant and dust collection baghouse are used to treat these emissions and further reductions in fluoride emissions are planned. Dust management and spillage have been important issues for the site, and improvements have been achieved in loading

Table 4.3 Stormwater pond discharges and loads at Impact Fertilisers (source: Impact Fertilisers AERs; EPA; [1]State of the Derwent, 2009)

Year	Number of overflow events	Total volume of stormwater	Nutrients (primarily phosphorus) (kg)	Combined metals (primarily zinc + minor cadmium) (kg)
2009	149[1]	33,921[1]	16,702	590
2010	8	2228	2105	60
2011	8	1,806	1130	41
2012	9	2904	1935	63
2013	5	2157	2041	40

and unloading operations at the Risdon wharf (movement of phosphate rock and single super phosphate). Further efforts are being directed at reducing windblown losses from the phosphate rock storage area and spillage during transport through implementation of the dust management plan that was developed in 2006.

4.2.4 Selfs Point

The Self's Point fuel storage area was established under the Self's Point Land Act 1951, which allowed for reclamation and use of the area for the storage, manufacture and packaging of fuel, alternative fuels, and industrial chemicals, municipal sewage disposal works and wharves. The area was largely constructed on reclaimed land and 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) and Crown Land Services.

Site uses since 2009 have included:

- five sites used for petroleum products(Mobil, BP, Caltex and Shell (now inactive);
- one site used for gas storage (Origin Gas);
- bitumen plant (BP)
- waste oil recycling (now closed)
- tanker berth and refuelling wharf (owned and operated by Tasports)

The majority of this area is Crown Land administered by Crown Land Services and has been leased or licensed to commercial operators under the provisions of the Crown Lands Act 1976.Other nearby land uses includes the Selfs Point WWTP, Cornelian Bay Cemetery, playing fields (Rugby Park), and public housing at Stainforth Court. Although the tenure agreements in this area are mainly administered by Crown Land Services the environmental management of the individual premises is largely responsibility of Hobart City Council (with the exception of BP Bitumen, which is regulated as a level 2 premise by the State Government).

A risk assessment and safety audit of the area was carried out in 1992 on behalf of the Department of Environment & Planning (ICI Australia Engineering, 1992). It 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 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 runoff. Under the new Planning Scheme, most of the area will be zoned Port and Marine. During the 2009–13 period, there have also been a number of planning applications and other activities to upgrade fire services and associated infrastructure (pers comm. R Probert HCC, Feb 2015).

It is recommended that an integrated environmental audit be carried out for the Self Point area to identify potential contamination associated with stormwater or groundwater discharges.

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.

Most (but not all) of the larger premises are regulated by the EPA as Level 2 Activities under EMPCA. A review of the EPA's New Environmental Licensing and Monitoring System (NELMS) database indicates that there are over fifty current Level 2 Activities located within the project area, including: wastewater treatment plants; chemical works, foundries and metal works; food, beverage and oil production/processing plants; wood processing plants; landfills or composting facilities; and rock or sand quarries.

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 or TasWater play a major role in managing potential impacts from many of these premises, for example through conditions on development applications or trade waste agreements, however, no full regional inventory or assessment has been carried out.

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

Name	Level	Location	Major Products	Effluent to	Site runoff to
Cadbury Schweppes	2	Claremont, Glenorchy	Chocolates, confectionary	Cameron Bay WWTP	Derwent
Incat	1	Glenorchy	Catamarans	Prince of Wales Bay WWTP	Derwent
National Foods	2	Lenah Valley, Glenorchy	Dairy products	Selfs Point WWTP	New Town Rivulet
Cascade Brewery	2	South Hobart, Hobart	Beer, beverages	Macquarie Point WWTP	Hobart Rivulet
BOC Gases	2	Selfs Point, Hobart		NA	Derwent
BP Bitumen	2	Selfs Point, Hobart		NA	Derwent
Bryn Estyn water treatment plant		New Norfolk	Water purification	NA	Derwent
Hobart Ports, including Domain Slipway		Hobart	Marine and port operations	NA	Derwent

4.3 Landfills, tips and contaminated sites

4.3.1 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. The EPA's *Landfill Sustainability Guide (2004)* sets out specific requirements for management of Tasmanian landfills. The EPA is in the process of renewing the regulatory instruments for all landfills with revised conditions based on best practice environmental management.

Parameters that 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.

There are a number of active and historic landfills within the DEP project area. The active landfills include three large municipal landfills (regulated as Level 2 Activities by the EPA) and four smaller scale industrial landfills associated with Level 2 activities. There are also 21 historic landfills located within the project area, the majority of which are generally small scale and located less than one kilometre from the estuary. These historic sites were once regulated by local council or not regulated at all (i.e. closed or illegal landfills). Currently, these sites are being assessed by the EPA to determine whether they present a high or low risk to the community and the environment. Figure 4.10 shows the locations of active and closed landfills, former rubbish tips, industrial landfills and industrial stockpiles around the Derwent estuary (with further details summarised in Table 4.5).

The three active landfills in the Derwent estuary region include: McRobies Gully (Hobart), Jackson Street (Glenorchy), and Peppermint Hill (New Norfolk). The life expectancy of McRobies Gully landfill site is until 2017 (currently under review), whereas Jackson Street has capacity until 2029. Leachate from these two sites is collected and diverted to WWTPs, and monitoring of leachate, groundwater 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. Previously, during prolonged storm events or water pipe/weir blockages, the leachate pond at McRobies Gully over-topped – or stormwater was diverted around the leachate pond – resulting in the release of some diluted leachate into the Hobart Rivulet. To address this issue, stormwater diversion drains have been constructed to direct clean water from the upper catchment around the site, without coming into contact with the landfill. This work is completed and has resulted in a reduction, but not complete cessation, of leachate release during periods of heavy rain. 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, 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.

Two large municipal landfill sites in the region have been closed in the past 10 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 the 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.

Figure 4.10 Refuse disposal sites and industrial stockpiles around the Derwent estuary

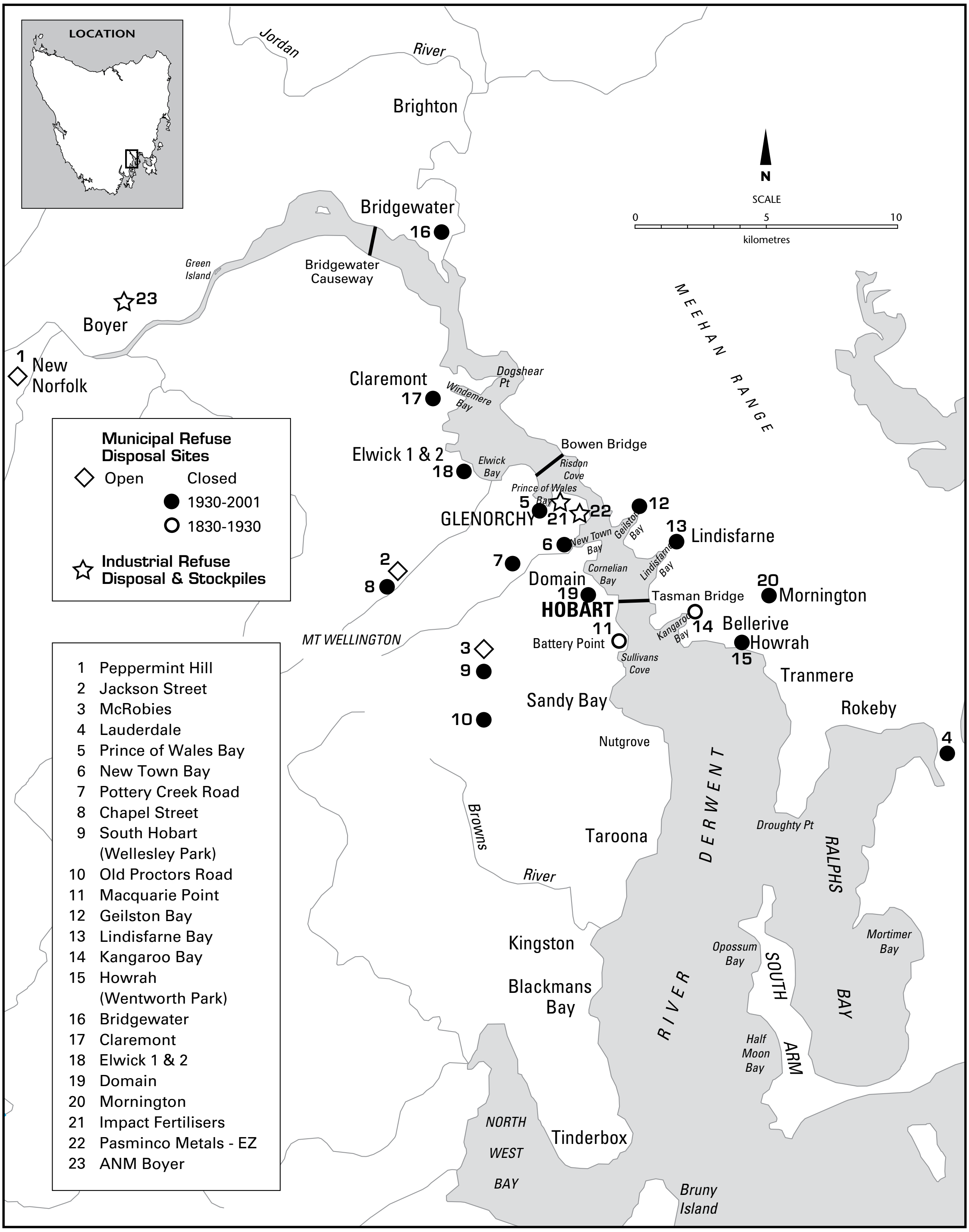


Table 4.5 Landfills - rubbish tips and industrial stockpiles in the Derwent estuary area.

MUNICIPAL LANDFILLS – RUBBISH TIPS

Active landfills – rubbish tips, 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, groundwater 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 – rubbish tips

4. Lauderdale

1970 – 2001 23 ha

- Previously a saltmarsh area
- The site has a clay/sand cover overlaid 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.

5. 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 – rubbish tips

6. 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.

7. 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.

8. 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.

Sites 16, 17, 18, 19 and 20 were recently added from the EPA database and additional details are not currently available

INDUSTRIAL STOCKPILES AND LANDFILLS

21. 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.
- Groundwater investigations underway.

22. Nyrstar Hobart Smelter

1917 – present 290 ha

- Large areas of industrial landfills and stockpiles; most now encapsulated and/or covered.
- Extensive stormwater and groundwater monitoring.
- Most stormwater and some groundwater captured/treated.

23. 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.

Approximately 15 old landfill areas are known to exist along both sides of the estuary as documented in Tamvakis (1994), and more recent EPA records. 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, Prince of Wales Bay and Elwick Bay) as well as areas identified as being at risk due to projected sea-level rise (e.g. Lauderdale).

4.3.2 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 are documented by the EPA, using several different databases. Registered contaminated sites are listed on the Contaminated Sites database, while 'potentially contaminating activities' (PCAs) 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 do not contain a full record 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. Previous queries of the Contaminated Sites database undertaken by the EPA have identified over thirty registered sites in the DEP area, though many more are likely to exist. The majority of these sites are located in urban and industrial zones and are associated with petroleum storage.

Potentially contaminating activities

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 underground storage tanks (ASTs and USTs), large and small waste depots (e.g. landfills), and some agricultural activities. For a more comprehensive list, please refer to the EPA Information Bulletin *Potentially Contaminating Activities, Industries and Land Uses* (http://epa.tas.gov.au/regulation/potentially-contaminating-activities).

Both the ERLUR and NELMS databases can be searched to evaluate potentially contaminating activities, by activity type. The ERLUR database primarily contains information on underground 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.

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.

The Environmental Management and Pollution Control (Underground Petroleum Storage Systems) Regulations 2010 (UPSS Regulations) came into force during 2010 and requires all active UPSS to be registered. The UPSS Regulations also require regular loss monitoring, in an effort to detect leaks as early as possible and help prevent large losses of petroleum products which can cause environmental harm and be very costly to clean up. One hundred and seven UPSS sites within the project area have been registered with the EPA. In addition, 143 inactive sites (both ASTs and USTs) have been mapped, some of which may be abandoned (pers comm. A Ezzy EPA).

4.4 Stormwater and urban rivulets

This section provides an overview of stormwater issues and management related to the Derwent estuary. It includes a summary of stormwater legislation and policy, recent monitoring and modeling, management of urban rivulets, and it explains the stormwater pollution reduction work undertaken by the DEP and our stakeholders between 2009 and 2014.

4.4.1 Stormwater and the Derwent estuary

Stormwater originates as rain, and ultimately reaches a waterway by flowing over land or via pipes, channels, gutters and urban rivulets. Stormwater includes rainwater and any other contaminant such as litter, vegetative debris, soil, faecal bacteria/pathogens, nutrients, hydrocarbons, heavy metals and pesticides. The quality of stormwater is strongly linked to land-use within a given catchment, together with the condition of individual rivulets (e.g. bank and riparian zone stability). Construction sites, roads, gardens, commercial sites, erosion of stream beds, banks and unpaved roads, and cross-connections between stormwater and sewerage systems are all potential contributors to stormwater contamination.

Fifty-seven catchments drain to the Derwent estuary, which receives stormwater from 13 major rivulets and over 270 large diameter outlet pipes. Stormwater modeling has previously been used to estimate the following annual pollutant loads to the estuary (DEP, 2010):

- 184 tonnes of total nitrogen;
- 30 tonnes of total phosphorus;
- 7996 tonnes of total suspended solids (TSS);
- 852 tonnes of gross pollution (including litter).

Stormwater pollution represents a major risk to the health of the Derwent estuary, particularly with respect to litter, faecal bacteria/pathogens and TSS. Stormwater systems that are not properly designed or managed can also result in downstream flooding, and increased stormwater flows may damage downstream infrastructure. High flows also increase stream bank erosion. As well as physical impacts to stormwater systems, pollutants in stormwater can have a number of potential impacts on estuarine water quality, as outlined in Table 4.6.

4.4.2 Stormwater legislation, policies, guidelines and coordination

Stormwater management is a shared statutory responsibility between state and local government. State government is responsible for the development of legislation, strategies and guidelines. Local government is considered to be primarily responsible for implementing stormwater management systems. In Tasmania, stormwater management is administered by a variety of legislative and policy tools, and guidelines. Key statutory tools and policy or guidance documents include:

- *State Policy on Water Quality Management 1997*. This policy provides a framework for the management and regulation of point and diffuse sources of emissions to surface waters and groundwater. It requires stormwater to be managed
  - o using best practice,
  - o according to stormwater management strategies (for land disturbance),
  - o in accordance with the *Australian Guidelines for Urban Stormwater Management* (ARMCANZ/ ANZECC 2000).

- State Stormwater Strategy (2010). This document sets out key principles and standards for stormwater management in Tasmania, and identifies accepted guidance documents. The strategy emphasises the need to manage stormwater at its source, and identifies performance criteria for stormwater discharges from new developments, of
  - o 80% reduction in the average annual load of total suspended solids
  - o 45% reduction in the average annual load of total phosphorus
  - o 45% reduction in the average annual load of total nitrogen.
- *Water Sensitive Urban Design: Engineering procedures for stormwater management in Tasmania (2012).* This document provides construction, engineering and development assessment advice for stormwater management systems in urban landscapes throughout Tasmania.
- *Urban Drainage Act 2013*. The objects of the Act include the minimisation of flood events, and the protection of stormwater services. The Act requires councils to develop a Stormwater System Management Plan within six years of adoption of the Act. It also states that nothing but stormwater (defined as runoff) is to be put into drains.

Local governments within the Derwent estuary catchment have also developed several municipality-specific strategies and plans, including:

- Hobart City Council Stormwater Strategy (2012–17). This strategy identifies stormwater-related activities, provides high level guidance and, in conjunction with other Hobart City Council management plans, addresses drainage, catchment management and asset management in the municipality.
- Hobart City Council catchment management plans (e.g. Hobart Rivulet, 2011; Wayne Rivulet (2000), Sandy Bay Rivulet (2000), Waterworks Valley (1999)); *Hobart*

Table 4.6 Some stormwater pollutants, their possible sources and potential impacts

Pollutant	Source	Impact
Suspended solids	Soil erosion Construction sites Road/footpath wear	Smother ecosystems Block sunlight Cause respiratory problems in fish Increase water temperature
Metals	Vehicle wear and emissions Atmospheric deposition Illegal/accidental discharges	Toxicity to aquatic organisms Bioaccumulation
Nutrients	Detergents Animal wastes Fertilisers Sewerage leaks	Promote aquatic plant, algal and weed growth, which may lead to eutrophication
Pathogens	Sewerage overflow/leak/illegal connection Animal feces	Disease in humans and animals Reduce recreational amenity
Hydrocarbons	Vehicle wear and emissions Spills and leaks Illegal discharges	Toxic to aquatic organisms Loss of aesthetic amenity
Litter (gross pollution)	Community rubbish	Reduce aesthetic amenity Human health hazard Aquatic animal and bird health hazard Reduction in stormwater system effectiveness/efficiency

Rivulet Strategic Master Plan (2011).

- *Hobart City Council Water Sensitive Urban Design Site Development Guidelines and Practice Notes* (Hobart City Council 2006).
- *Brighton Council Stormwater Strategy* (2012). This strategy outlines council's stormwater policies in terms of treatment, drainage and future direction.
- Clarence City Council stormwater management plans (under development in 2014) will set management goals for water quality, as well as quantity. The management plans will include separate catchment models.

Derwent Estuary Program role

Between 2009 and 2014, the DEP has continued to play an important role in coordinating stormwater initiatives within the region, with assistance from a specialist stormwater officer. Key activities have included:

- Continuation of the DEP Stormwater Taskforce. 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;
- Development and publication of key guidance documents and fact sheets, e.g:
  - *Water Sensitive Urban Design: Engineering procedures for stormwater management in Tasmania* (2012);
  - Soil and Water Management on Building and Construction Sites: Fact sheets with practical measures to prevent pollution from building and construction sites (2008);
  - Water Sensitive Urban Design fact sheets (2007);
- Organisation of specialist training courses in stormwater modeling (MUSIC), Water Sensitive Urban Design (WSUD), and sediment and erosion control on building sites for council officers, engineers, consultants and builders;
- Technical support to inspect, improve and better implement sediment and erosion control controls on building sites;
- Coordination of audits of gross pollutant traps (GPTs) and WSUD assets to assess their efficacy with respect to design, construction and maintenance; and,
- Raising funding for stormwater projects through Caring For Our Country grants and other sources (see Section 4.7.6).

4.4.3 Rivulet and stormwater monitoring

DEP 2010–2011 Rivulet and Stormwater Monitoring Program

In 2010–11, DEP coordinated a rivulet and stormwater monitoring program that followed on from the monitoring previously undertaken in 2002–05. The program, which involved the six councils around the estuary, primarily focused on monitoring during baseflow conditions. Details of the two program, and results, are published in the DEP 2010–11 *Stormwater and Rivulet Monitoring Report* and the *DEP Stormwater and Rivulet Monitoring Program Summary Report 2005–05.*

The same monitoring sites and parameters were tested in 2010–11 as in 2002–05 (Figure 4.11 and Table 4.7), however the 2002–05 program ran for 36 months, while the 2010–11 program ran for only 12 months. Most rivulets were monitored on a monthly basis – at both upper and lower catchment sites – with some exceptions as noted in Table 4.7.

Figure 4.11 Stormwater monitoring sites

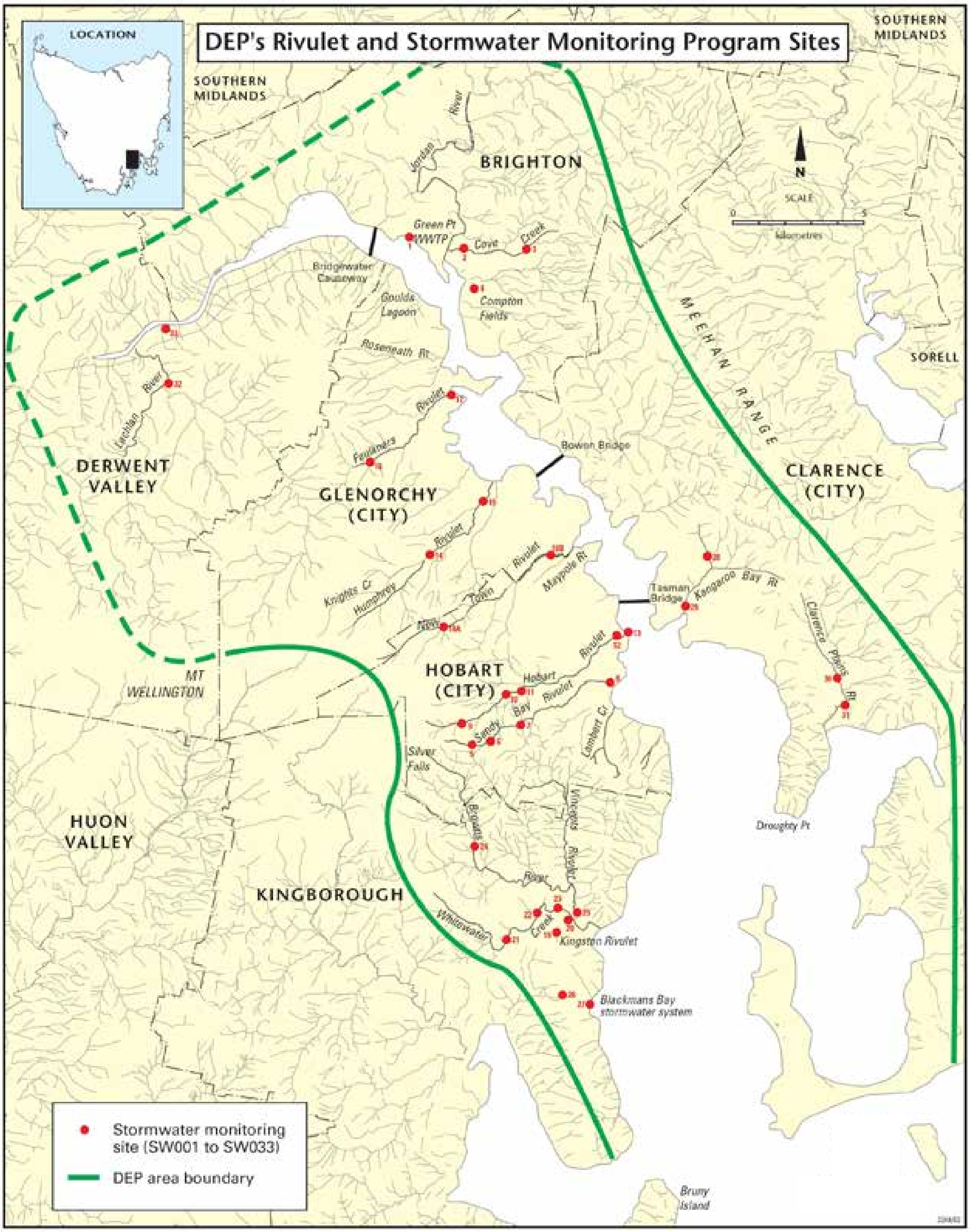


Table 4.7 Stormwater monitoring sites, frequency and parameters measured in 2002–05 and 2010–11

Council	Site ID	Site Location	Monitoring Frequency
Brighton Council	SW001	Green Point WWTP	Quarterly
	SW002	Cove Creek lower site	
	SW003	Cove Creek upper site	
	SW004	Compton Fields	
Hobart City Council	SW007	Sandy Bay Rivulet upper site	Monthly
	SW008	Sandy Bay Rivulet lower site	
	SW009	Hobart Rivulet upper site	
	SW012	Hobart Rivulet lower site	
	SW018A	New Town Rivulet upper site	
Glenorchy City Council	SW014	Humphreys Rivulet upper site	Monthly
	SW015	Humphreys Rivulet lower site	
	SW017	Faulkners Rivulet lower site	
	SW018B	New Town Rivulet lower site	
Kingborough Council	SW019	Kingston Rivulet upper site	Monthly
	SW020	Kingston Rivulet lower site	
	SW021	Whitewater Creek upper site	
	SW023	Whitewater Creek lower site	
	SW024	Browns River upper site	
	SW025	Browns River lower site	
Clarence City Council	SW028	Kangaroo Bay Rivulet upper site	Monthly
	SW029	Kangaroo Bay Rivulet lower site	
	SW030	Clarence Plains Rivulet upper site	
	SW034	Clarence Plains Rivulet lower site	
Derwent Valley Council	SW032	Lachlan River upper site	Bi-annually
	SW033	Lachlan River lower site	

Parameters measured
Total suspended solids (TSS)
Turbidity
Enterococci
Theromtolerant coliforms
Total nitrogen (TN)
Total phosphorous (TP)
Copper, lead and zinc
Oil & grease

Rainfall from the Ellerslie Road weather station (Bureau of Meteorology) was used to assess the potential impact of rainfall on pollutant levels. Rainfall data for the 24 hours prior to monitoring was used to determine the flow conditions under which sampling occurred. Flow conditions were classified as:

- base flow – no rainfall in the 24 hours prior to monitoring
- moderate flow – 0–10 mm rainfall in the 24 hours prior to monitoring
- storm flow – more than 10 mm rainfall in the 24 hours prior to monitoring

For the 2010–11 monitoring program, six sampling events were undertaken during base flow conditions, five during moderate flow, and one during storm flow. Results for key parameters are presented for both upper and lower rivulet sites in Figure 4.12.

These graphs clearly show the impact of urbanisation, as demonstrated by the deterioration in water quality between most upper vs lower rivulet sites, and also highlight significant differences in water quality between rivulets.

Median values were compared against ANZECC (2000) trigger values. Results indicate that aside from the Lachlan River, many sites exceeded the ANZECC guidelines for one or more parameter. Bacteriological water quality, particularly

Figure 4.12 Monitoring results for Derwent rivulet and stormwater monitoring program (2011–12) showing median values of TSS, TN, TP and enterococci at upper and lower sites

at most lower sites, was poor. This, combined with elevated nutrient levels suggests that sewage may be entering stormwater drains and rivulets. This could be due to cross connections between sewage and stormwater pipes or sewage overflows.

TSS was also elevated at several sites indicating that further attention should be given to preventing sediment sources to stormwater. This includes regulating sediment and erosion control on construction, promoting the use of WSUD to minimise stormwater volumes and improve quality, and prevention of stream bank erosion. Seven of the rivulets were monitored for metals, oil and grease, with low concentrations detected at most sites except for Kangaroo Bay Rivulet (elevated zinc, lead, copper, oil and grease) and New Town Rivulet (elevated copper). (See the 2010/11 DEP Rivulet & Stormwater Monitoring Report for details (DEP, 2011).)

Comparison of the results from the 2010–11 monitoring with the 2002–05 monitoring suggests that there was an apparent general decline in water quality over this time, particularly at the upper sites. However, this may be attributable to the different rainfall (and subsequent runoff) conditions of the two sampling periods. Overall, the 2002–05 monitoring program experienced a higher proportion of dry weather conditions during sampling than the 2010–11 monitoring program.

These two rivulet monitoring programs provided valuable data about water quality in rivulets. However, because the sampling was undertaken monthly rather than in response to rain events, the results are more useful in assessing baseline rivulet water quality than water quality during storm events.

DEP 2012 Storm Event Monitoring Program

In 2012, the DEP coordinated a program to monitor rivulet water quality immediately following rainfall events, in collaboration with councils. Samples were collected at nine sites across four Council areas (Hobart, Kingborough, Glenorchy and Clarence) when rainfall exceeded 10 mm in the 24 hours to 9am on the day of sampling. The sites monitored were all located in the lower reaches of the following rivulets and creeks:

- Sandy Bay Rivulet
- Hobart Rivulet
- Humphries Rivulet
- Faulkners Rivulet
- New Town Rivulet
- Kangaroo Bay Rivulet
- Clarence Plains Rivulet
- Whitewater Creek
- Browns River

Samples were monitored for enterococci, total suspended solids, and nutrients (total nitrogen, total phosphorus). Five monitoring events took place in 2012, which are detailed in Table 4.8.

Table 4.8 Storm events monitored in 2012

Date	Rainfall (mm) in the 24 hours to 9am of the day of sampling
18 January	18
31 January	30
03 May	24
01 August	11
06 August	15

As illustrated in Figure 4.13 , concentrations of total suspended solids were notably higher following heavy rainfall, compared to monitoring programs 2010–11 and 2002–05, which focused largely on baseflow conditions. In contrast, enterococci levels were more variable (see Figure 4.13). Some rivulets had higher levels of enterococci associated with rain events, suggesting catchment sources and/or cross connections between the sewer and stormwater systems, while others had lower levels during storm events, suggesting possible sewage inputs during dry weather. (Note: the 2002–05 program measured faecal streptococcus, which is broadly comparable to enterococci. See full *DEP 2012 Storm Event Monitoring* report for details.)

To improve our understanding of how stormwater transports contaminants to the Derwent estuary, it is recommended

Figure 4.13 Comparison of median TSS values across three different monitoring programs.

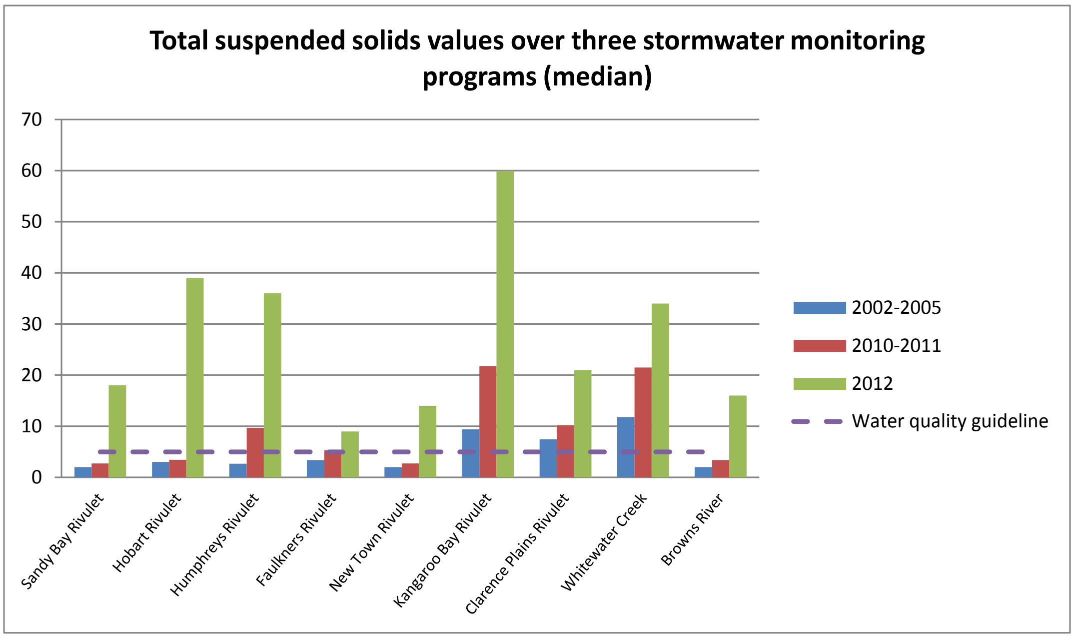
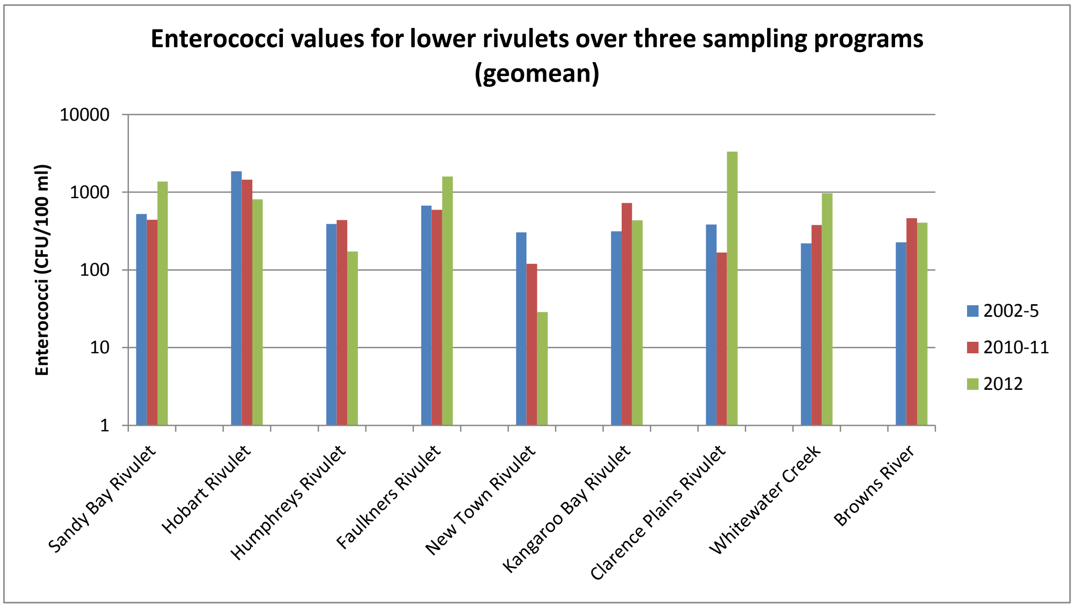


Figure 4.14 Comparison of median enterococci values across three different monitoring programs.



(Notes: 2002-2005 and 2010-2011 programs involved monthly monitoring, while 2012 program focused on storm events;

TSS water quality guideline adapted from Australian Drinking Water Guidelines (2004) for aesthetic purposes and should be cautiously applied) that future stormwater monitoring include both water quality and flow monitoring elements, and incorporate both baseflow and storm event monitoring.

In addition to the regional monitoring programs described above, councils undertook a number of other stormwater monitoring activities since 2009 as outlined in Table 4.9.

4.4.4 Stormwater modeling, flood studies and other planning studies

A number of stormwater models, flood studies, urban drainage schemes and other tools have been used to better predict and manage stormwater impacts in the Hobart metropolitan area. These methods will become increasingly important to underpin the development of Stormwater

Table 4.9 Greater Hobart municipal council stormwater monitoring actions 2009–14.

Clarence	• 60 community complaints were responded to by council with water monitoring for turbidity and enterococci, and follow up monitoring at Lower Clarence Plains. • Council trialed a granulated activated carbon sampling program in the Mornington Industrial Park (which drains to Kangaroo Bay), as part of a regional DEP initiative. • A rivulet monitoring program is currently (2015) being designed for up to 16 sites and will include sampling in both the upper and lower reaches of rivulets. This program will be an expansion of an existing program, and includes monitoring for baseline conditions with a focus on storm events.
Hobart	• Sampling for enterococci and thermotolerant coliforms has been carried out monthly at 18 sites for the Waterways program since 2006. Spikes are reported to TasWater for action. • Groundwater and surface water monitoring of McRobies Gully landfill is undertaken at various sites, including Hobart Rivulet and Pottery Creek.
Glenorchy	• Starting in 2014, council has been monitoring four sites along Faulkner's Rivulet (total and dissolved nutrients, enterococci). • Performance monitoring for the Windermere Bay WSUD ephemeral wetland was carried out in 2014 (nutrients, bacteria, total hydrocarbons and metals). • As part of the Derwent Park Stormwater Harvesting and Industrial Reuse project, hot spot surveys of hydrocarbon contamination are undertaken to identify key sources. • Sampling after rain/storm events is undertaken intermittently.
Kingborough	• Commencement of Browns River Flood Risk Study as part of the Tasmanian Coastal Adaptation Pathways Project (2014) • A monitoring program investigating enterococci concentrations in the Kingston Wetland was conducted in 2013. • A study investigating bacteriological contamination in the Browns River catchment was undertaken in 2012. • A longer-term waterway monitoring program was undertaken at a number of waterways from 1991 – 2010, with a focus on nutrients.
Derwent Valley	• Sampling occurs mainly in response to community complaints. • The Lachlan Community group conducts some sampling of the Lachlan River.
Brighton	• In 2014, council was in the process of designing a stormwater flow monitoring program using flow meters, to support a stormwater model for its catchments.

System Management Plans (SSMPs) over the next five years, as required by the *Urban Drainage Bill 2013.*

Stormwater models simulate the infiltration and drainage pathways rainwater and stormwater take before terminating in a waterway. Models can be used to better inform stormwater system planning and can predict the effectiveness of design features on stormwater flows and pollution reduction. There are a wide variety of stormwater models available. In particular, the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) has been used by the DEP and a number of councils to estimate pollutant loads from specific catchments or proposed developments, to assess potential treatment options and to estimate pollutant load reductions associated with different WSUD designs.

Master Drainage Schemes

Hobart City Council has completed Master Drainage Schemes (MDS) for Ashfield, Wellington, Sullivans Cove, Lambert, and Providence Gully catchments, which included hydrologic and hydraulic models for Sandy Bay, North Hobart, Mt Stuart, Mt Nelson and Battery Point sub-catchments. A MDS for minor sub-catchments within the New Town and Brushy Creek catchments has also been initiated. A MDS for each of the 23 major catchments in the HCC municipality is proposed as part of the HCC State Stormwater Strategy Action Plan.

Kingborough Council is also undertaking a Master Drainage Scheme project, starting with the formation of a council stormwater modelling taskforce.

Flood Studies

In 2014, HCC engaged a consultant to review and update the Sandy Bay Rivulet Flood Study, including a climate change scenario model, a conversion of the 1D Mike 11 model to a 2D hydraulic model at major breakout flow paths, and a re-calibration of the model to include flood level data that has been gathered since the initial model was developed. This followed the extension and updating of the Hobart Rivulet Flood Study in 2010 and 2013 respectively.

A New Town Flood Study, which incorporates the New Town Rivulet, Brushy Creek and Maypole Creek, is expected to be completed by the end of 2015.

Stormwater System Management Plans

The adoption of the Urban Drainage Bill 2013 requires all Tasmanian councils to develop a SSMP, which identifies and quantifies flood risks. Some councils are also seeking to integrate this work with stormwater quality management planning. Councils will be using a number of stormwater models to complete the SSMPs.

4.4.5 Urban rivulets

Over a dozen major waterways and rivulets drain to the Derwent estuary, as shown in Figure 4.11. The largest of these include the Jordan River (discussed in Section 3), the largely rural Lachlan River and Sorell Creek in the upper estuary, Browns River in Kingborough, the more urbanised Hobart, New Town, Humphrey and Faulkners rivulets on the western shore, and the Risdon Brook, Kangaroo Bay and Clarence Plains rivulets on the eastern shore. As a general rule, rivulets on the western shore are steeper and carry higher flows than eastern shore rivulets due to differences in topography and rainfall patterns.

Urban rivulets provide many benefits both to people and the natural environment. They can be a source of aesthetic beauty, and provide recreational benefits such as bushwalking, jogging or nature contemplation. Rivulets provide habitat and food resources for birds, frogs, fish and invertebrate species, as well as aquatic mammals such as platypus and native water rats. Rivulets also provide important breeding areas for fish and eels. Natural vegetation cover, particularly along riparian zones, promotes stormwater infiltration and slows overland flow. Naturally flowing and vegetated waterways can filter contaminants before they are discharged into downstream waterways.

In an urban rivulet, the clearing of native vegetation, and its replacement with impervious pipes or concrete bottoms, alters natural drainage and runoff patterns. Combined with the increases in impervious surfaces in catchments associated with urbanisation, the result leads to larger flows occurring at higher velocities together with flash floods and erosion of stream banks.

In addition to stormwater-related water quality and flow issues, there are a number of other management concerns associated with urban rivulets, including:

- Proximity to aging sewage and stormwater infrastructure, which is frequently located adjacent to rivulets. These systems may pollute waterways during both dry and wet weather conditions;
- Loss of riparian vegetation and associated bank erosion: as well as increasing the amount of sediment in water, eroding banks can be unsightly, unstable and unsafe, and may reduce the ability for native plant species to establish and survive;
- Invasive species: weed seed can be transported by stormwater, and can more easily establish on banks that have exposed soil. Once established, weeds can choke out other native species, or block light from the water, making it difficult for aquatic plants and animals to survive;
- Fish passage: weirs, tunnels and culverts can prevent passage of migratory fish and eels, disrupting breeding and reproductive cycles.

Local governments are primarily responsible for the management of urban rivulets, however there are also a number of community groups and schools that undertake restoration and educational activities along their adopted sections (e.g. New Town Rivulet, Sandy Bay Rivulet, Wayne Rivulet). Rivulet management activities include maintenance of litter, boulder and sediment traps, clearing of flood debris, bank stabilisation, riparian revegetation and weed control, as well as the development and maintenance of linear parks and walking tracks. (See Table 4.10 for actions undertaken in the DEP region in the period from 2009–13.)

There have been several major planning and design studies associated with improved amenities of urban rivulets, in particular:

- *Hobart Rivulet Park Regional Strategic Master Plan* (Inspiring Place, 2011): this plan sets out a long-term vision, policies and principles for the upper sections of Hobart Rivulet, along with concept plans for specific segments that include shared pedestrian and cycling use, improved safety and sustainability, amenity and enjoyment. It has been adopted by Hobart City Council as a basis for ongoing works.
- *Hobart Rivulet: Social restoration – re-envisioning urban waterways as a catalyst for social rejuvenation* (Navratil, 2012). This conceptual study looked at ways of building on the natural and recreational amenities of the Hobart Rivulet, but focused on the lower portion of the rivulet, which is fully confined in a concrete drain, and in poor ecological condition. It envisions redevelopment of a number of sites that integrate communities, art, culture and greenscapes, and where public transport and cycleways are improved.

4.4.6 Stormwater and litter management actions 2009–14

There are a number of ways to manage and reduce stormwater pollution, including litter. These include 'at source' controls to minimise and capture pollutants before they enter the system, 'end-of-pipe controls' such as large gross pollutant traps (GPTs) and floating litter booms, WSUD systems that integrate stormwater treatment within urban landscapes, education and training programs, and litter clean-ups. A summary of key areas and actions supported by DEP and our partners during the period 2009–14 is provided below and in Table 4.10, with the location of key projects shown in Figure 4.15.

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 (DEP Community Survey, 2013).

Litter is regulated via the *Litter Management Act 2013* and can be managed in a number of different ways, including litter traps, gross pollutant traps, enforcement, education and awareness, and litter clean-up activities.

As summarised in Table 4.10, a number of different types of litter traps have been installed by councils throughout the region, ranging from small-scale traps installed in individual pits to large-scale gross pollutant traps and floating litter booms. A common issue with GPTs is the maintenance required to keep them functioning optimally. Not all GPTs are suited to all catchments. In 2012, DEP coordinated a GPT audit with participating councils. The audit identified a number of common issues resulting in poorly functioning systems, including GPTs that were undersized for the catchment, designs that were difficult to access, and irregular maintenance resulting in blocked systems. A number of recommendations were made to address these issues

The DEP has coordinated several regional litter clean-up campaigns in association with the annual Clean Up Australia Day. The most successful of these was a week-long regional litter campaign in March 2010, which involved 98 business, school and community groups and collected 24 tonnes of litter, primarily along the estuary foreshore. See Table 4.10 for a summary of other activities undertaken during the period 2009 to 2014.

Sediment and erosion control (SEC)

Poorly managed construction sites are a major source of sediment runoff to urban stormwater systems and associated waterways, particularly on sites with steep slopes. There are a number of proven methods to manage this issue, and the DEP coordinated a multi-year project to improve building site practices, with support from Australian Government and NRM South grants. Key elements of this project included:

- Sediment & Erosion Control Fact Sheets
- training courses for builders and council work crews
- provision and demonstration of materials
- regional extension officer to assist councils with site inspections and follow-up

Water sensitive urban design, including stormwater harvesting

Water sensitive urban design (WSUD) represents best practice for stormwater management, managing urban stormwater as a resource, and protecting receiving waterways and aquatic ecosystems. Examples of WSUD include collecting and reusing roof runoff (e.g. in rainwater tanks); promoting infiltration by retaining native vegetation and installing porous pavements; construction of stormwater treatment swales, wetlands and other biofiltration systems; and larger-scale stormwater harvesting projects.

A number of WSUD projects were constructed in the DEP region over the period 2009–14, many of these were initiated by the DEP with Australian Government support. In addition, two major stormwater harvesting projects were funded in Glenorchy: the Derwent Park Stormwater Harvesting and Industrial Reuse Scheme, and the Nyrstar Stormwater Harvesting Project. (See Table 4.10 for additional details.)

4.5 Summary of pollution loads 2009–13

A comparison of estimated mass emissions from major sources (i.e. industries, WWTPs, and stormwater from the greater Hobart catchment runoff and the River Derwent (above New Norfolk)) for several key pollutants from 2009–13 is provided in Figure 4.16.

These figures should be considered as indicative only, as some of the load estimates require further development (particularly the stormwater and catchment loads). Nonetheless, some useful patterns and trends are evident. Key points over the 5-year period include the following:

- Wastewater treatment plants contribute the majority of dissolved inorganic nitrogen and total phosphorus loads to the estuary;
- Nutrient loads to the estuary have remained relatively steady or increased slightly over the five-year period;
- BOD loads have declined by over 50%, largely due to additional process changes at the Norske Skog mill;
- The majority of TSS and TN are associated with stormwater runoff and catchment loads carried by the Derwent River;
- Zinc loads are primarily associated with groundwater emissions at the Nyrstar Hobart smelter.

Table 4.10 Stormwater management activities conducted by four locals councils in the Derwent estuary

Management activity	Hobart	Glenorchy	Kingborough	Clarence
Litter and gross pollutant traps	• Urban litter trap infill (2009) and review/ rationalisation • Floating litter traps on New Town and Hobart Rivulets(2009/10) • New GPT at Red Chapel beach	• Floating litter traps on Barossa and Humphrey Rivulets (2010) • New GPT installed at Windermere Bay	• New litter trap system at Kingston Bypass	• Three new GPTs at Simmons Park (2012) • Annual CUAD coordinator engaged by CCC
WSUD and stormwater harvesting	• StormTreat system installed at Clearys Gate Depot (2011) • UTas raingarden installed at Student Union (2011) • Anglesea Street raingarden • Cornelian Bay car park swales • Princes Wharf & Menzies Centre – capture and reuse of roof runoff	• Windermere Bay WSUD (2013) • Chigwell subdivision WSUD (2010) • Windermere Primary School WSUD (2010) • Derwent Park stormwater harvesting project to capture and treat stormwater using reverse osmosis for industrial reuse and/or irrigation • Nyrstar WSUD projects (Lake Louise, car park rain gardens, wharf detention pond) • Nyrstar stormwater harvesting to capture and treat stormwater using reverse osmosis for industrial reuse	• Kingston Bypass WSUD projects, including rock-lined and vegetated swales, bioretention system (DIER) • Whitewater Creek/Kingston Bypass WSUD (2013) • Central area WSUD project	• WSUD and reuse system designed for Simmons Park (to be completed in 2015) • Rosny Point sedimentation basins and rock-lined outfalls to arrest erosion concerns
Urban rivulets	• Hobart Rivulet Linear Park Strategic Plan (2011) and associated improvements (willow and weed removal, revegetation, bank stabilisation, track improvements) • Sandy Bay Rivulet – gabions and fish passes installed at Digney St and Regent St • Rivulet assessments completed for key waterways, including geomorphology, vegetation, weeds and hydraulic obstructions • Conceptual plan for lower Hobart Rivulet (Navratil, 2012)	• Weed and/or willow removal and revegetation along sections of New Town, Faulkners, Barossa, Humphey, Rosneath, Islet and Abbotsfield rivulets. • Hilton Creek gabions/rehab	• Whitewater Creek: ongoing project to remove willows/ weeds, revegetate and stabilise banks	• Riparian works along sections of Kangaroo Bay Rivulet, Clarence Plains Rivulet and Faggs Gully Creek (Geilston Bay)

Figure 4.15 Major WSUD projects in the Derwent estuary region installed since 2009

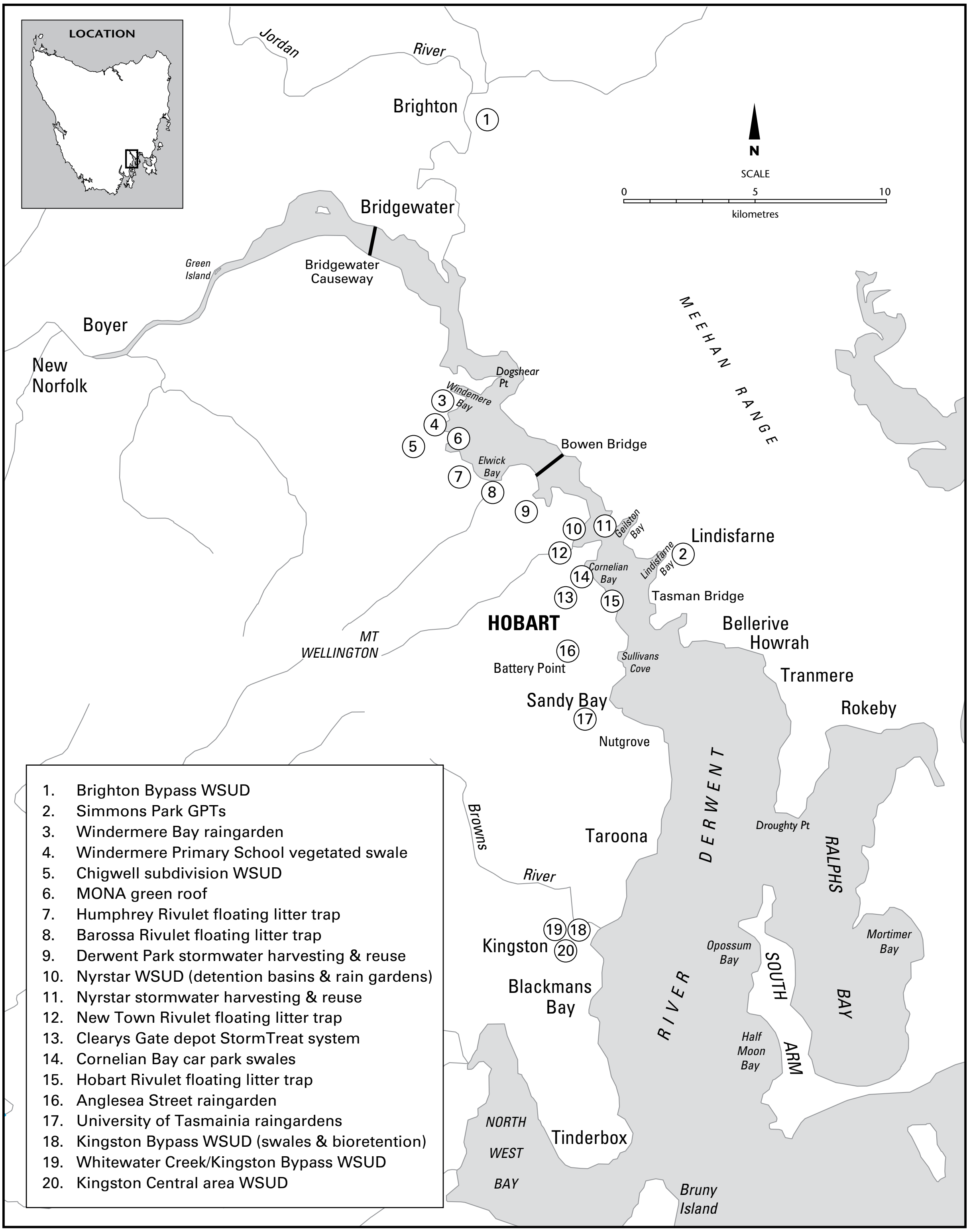
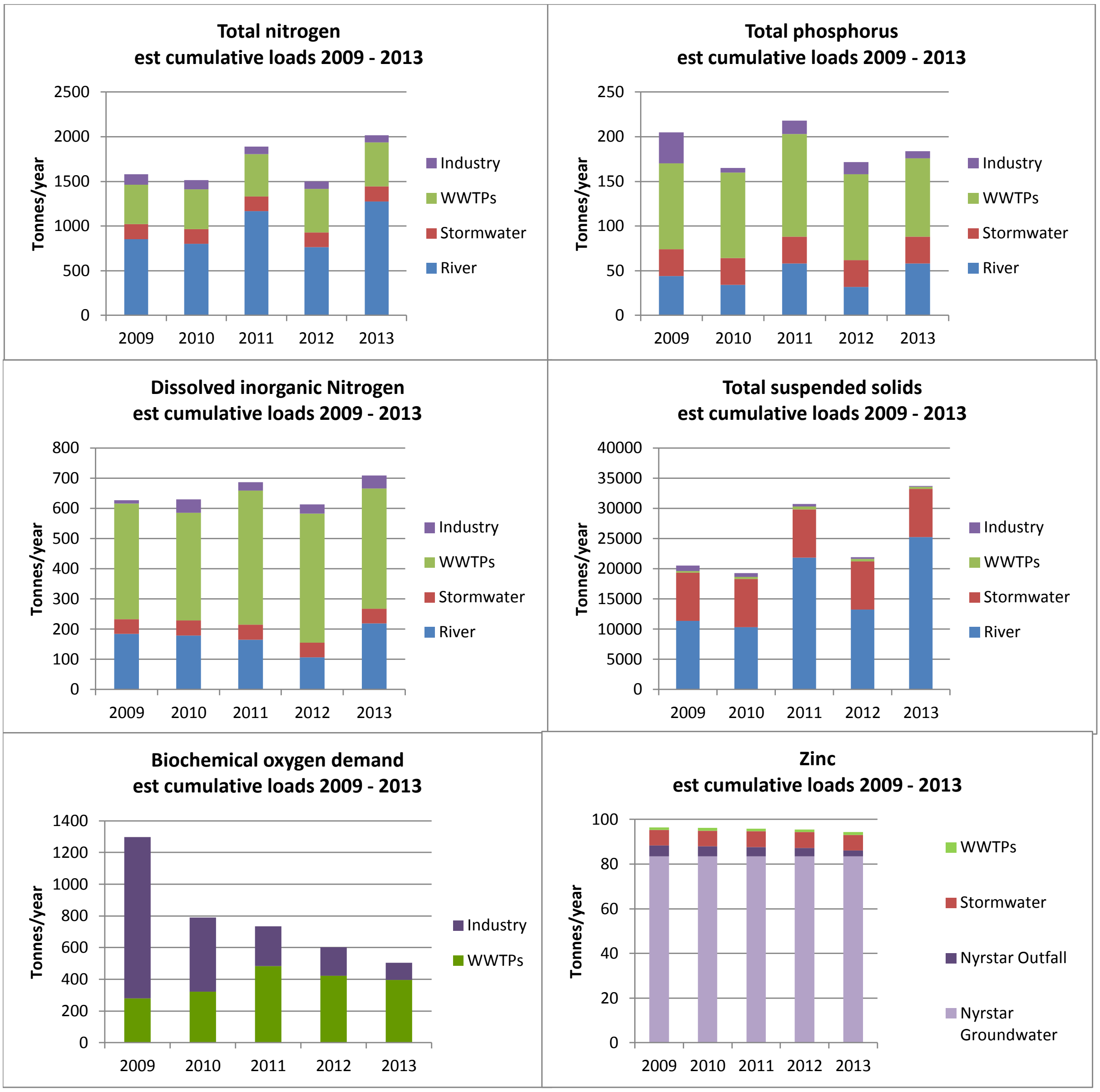


Figure 4.16 Estimated cumulative loads and trends in pollutant loads to the Derwent estuary (2009 to 20013)



Notes: Catchment loads derived from River Derwent flows at Meadowbank and monthly monitoring data at New Norfolk. Stormwater loads based on MUSIC modeling carried out by the DEP and regional stormwater monitoring data based on an average rainfall year and does not reflect interannual variability

5.0 AMBIENT WATER QUALITY

The Derwent Estuary Program (DEP) coordinates monthly ambient water quality monitoring as a cooperative initiative between the Tasmanian Government, Nyrstar Hobart and Norske Skog Boyer. The principle objectives of this monitoring program are to:

- Coordinate and better integrate existing monitoring activities;
- Compile and interpret water quality data;
- Report on water quality conditions and trends;
- Provide water quality data to support informed assessment and management;
- Support scientific investigations into physical, chemical and ecological processes.

5.1 Introduction

Ambient water quality monitoring in the Derwent estuary commenced in 1972 and has changed considerably over the years in terms of the number and location of sampling sites, the frequency of monitoring and the parameters measured. This chapter focuses on water quality data collected since the previous State of the Derwent Report, primarily for the five-year period between January 2009 and December 2013, but also evaluates longer-term trends. See previous State of the Derwent Reports for additional information (Coughanowr, 1995; Green and Coughanowr, 2003; Whitehead et al., 2010).

Sampling was conducted on the third Tuesday of each month at 29 sites between New Norfolk and the Iron Pot as shown in Figure 5.1. Samples were collected by Norske Skog (upper estuary), Nyrstar (mid estuary), and the Environment Protection Authority (EPA) and DEP (lower estuary and Ralphs Bay). At each site, in situ field data were collected using calibrated sensors, which record temperature, salinity, pH and dissolved oxygen. Field turbidity was also recorded at all sites sampled by the DEP. In situ field measurements were collected at the surface (<0.5 m water depth), then at 1 m intervals to 10 m depth, at 5 m intervals between 10 m and the bottom, with a final measurement at 0.5 m above the seabed. Water clarity was also measured at each site using a Secchi disc.

Water samples were collected at most sites from the surface (~0.5 m below the water surface) and bottom (~0.5 m above the benthos) for laboratory analysis of combined ammonia+ammonium (NH_8+NH_4), combined nitrite+nitrate (NO_2+NO_3, or NO_X), total nitrogen (TN), dissolved reactive phosphorus (DRP), total phosphorus (TP), true colour, total suspended solids (TSS), total organic carbon (TOC) and total zinc. Depth integrated samples were collected using a Lund tube (Talling and Lund, 1957) for laboratory analysis of chlorophyll-a. Samples were placed in an insulated cool-box containing ice before taking them to the laboratory immediately upon completion of the sampling event. All laboratory analysis was conducted by the NATA-accredited laboratory Analytical Services Tasmania.

The following is a list of exceptions to the sampling regimen described above that occurred in this reporting period (January 2009 to December 2013):

- All Nyrstar sites were also sampled for total cadmium, copper, lead, mercury and iron;
- Zinc data collected from Nyrstar sites prior to September 2011 have been omitted as samples were analysed at another lab and the data were not considered comparable;
- Sampling for the suite of laboratory analyses at Nyrstar sites NTB5, PWB, U3 and U5, and DEP sites G2 and KB, commenced in November 2010;
- DEP sites B5, C, RB, RBS, SC, CB, LB were sampled for in situ parameters and Secchi depth only;
- Norske Skog Boyer collected in situ physical and chemical data for surface and bottom (~0.5 m above the benthos) depths only, not full water column profiles.

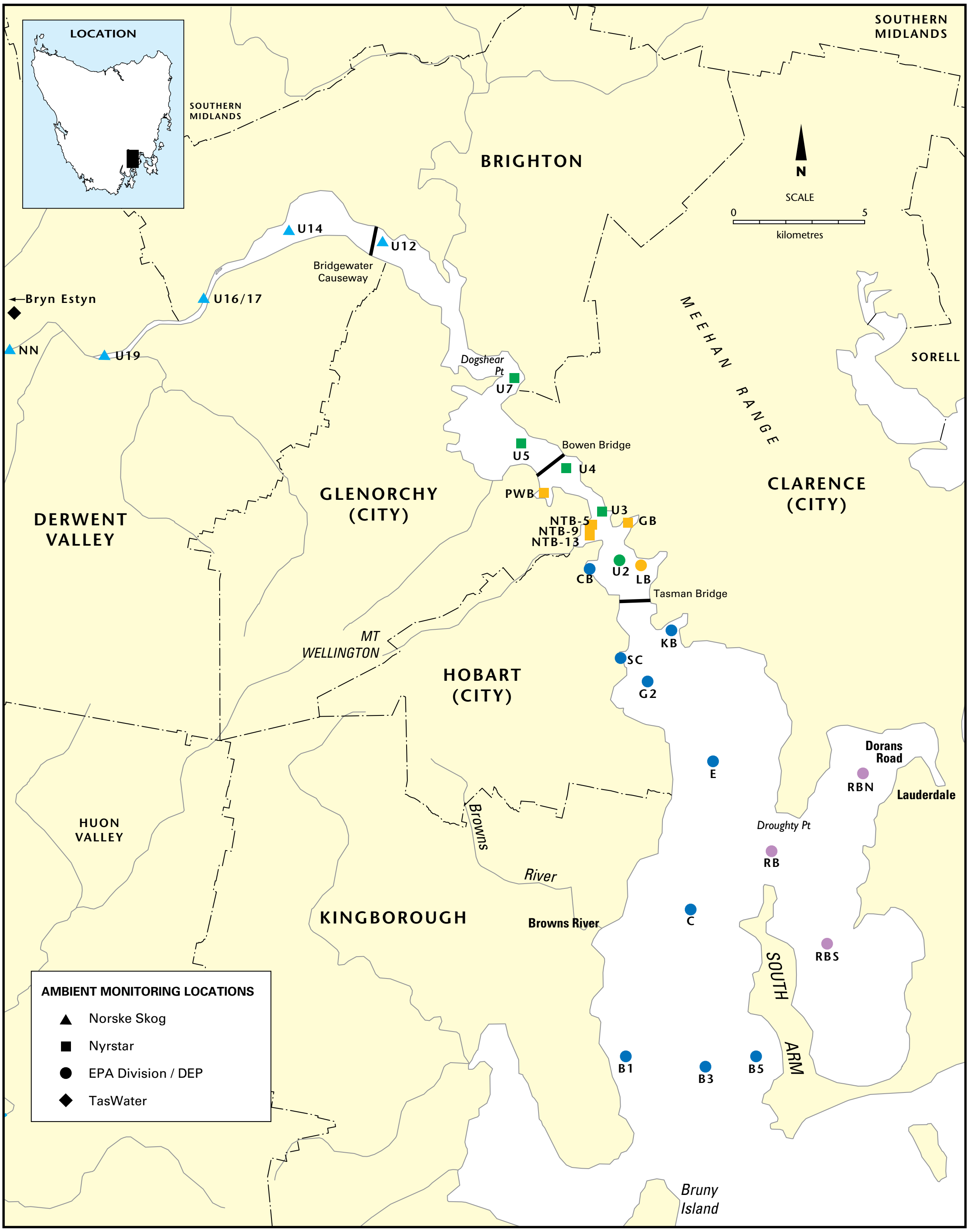
5.1.1 Quality Assurance and Quality Control

Quality Assurance (QA) is the process whereby field sampling and laboratory activities are carried out in a way that ensures accurate and reliable results. The DEP monitoring program achieves this through the use of standard operating procedures that are used by all sampling teams. The DEP also coordinates regular inter-calibration exercises with sampling teams to ensure consistency of sampling method and functionality of physic-chemical multi-probes. All water samples are analysed by Analytical Services Tasmania (AST), a NATA-accredited laboratory, to ensure consistency of analytical method.

Quality Control (QC) is a set of activities or techniques used to ensure that quality assurance procedures are effective. Specific control samples are used to achieve this, including the use of an artificial seawater standard prepared by AST as the nutrients blank and deionised water as the metals blank. These blanks are handled as if they were collected from the field, that is, for nutrients filtered and transferred into a laboratory supplied sample vial and for metals transferred to another sample container. This process identifies any possible sources of contamination that may occur during sample collection. Trip blanks consist of sample bottles that

Figure 5.1 Ambient water quality monitoring sites in the Derwent estuary (2009–13)

Colours correspond to different functional zones.



are not opened, but are handled and stored in the same manner as other samples, and are indicative of sample changes that may occur due to storage and transport effects.

5.1.2 Derwent estuary functional zones

Estuaries represent a continuum of water chemistry from freshwater to saltwater. For the purposes of discussion, it is useful to separate the estuary into broad zones based on key indicators of water quality and their geographical location within the estuary. Given that salinity is a characteristic feature of different portions of an estuary, the mean and standard deviation of surface water salinity were used to determine the similarity between sites using the analytical technique known as hierarchical cluster analysis, resulting in the following zones:

- Upper estuary including sites (NN, U19, U16/17, U14 and U12)
- Mid-estuary channel including sites (U2, U3, U4, U5 and U7)
- Mid-estuary bays including sites (CB, GB, LB, NTB 1, NTB 2, NTB 5, NTB 13 and PWB)
- Lower estuary including sites (SC, KB, G2, E, C, B1, B3 and B5)
- Ralphs Bay including sites (RBN, RB and RBS)

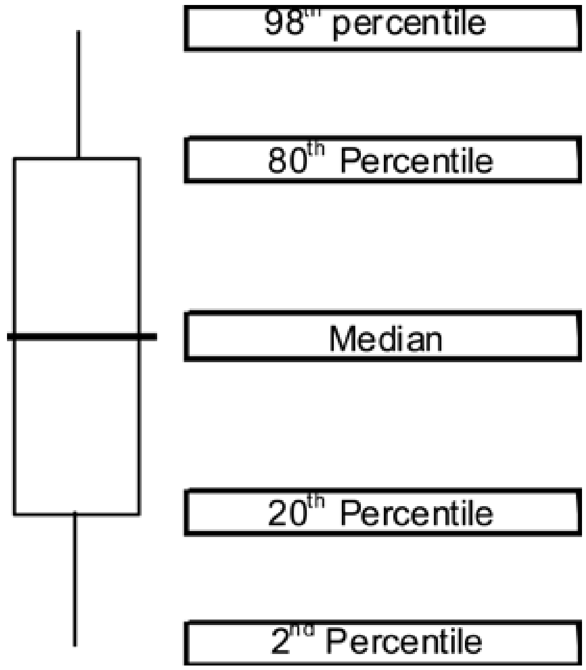
Some discretion was used to create five zones that were geographically logical as well as broadly similar in water quality. For example, the statistical results placed Sullivans Cove in the Ralphs Bay zone and Cornelian Bay in the lower estuary zone, but for logical geographical representation, Sullivans Cove was included in the lower estuary zone and Cornelian Bay with the mid estuary bays. Also, it should be noted that the selected zones are based only on surface water salinity so the site groupings would differ if other parameters and depths were used to identify similarity between sites.

The three estuarine regions – upper, mid and lower – are each characterised by different physical, chemical and biological conditions. The upper estuary is dominated by freshwater inflow from the River Derwent, particularly in surface waters. However, an underlying layer of saltwater extends along the bottom of the estuary, often as far as New Norfolk; the distance up-estuary to which the underlying salt water extends depends on the volume of freshwater flow and tidal forcing. This type of stratification with freshwater overlying a saltwater tongue is the definitive feature of salt-wedge estuaries. The mid estuary extends from Dogshear Point to the Tasman Bridge, excluding Cornelian Bay (site CB), which is closer to the lower estuary sites with respect to its surface-water salinity. The mid estuary is the most industrialised and urbanised section of the Derwent and it is also frequently stratified with fresher surface water and saltier bottom waters, particularly during periods of high river flow. The lower estuary zone includes Cornelian Bay and sites south of the Tasman Bridge to the estuary mouth, excluding Ralphs Bay. The lower estuary is dominated by marine waters but the upper 10 m of the water column is frequently influenced by water from further up the estuary. Ralphs Bay is a geographically unique part of the lower estuary as it is broad and shallow and thus supports large intertidal areas. Water quality in Ralphs Bay is influenced by a variety of sources, with surface water predominantly influenced by water from the greater Derwent estuary and from its own expansive catchment while bottom waters are predominantly influenced by marine sources (Wild-Allen et al., 2009).

5.1.3 Data presentation, analysis and guidelines

Ambient water quality data collected over the five-year period between January 2009 and December 2013 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 5.2). The functional zones described above are grouped together and colour-coded. 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.

Figure 5.2 Example of box and whisker plot statistics used in this report.



Water quality indicators from the Derwent estuary are compared to National Water Quality guidelines (ANZECC, 2000) as set out in Table 5.1, as described in the relevant sections. For zinc – a toxicant – the 95% trigger value (protection of slightly to moderately disturbed ecosystems) was used. 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.

The seasonal Mann Kendall analysis was used to identify whether there were any statistically significant trends in water quality over the 10-year period (January 2004 through to December 2013). This robust and powerful non-parametric analytical technique is often used to detect trends in water quality data (Helsel and R.M., 1992; U.S. EPA, 1997). It does not require that data is normally distributed, allows for data gaps and missing values, and it identifies trends by comparing the direction of the difference between subsequent sample results while allowing for seasonal variability.

Table 5.1 Summary of relevant national water quality guidelines (default trigger values for slightly disturbed ecosystems in south-eastern Australia (ANZECC, 2000), together with detection limits at Analytical Services Tasmania (as of May 2014)

ANZECC trigger value	NH_4^+ (µg/L)	NO_x (µg/L)	DRP (µg/L)	TP (µg/L)	TN (µg/L)	Chl-a (µg/L)	DO (mg/L/ % sat.)	pH	Zinc* (µg/L)
Estuaries	15	15	5	30	300	4	6/80–110	7.0–8.5	NA
Marine	15	5	10	25	120	1	6/90–110	8.0–8.4	15
AST detection limit	2	2	2	5	40	0.5	NA	NA	1

* 95% trigger value for protection of slightly to moderately disturbed ecosystems; NA = not applicable

5.2 In situ physical and chemical parameters

5.2.1 Salinity

Salinity is key characteristic of aquatic habitats and largely controls the spatial distribution of estuarine biota. Salt water is denser than fresh water and this can cause distinct layering (or stratification) throughout the water column. Higher salinity water buffers pH, maintaining higher pH in marine water compared with fresh water. Salinity also influences the flocculation and settling of fine-grained sediment particles and their entrained contaminants, as dispersed particles tend to flocculate at the interface between fresh and salt water (Li et al., 1983; Sholkovitz, 1978).

During the 2009–13 period, median salinity of the Derwent estuary ranged from freshwater (0 PSU) in surface waters of New Norfolk to seawater (34 PSU) at depth in the lower estuary (Figure 5.3). Surface waters of the upper and mid estuary were markedly less saline (combined median of 15.4 PSU) than bottom waters (combined median of 31.7 PSU). In contrast, median salinity in the lower estuary and Ralphs Bay was typically high throughout the water column (surface waters: 30.8 PSU, bottom waters: 34 PSU). Salinity of mid estuary bays was generally more variable and less saline than sites in the mid estuary channel. Salinity in Derwent estuary surface waters tends to be highly variable due to seasonal variability and the intermittent influence of water from the River Derwent.

Over the 10-year period from 2004–13, no significant trend was detected in surface water salinities but a significant decrease was observed in the bottom waters in the middle and lower estuary (Table 5.2). In the upper estuary, the apparent increase in salinity at NN and lack of a declining trend in bottom waters may be due to the use of a new and more sensitive field probe commencing in January 2011, This resulted in an increase in the number of values greater than 0, particularly significant at sites with predominantly fresh water, such as site NN.

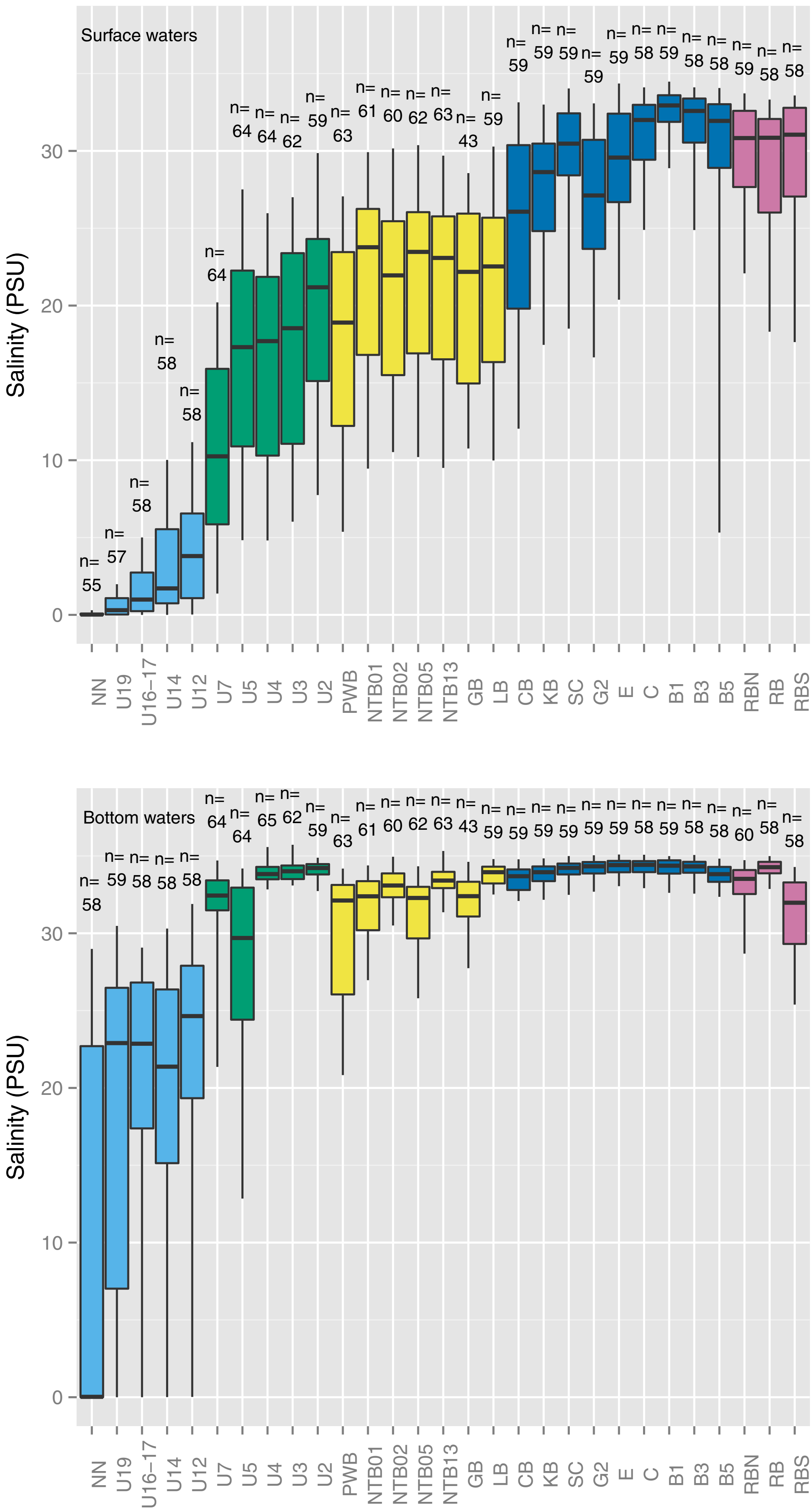
Table 5.2 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for salinity during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges between -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	**NN** (0.27)
	Bottom	None
Mid-channel	Surface	None
	Bottom	**U7** (-0.31), **U4** (-0.44), **U3** (-0.46)
Mid-bays	Surface	**NTB** 5 (-0.16)
	Bottom	**GB** (-0.39), **LB** (-0.21), **NTB** 5 (-0.34), **PWB** (-0.16)
Lower	Surface	**C** (-0.25), **SC** (-0.17) , **B1** (-0.16)
	Bottom	**SC** (-0.19) , **KB** (-0.24), **G2** (-0.18) , **E** (-0.23) , **C** (-0.23), B3 (-0.22)
Ralphs Bay	Surface	**RB** (-0.16)
	Bottom	**RB** (-0.19)

Figure 5.3 Salinity in a) surface waters and b) bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



5.2.2 *Water temperature*

Water temperature influences the rates of biological and chemical processes, including biological growth, respiration rates, seasonality and reproductive timing. Temperature is a key influence on the growth and senescence phases of submerged aquatic vegetation such as seagrass, and the timing of fish migration (Sims et al., 2001; Verwey, 1949). The rate of biochemical reactions in sediment and water increase at higher temperature and the capacity of water to retain dissolved oxygen is lower at higher temperature (Boylen and Brock, 1995; Zeikus and Winfrey, 1976).

During the 2009–13 period, median water temperature ranged between 12.5oC (site U19 surface) and 14.3oC (site C surface) and all sites were warmer in summer and cooler in winter. Surface waters of the upper estuary are slightly cooler than surface waters of the lower estuary, while the opposite is true in bottom waters (Figure 5.4). Water temperature in the upper estuary and in bays and coves is generally more variable than at sites in the lower estuary and the main channel.

Over the 10-year period from 2004–13, there was a general increasing trend in water temperatures at depth in the mid-estuary, lower estuary and Ralphs Bay, as shown in Table 5.3. This may be related to changes in regional current patterns, possibly associated with longer-term impacts of climate change (IPCC, 2013).

5.2.3 *Dissolved oxygen*

Oxygen influences most aquatic chemical and biological processes and is essential to many forms of life. Dissolved oxygen concentration (DO) is influenced by temperature, salinity, primary productivity, water turbulence, biological respiration and bacterial decay. Oxygen dissolves more readily at low temperature and low salinity, thus DO is generally much 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. Low DO 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. Low DO can kill or exclude more sensitive organisms, significantly altering benthic community structure. Some broad-scale fish kills have also been attributed to acute low DO events.

Low DO affects the types and rates of bacterial processes in sediments with consequences such as the release of sediment-bound nutrients and heavy metals, and the production of toxic methane and hydrogen sulfide gasses. DO in healthy estuarine environments is generally between 6.5 and 9 mg/L (ANZECC, 2000; Vaquer-Sunyer and Duarte,

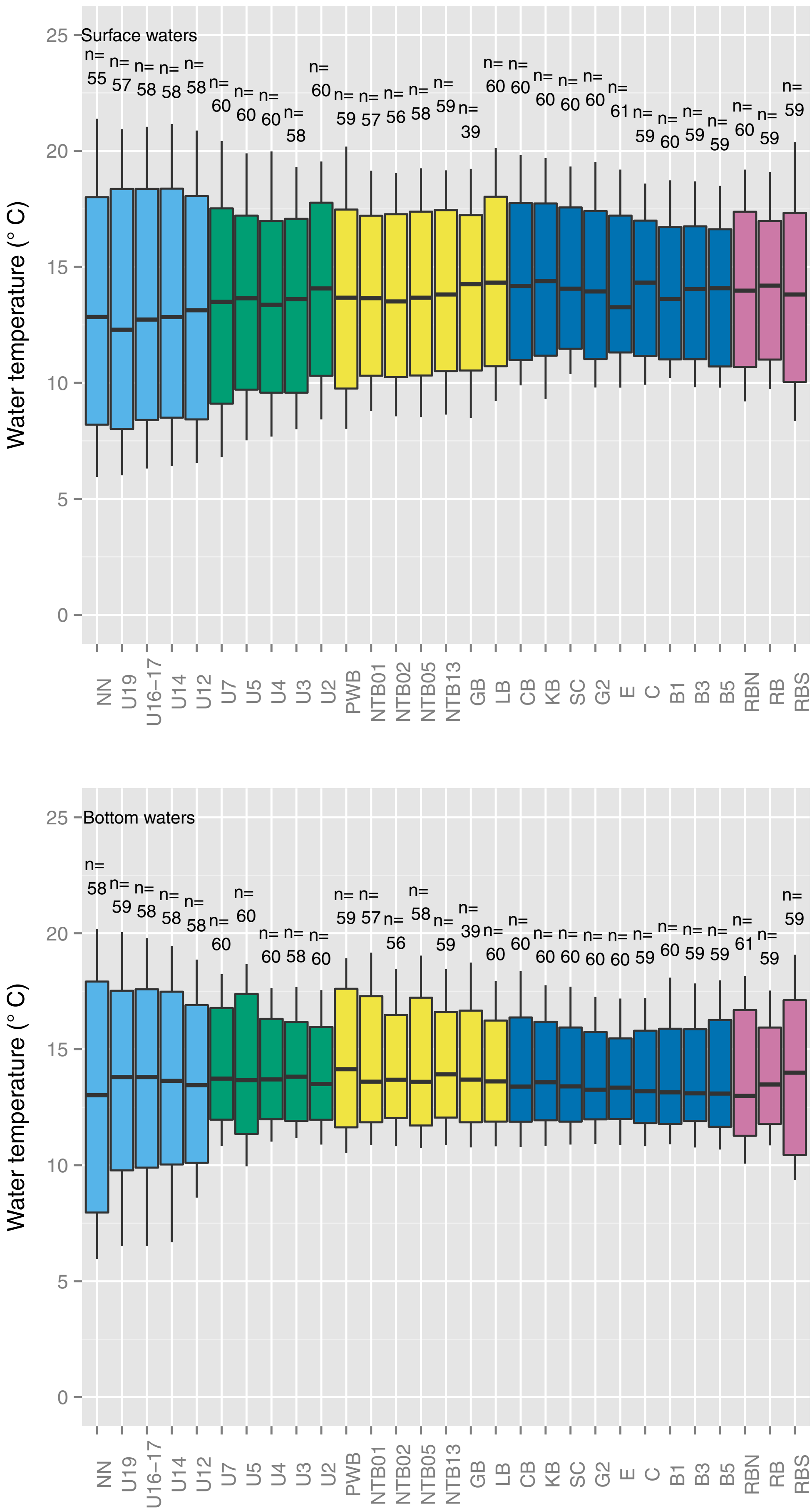
Table 5.3 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for temperature during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges between -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	None
	Bottom	None
Mid-channel	Surface	None
	Bottom	**U7** (0.21), **U4** (0.15), **U3** (0.26), **U2** (0.25)
Mid-bays	Surface	None
	Bottom	**GB** (0.22), **LB** (0.17), **NTB** 5 (0.16)
Lower	Surface	**B1** (0.19), **B3** (0.17), **B5** (0.19),
	Bottom	**SC** (0.23) , **KB** (0.25), **G2** (0.25) , **E** (0.21) , **C** (0.26), **B1** (0.22) , **B3** (0.24)
Ralphs Bay	Surface	None
	Bottom	**RB** (0.23)

Figure 5.4 Water temperatures in a) surface waters and b) bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



2008; Brezonik and Arnold, 2011; Banks and Ross, 2009).

A summary of the biological effects of low DO concentration is provided below (USEPA, 2002):

- >5 mg/L – Most organisms grow and reproduce unimpaired
- Between 3 and 5 mg/L – organisms become stressed
- < 3 mg/L (hypoxia) – many species move elsewhere and immobile species may die
- <0.5 mg/L (anoxia) – death of all organisms that require Oxygen for survival

During the 2009–13 period, median dissolved oxygen concentrations were generally high in surface waters throughout the estuary, with a maximum of 9.9 mg/L at New Norfolk and declining gradually downstream to 8.5 mg/L at the estuary mouth (Figure 5.5). DO was higher in surface waters than in bottom waters and was seasonally variable, being generally highest in winter and spring and lowest in summer and autumn. Median DO levels at depth ranged from a minimum of 3.3 mg/L at U19 to a maximum of 8.5 mg/L in Ralphs Bay (RBS). Particularly low levels were observed at depth in the upper estuary, which experienced hypoxia (severe low dissolved oxygen) in summer and autumn, especially at site U19 where hypoxia persists for between five and seven months each year.

Over the 10-year period from 2004–13, there has been an increase in surface water DO levels at several sites in the middle and lower estuary, but an apparent decline in both surface and bottom waters in the upper estuary (see Table 5.4). However, a more detailed review of the data set for the upper estuary suggests that this apparent decline may be the result of a faulty sensor, and the data during the period Jan 2011 through 2014 may not represent actual conditions.

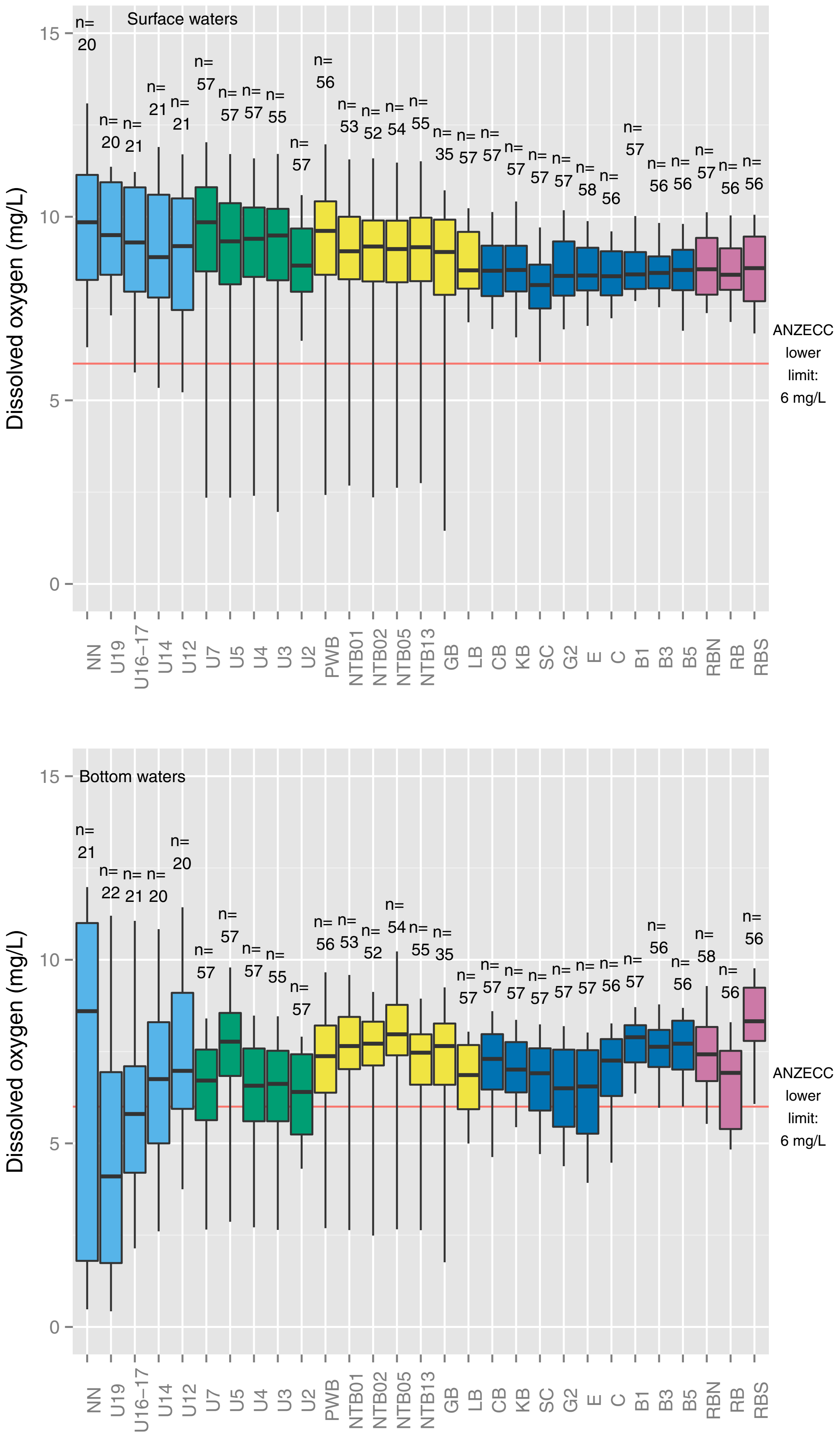
Table 5.4 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for dissolved oxygen during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges between -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	**NN** (-0.47), **U19** (-0.39), **U16/17** (-0.44), **U14** (-0.34), **U12** (-0.25)
	Bottom	**NN** (-0.19), **U14** (-0.25), **U12** (-0.32)
Mid-channel	Surface	**U2** (0.25)
	Bottom	None
Mid-bays	Surface	**LB** (0.26)
	Bottom	None
Lower	Surface	**CB** (0.3), **KB** (0.21), **SC** (0.17)
	Bottom	None
Ralphs Bay	Surface	**RBS** (0.19)
	Bottom	**RBS** (0.18)

Figure 5.5 Dissolved Oxygen concentration (mg/L) in surface and bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



The upper reaches of the Derwent estuary are highly susceptible to 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 historically low in this region, particularly at sites NN, U19 and U16/17, and have been exacerbated by discharges of organic and nutrient-rich paper mill and wastewater treatment plant effluent to the upper estuary (see Chapter 4 for further discussion). Reduced river flows and declining water quality from the catchment above New Norfolk are likely to further reduce DO levels in this region, as discussed in Chapter 3.

5.2.4 pH

pH is a measure of the acid balance of water and it influences many biological and chemical processes, including the solubility of metals, such as iron and copper. Extremely low pH levels can cause metals bound to sediments to become biologically available or can kill fish and other aquatic species. pH is generally lower in freshwater than saltwater, with typical estuarine pH levels averaging 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).

During the 2009–13 period, median pH ranged between 7.4 (upper estuary bottom waters) and 8.1 (lower estuary surface waters) and generally increased with distance toward the lower estuary (Figure 5.6). pH values at all sites fell within the ANZECC upper and lower limit thresholds (ANZECC, 2000).

Over the 10-year period from 2004–13, there was a statistically significant increase in pH levels at a number of sites, particularly in the lower estuary, but no significant trend was detected in the upper estuary (see Table 5.5).

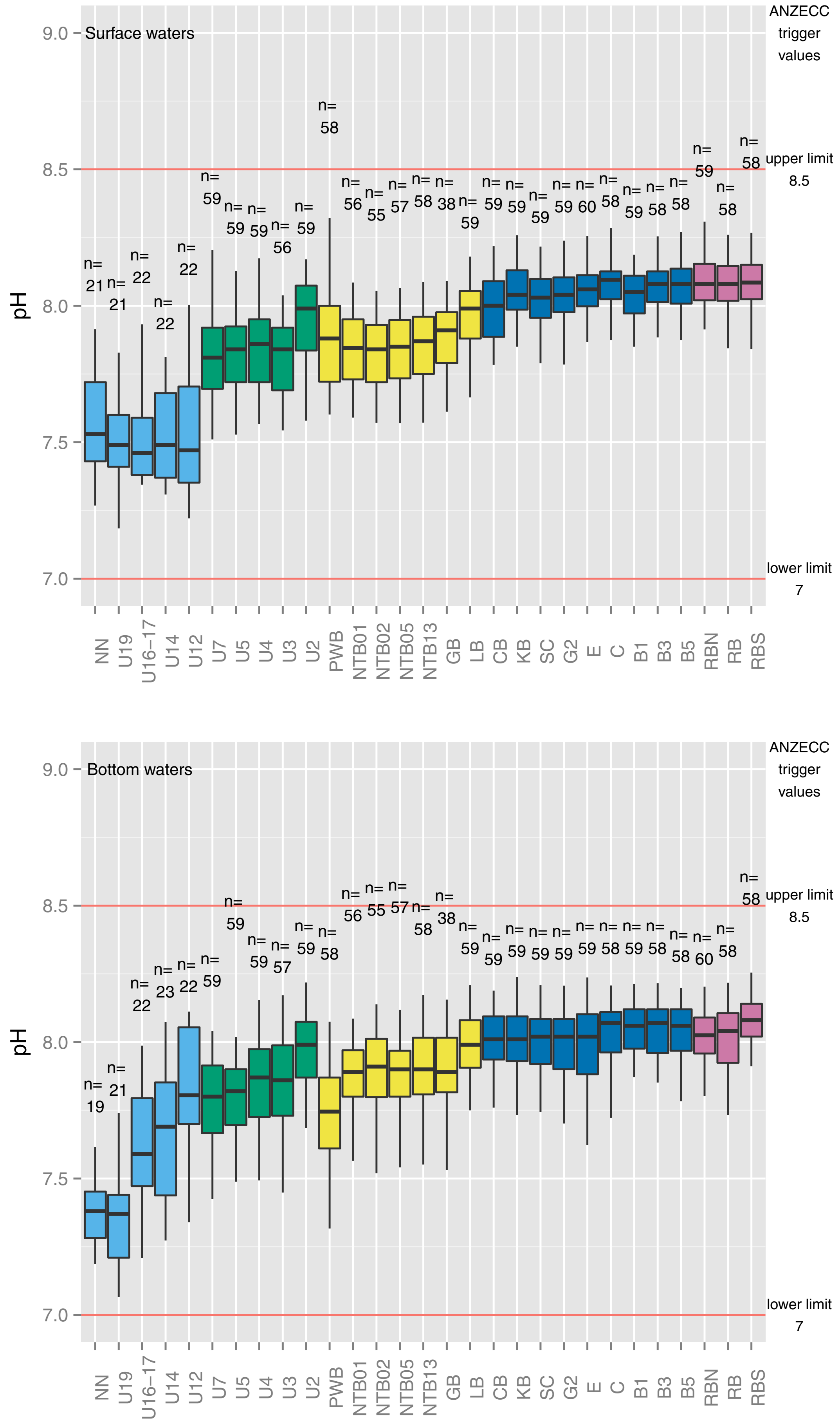
Table 5.5 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for pH during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges between -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	None
	Bottom	None
Mid-channel	Surface	**U7** (0.22)
	Bottom	**U2** (0.23)
Mid-bays	Surface	None
	Bottom	**LB** (0.2), **PWB** (-0.17)
Lower	Surface	**CB** (0.19) , **C** (0.2), **B3** (0.18), **B5** (0.21)
	Bottom	**SC** (0.23), **G2** (0.19) , **E** (0.16) , **C** (0.16), **B5** (0.2)
Ralphs Bay	Surface	**RB** (0.23), **RBS** (0.17)
	Bottom	**RB** (0.17), **RBS** (0.22)

Figure 5.6 pH in a) surface waters and b) bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



5.3 Water clarity, colour and suspended solids

The optical qualities of water, including its clarity, turbidity and colour, are determined by the attenuation of light as it passes through the water column. Optical properties in water bodies are important because (ANZECC, 1992; USEPA, 2002):

- attenuation of light through the water column can limit the growth of plants reliant on photosynthesis such as phytoplankton, seagrasses and macrophytes, macroalgae and benthic microalgae;
- changes in water colour can alter the spectral distribution of underwater light available for photosynthesis and illumination;
- decreased light penetration and high total suspended solids can reduce DO levels due to lower rates of photosynthesis combined with greater heat absorption and faster decomposition of organic matter;
- high levels of suspended 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;
- many predatory fish and birds rely on clear water to see their prey;
- clear water is aesthetically valued.

The DEP ambient monitoring program measures optical properties using three methods: Secchi depth, turbidity (DEP sites only) and true colour. TSS is also measured at all sites.

5.3.1 Secchi depth

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 estimate the euphotic depth (Ze). This is the depth at which photosynthetically active radiation (PAR) is reduced to 1% of the level at the water surface, whereby Ze = 2 x 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). It should be noted that Secchi depth measurements have a high degree of inherent error (Preisendorfer, 1986), and there are more accurate (albeit more expensive) methods to measure PAR.

Secchi depth observations for the period January 2009 to December 2013 indicate that median SD ranged from 1.0 (U7) to 6.0 (B1) metres, 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 (Figure 5.7). In the upper estuary, the SD was greatest in summer and early autumn, probably as a result of lower river flows from the catchment together with lower colour.

Trend analysis over the 10-year period from 2004– 13 suggests that Secchi depths decreased at few sites in the upper (NN and U19) and mid estuary (U7 and U4), as well as at site B5 (Table 5.6).

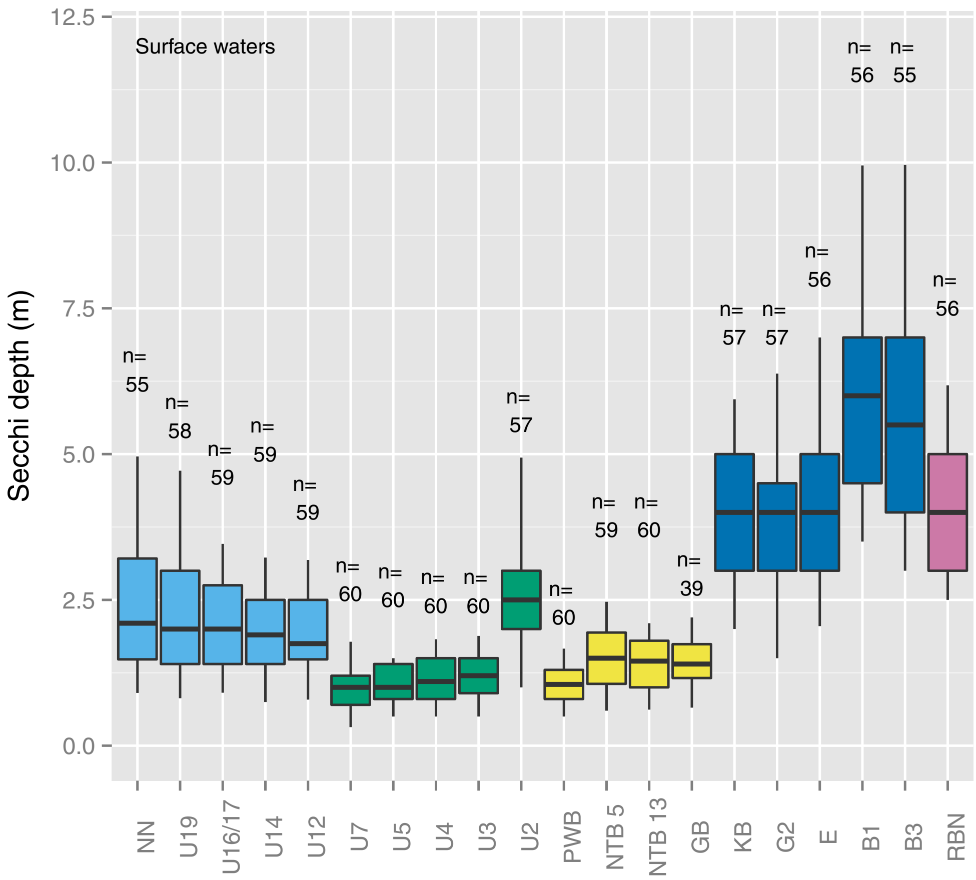
Table 1.6 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for Secchi disk depth during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges from -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Sites with significant trend
Upper	**NN** (-0.18), **U19** (-0.19)
Mid-channel	**U7** (-0.25), **U4** (-0.16)
Mid-bays	None
Lower	**B5** (-0.18)
Ralphs Bay	None

Figure 5.7 Secchi depth (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



5.3.2 Turbidity

Turbidity is an optical property that expresses the degree to which light is scattered and absorbed, and is influenced by both coloured dissolved organic matter as well as TSS in the water column. Turbidity is measured using a nephelometer as nephelometric turbidity units (NTUs). During the 2009–13 period, turbidity was sampled only at sites monitored by the DEP in the mid to lower estuary using an in situ Hydrolab sensor.

Turbidity levels in this area were generally very low and were slightly higher in bottom waters than surface waters. Median values ranged from 0 to 0.6 NTU, with samples rarely exceeding 5 mg/L. This is well within the ANZECC guidelines of 0.5 to 10 NTU, based on slightly disturbed estuarine to coastal marine ecosystems throughout southeastern Australian (ANZECC, 2000).

5.3.3 Colour

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. 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 filtered water samples, 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 tannins and humic acids give true colour to water. True colour analyses were carried out at the AST lab using water samples collected at all sampling sites.

For the 2009–13 period, median values ranged from near zero at depth in the lower estuary to a maximum of 34 to 36 Hazen Units in the surface waters of the upper estuary. True colour was highest in the upper estuary, progressively decreasing with distance downstream and was much higher in freshwater-influenced surface waters than the marine-influenced bottom waters (Figure 5.8). There is a strong seasonal trend in true colour levels in the upper estuary – with highest concentrations observed during winter months – and a strong correlation between true colour and total organic carbon.

Trend analysis over the 10-year period from 2004–13 suggests that true colour values have decreased at a number of sites throughout the estuary, but particularly at lower estuary sites and at depth (Table 5.7). This suggests that changes in marine boundary conditions may be involved. In contrast, there was no apparent trend in true colour values at New Norfolk or the surface waters of the upper estuary, with the exception of a decline at U16/17, which is probably related to improved clarity of wastewater discharges at the Norske Skog Boyer paper mill, commencing in 2009.

5.3.4 Total suspended solids

Total suspended solids (TSS), sometimes also referred to as 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 also tends to bind with some nutrients, heavy metals, hydrocarbons and bacteria. 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, stormwater run-off, wastewater discharges and other factors. TSS concentrations are typically higher during periods of high river flow or in shallow areas where wind- or tide-driven resuspension of sediments occurs. TSS concentrations are also affected by salinity levels, enabling clay flocculation. All TSS analyses were carried out at AST using a 0.45 µm filter.

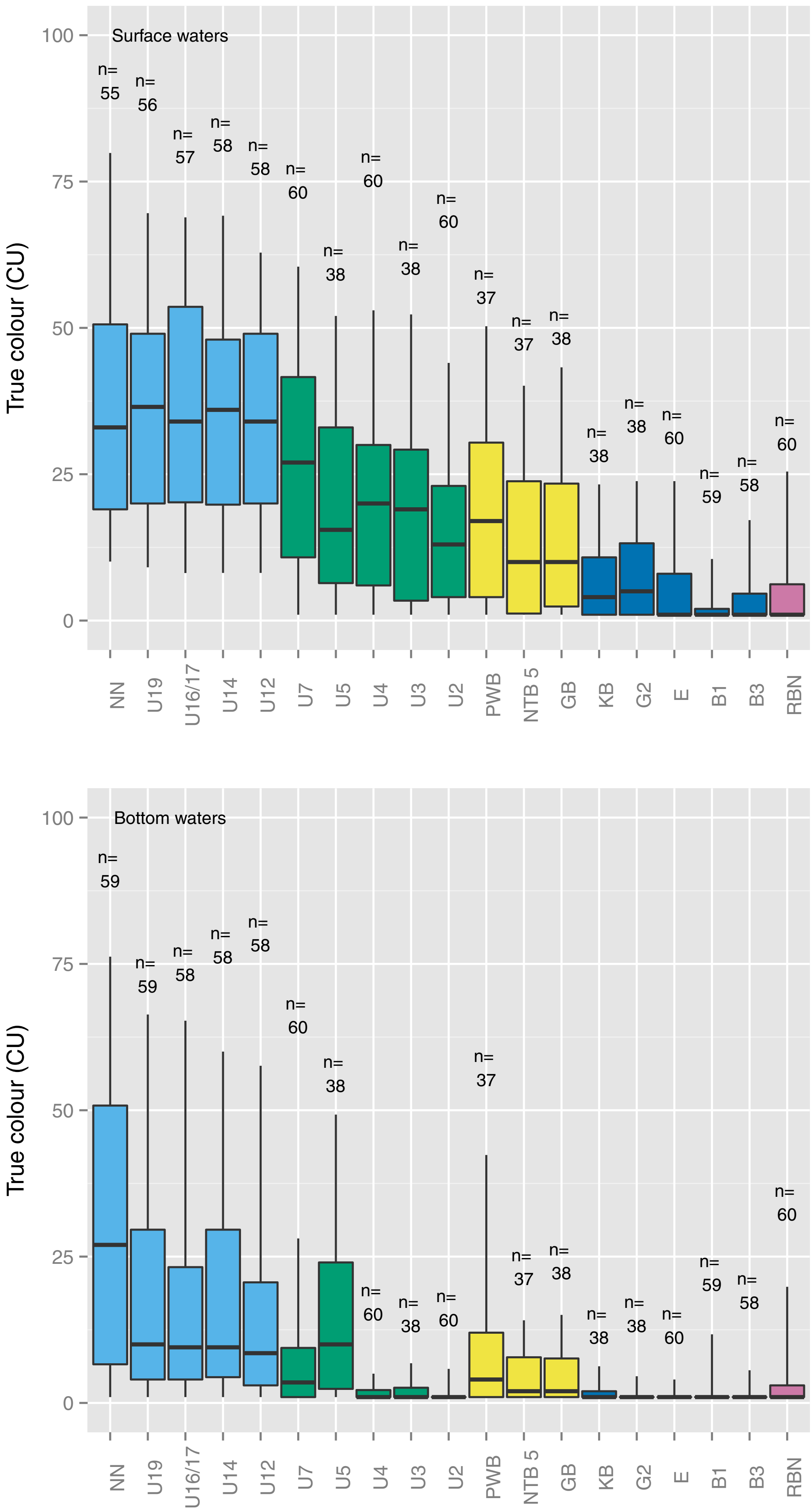
Table 5.7 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for true colour during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges from -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	**U16/17** (-0.17)
	Bottom	**U14** (-0.17), **U12** (-0.18)
Mid-channel	Surface	**U3** (-0.2)
	Bottom	**U4** (-0.29), **U2** (-0.34)
Mid-bays	Surface	**GB** (-0.24), **LB** (-0.23)
	Bottom	**PWB** (-0.25)
Lower	Surface	**CB** (-0.23) , **KB** (-0.24) , **E** (-0.18), **B1** (-0.35), **B3** (-0.28)
	Bottom	**KB** (-0.45) , **G2** (-0.48) , **E** (-0.42), **B1** (-0.35), **B3** (-0.38)
Ralphs Bay	Surface	None
	Bottom	None

Figure 5.8 True colour in a) surface waters and b) bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



For the 2009–13 period, median TSS values were relatively low, ranging from 2 mg/L or less at multiple sites to a maximum of 8 mg/L in the bottom waters of site U12. TSS levels were 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 reflects an important zone of sediment flocculation and deposition, where colloidal clay carried in fresh river water interacts with saltier marine waters at depth. During periods of high rainfall and river flow, TSS values were considerably higher as a result of urban stormwater runoff and/or high sediment loads carried by the River Derwent.

Trend analysis over the 10-year period from 2004–13 suggests a significant increase in TSS concentrations throughout all estuary zones, including at both the freshwater and marine boundaries (NN and B3).

5.4 Nutrients, chlorophyll a and algae

5.4.1 Nutrients, estuaries and algal blooms

Nutrients are essential for biological growth and function. Plants and algae (including phytoplankton) readily uptake nutrients from their environment and their growth can be limited by low nutrient availability. When nutrients occur in low concentrations, conditions are termed oligatrophic; intermediate concentrations are termed mesotrophic; and systems with excessive nutrient concentration are termed eutrophic. 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 may have a number of adverse effects including the following:

- High concentrations or 'blooms' of phytoplankton, sometimes including toxic species;
- Excessive growth of filamentous or epiphytic algae, which may result in the loss of seagrass and macrophyte beds due to shading or overgrowth by. This has been observed in the upper estuary and has also 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;

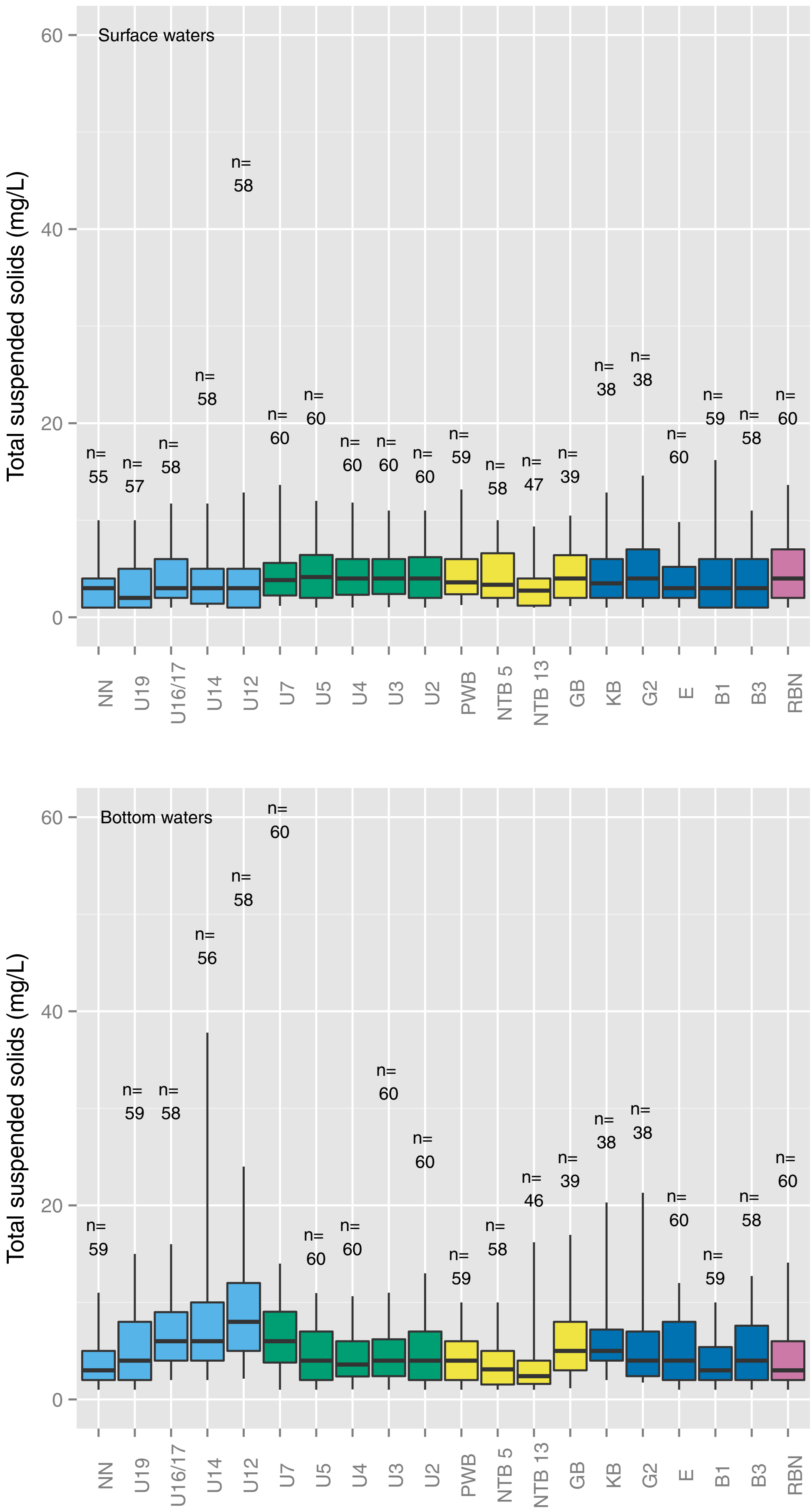
Table 5.8 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for total suspended solids during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges from -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	**NN** (0.19), **U19** (0.18), **U16/17** (0.16)
	Bottom	**NN** (0.23), **U19** (0.19), **U16/17** (0.34), **U14** (0.19), **U12** (0.18)
Mid-channel	Surface	**U7** (0.19), **U5** (0.24), **U4** (0.27), **U3** (0.34), **U2** (+0.18)
	Bottom	**U5** (0.18), **U2** (0.26)
Mid-bays	Surface	**GB** (0.29) , **NTB** 5(0.27), **PWB** (0.26)
	Bottom	**GB** (0.49) , **PWB** (0.21)
Lower	Surface	**CB** (0.19) **G2** (0.29) , **E** (0.17), **B1** (0.18), **B3** (0.2)
	Bottom	**KB** (0.35), **E** (0.29) , **B1** (0.17), **B3** (0.19)
Ralphs Bay	Surface	None
	Bottom	None

Figure 5.9 Total suspended solids in a) surface waters and b) bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



- Excessive macroalgal growth (notably *Ulva* sp.) in intertidal areas of the middle estuary 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 may create an unfavourable habitat for the endangered spotted handfish (see Section 9.3.6);
- Low or fluctuating oxygen levels, particularly when algal blooms die off and decompose, which can kill or cause physiological stress to fish and other organisms;
- Diminished aesthetic appeal due to foul odours, dead fish and rotting algae, surface scum and discolouration of the water column.

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 also be limiting at times in the upper estuary where freshwater is more prevalent (Coughanowr, 1995; NSR Environmental Consultants Pty Ltd, 2001). 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 may also be a limiting nutrient for some types of phytoplankton (diatoms).

5.4.2 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 sediments within the estuary and from adjacent coastal waters.

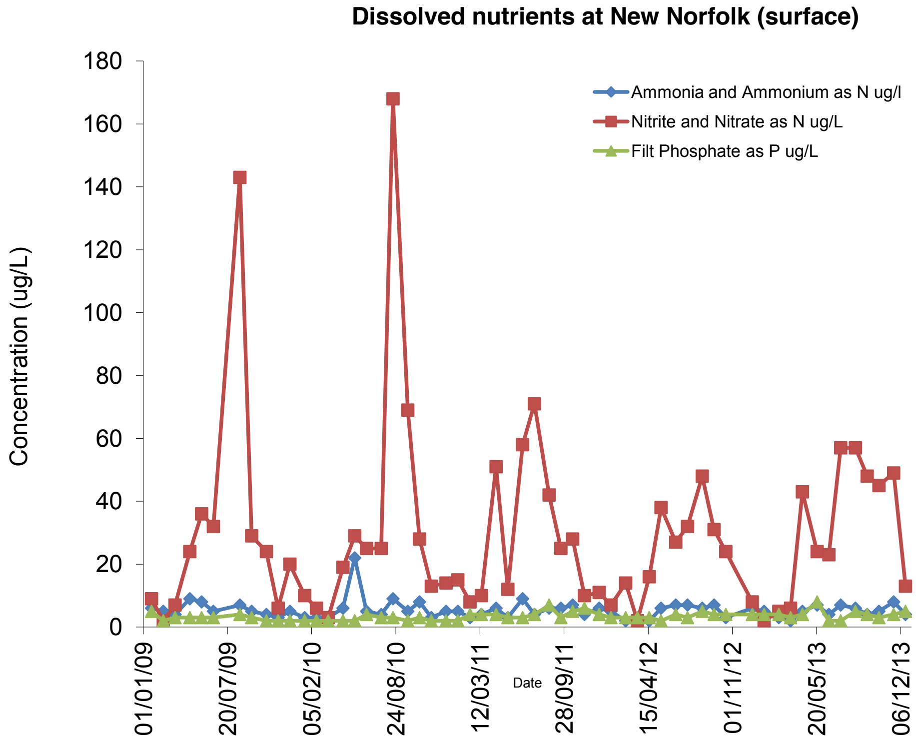
Anthropogenic sources of nutrients include sewage, fertilisers, livestock wastes, industrial discharges, urban runoff, air pollution, landfills and numerous lesser sources. These are commonly categorised as either point or diffuse sources. Point sources, such as WWTPs or industrial discharges are readily identified, and can often be mitigated through capital improvements. Diffuse sources, such as agricultural or urban runoff, typically require a broader catchment management approach for effective control.

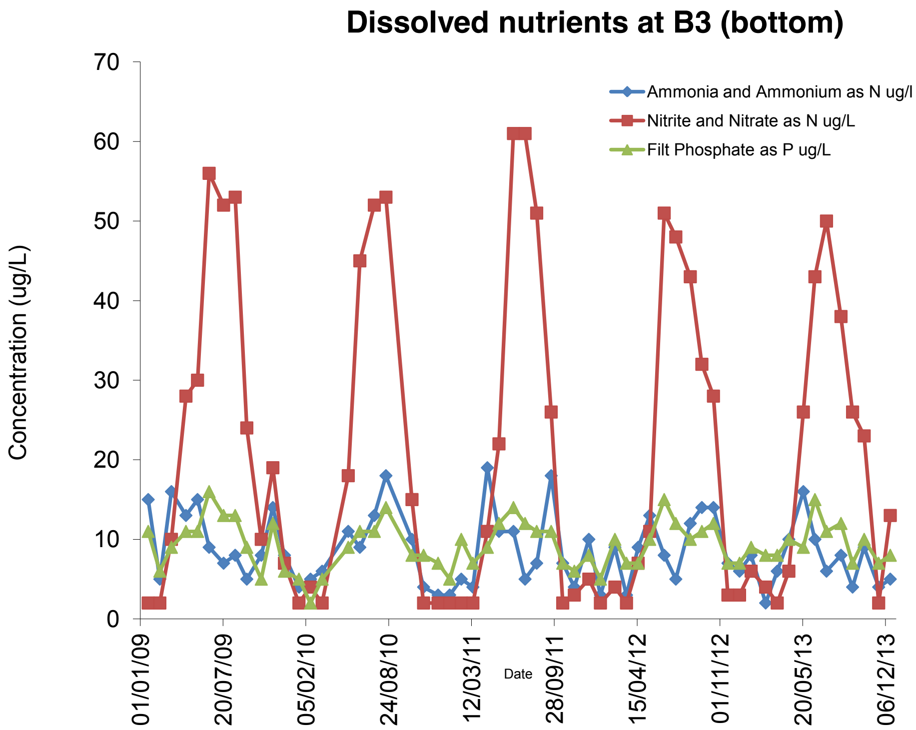
Nutrients are constantly cycling in the estuarine environment between the water column, biota, sediments and the atmosphere. In order to fully understand the cycling and availability of nutrients in the Derwent estuary, a complete nutrient 'budget' is required, which accounts for inputs, exports and '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. Further detail on the nitrogen cycle is provided in the text box opposite, and additional references on nutrients in aquatic systems and impacts of eutrophication include: Hutchinson, 1973, 1969; Laws and Bannister, 1980; Lee et al., 2007; Anderson et al., 2002; Cambridge et al.,1986; Kendrick et al., 2005; Short et al., 2011; Smith, 1998; Walker and McComb, 1992.

To improve our understanding of the nutrient cycling within the Derwent estuary, several biogeochemical models have been developed, as described in Section 10 (Wild-Allen et al., 2009).

A strong seasonality in nutrient concentrations occurs in the Derwent, particularly with respect to nitrate+nitrite (NOx), dissolved reactive phosphate (DRP), and to a lesser degree ammonia plus ammonium (NH4). This is linked to seasonal variability in both marine conditions and River Derwent inputs, as illustrated in Figure 5.10, 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 months.

Figure 5.10 Season fluctuations in NOx, DRP and NH4 at New Norfolk (NN, surface) and the estuary mouth (B3, bottom), 2009–13



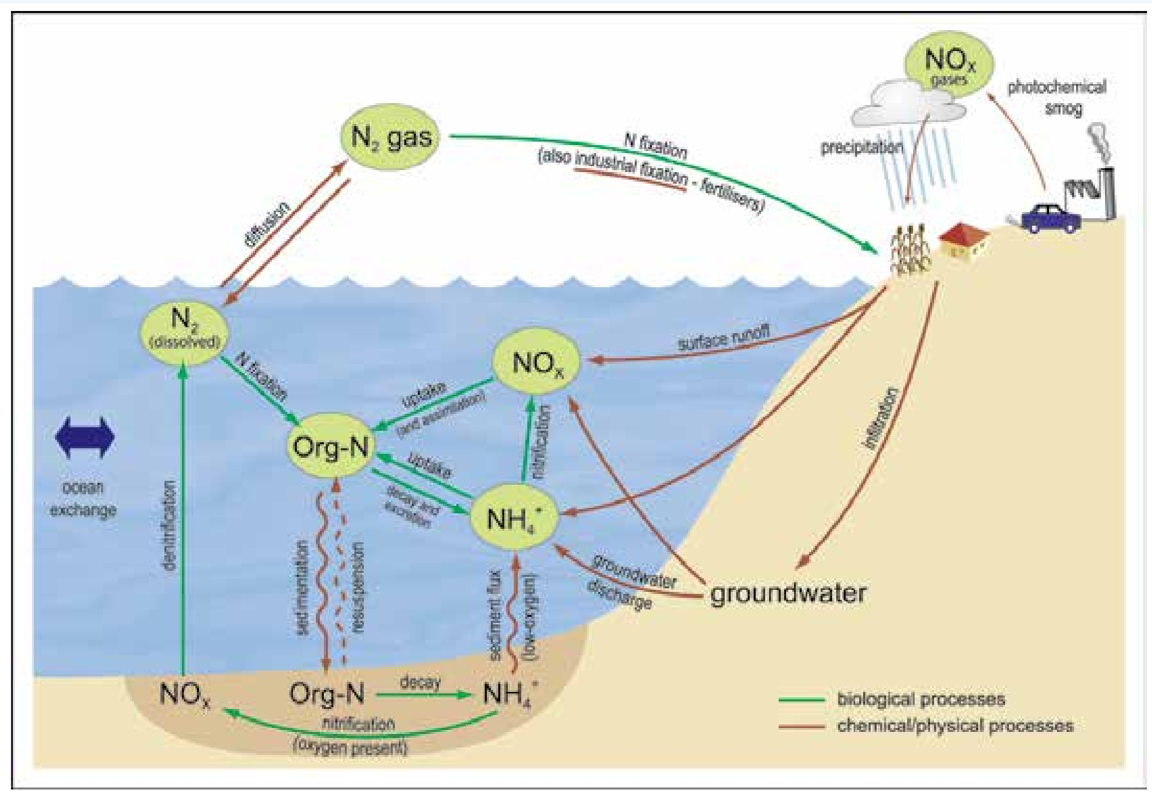


Nitrogen Cycling

Nitrogen is critical for cell growth and forms a key component of amino acids and nucleic acids such as ribonucleic acid (RNA – essential for gene expression) and deoxyribonucleic acid (DNA – genetic instruction for all living organisms). Nitrogen occurs as various chemical species illustrated below (reproduced with permission: WA Department of Water) and each species of nitrogen has different ecological effects.

Ammonia (NH_3) is a soluble gas in water which is toxic to aquatic fauna (Randall and Tsui, 2002) whilst ammonium (NH_4^+) occurs as dissolved inorganic ions in water and is an important nutrient for aquatic algae and bacteria, with elevated concentration of ammonium causing algal blooms (Anderson et al., 2002). Ammonia in seawater generally converts rapidly to ammonium through chemical reaction. Bacteria sequentially convert ammonium to nitrite then nitrate in the presence of oxygen through a process called nitrification while denitrification (conversion of nitrate to nitrogen gas) occurs in low oxygen environments. Low temperature slows the rate of nitrification which can result in seasonal differences in the relative concentration of ammonium, nitrite and nitrate. Nitrification consumes dissolved oxygen which can contribute to the generation of hypoxic zones near the sediment-water interface of rivers and estuaries and in these conditions, nitrite and nitrate is converted to nitrogen gas and is thus removed from the aquatic and underlying sediment systems. Hypoxic conditions in estuaries typically occur when a number of factors combine to reduce dissolved oxygen concentration, such as high temperature, low freshwater flow and high loads of organic matter (Rabalais et al., 2010). Total nitrogen (TN) is a measure of the sum of ammonia (NH_3^+), ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-) together with organic nitrogen which occurs in both dissolved forms such as urea and particulate forms such as phytoplankton and suspended solids.

Nitrification rates, and thus the relative proportion of each species of nitrogen, are influenced by physical and chemical properties of the water such as pH, temperature and dissolved oxygen availability (Gruber, 2008).



5.4.3 Ammonia plus ammonium-N

Ammonia (NH_3) plus ammonium (NH_4+) is an important nutrient for aquatic algae, and elevated levels may cause algal blooms. As noted in the text box, the majority of aqueous ammonia is in the non-toxic form of ammonium, except under unusual conditions of high pH and high water temperatures. In the Derwent, ammonia+ammonium levels tend to be particularly high in the bottom waters of the upper 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. Ammonia-N can also be a significant factor in sediment toxicity, primarily through porewater exposure routes.

During the period from 2009–13, median ammonia+ammonium concentrations ranged from 5 µg/L in surface waters at NN and RBN, to 82 µg/L at depth in the upper estuary (U19). Levels were generally higher at depth than in surface waters. The highest ammonia+ammonium levels were observed at depth in the upper estuary, where previous investigations have attributed this to the release of nutrients from sediments, particularly during summer months when DO levels are low (NSR, 2001; Ross et al., 2012 – see Section 10 for further discussion). High ammonia+ammonium levels were also observed in Prince of Wales Bay (median 74 ug/L), associated with WWTP discharges to this poorly flushed bay. Several sites – notably U12 and U7 – had relatively low levels that could potentially be attributed to nutrient uptake in this area of extensive wetlands and macrophtyes. However, this drawdown is less pronounced than in previous reporting periods.

Median ammonia+ammonium concentrations exceeded the ANZECC water quality guidelines for slightly disturbed ecosystems (15 µg/L) at 42% of sites in surface waters and at 53% of sites in bottom waters (see Figure 5.11). The bottom waters of the upper estuary (excluding site NN) and both the surface and bottom waters of Prince of Wales Bay sustain particularly high NH4 concentration with almost all samples collected at these sites exceeding the guidelines. Concentration also often exceeded the guidelines in mid-estuary sites but excedances were rare in the lower estuary and Ralphs Bay.

Trend analysis over the 10-year period from 2004–13 indicates a significant increase in ammonia+ammonium concentrations in surface waters of the upper and mid estuary, but not at NN or U19, suggesting the increase is not related to catchment inputs. Over the same time period, there has been a decline in ammonia+ammonium levels at a number of lower estuary sites (both surface and depth), and at depth at some mid estuary channel sites. NH4 levels in PWB also increased over the 10-year period.

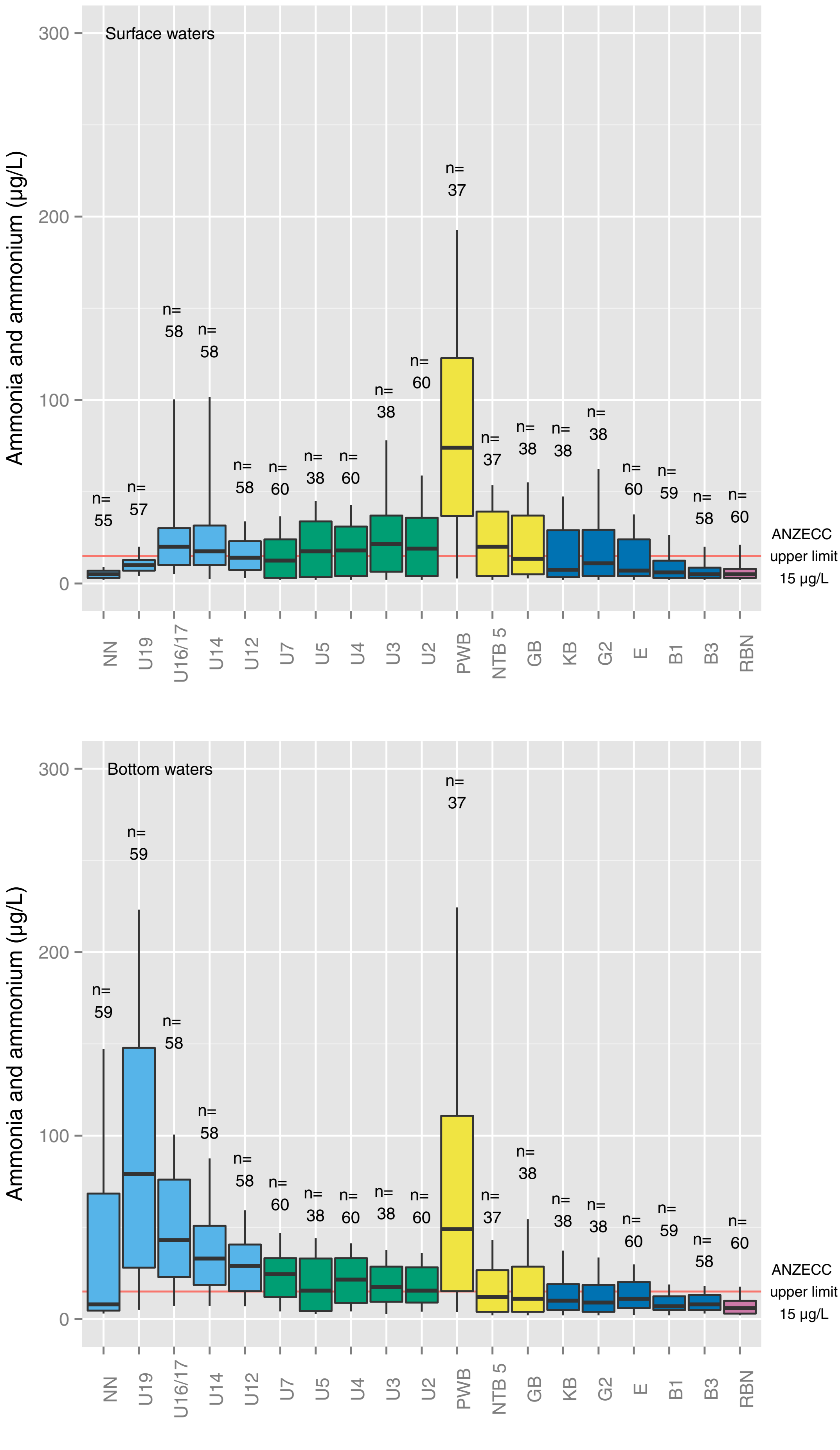
Table 5.9 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for ammonia+ammmonium during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges from -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	**U16/17** (0.38), **U14** (0.49), **U12** (0.51)
	Bottom	**U14** (0.23)
Mid-channel	Surface	**U7** (0.26), **U5** (0.3), **U3** (0.37)
	Bottom	**U3** (-0.22), **U2** (-0.2)
Mid-bays	Surface	**PWB** (0.21), **GB** (0.21)
	Bottom	**PWB** (0.21)
Lower	Surface	**B1** (-0.26) , **B3** (-0.27)
	Bottom	**KB** (-0.23) , **B3** (-0.22)
Ralphs Bay	Surface	None
	Bottom	None

Figure 5.11 Ammonia+ammonium levels in a) surface waters and b) bottom (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



5.4.4 Nitrate plus nitrite

In marine waters, the majority of nitrate+nitrite (NO_x) is present as nitrate, as nitrite (NO_2) is rapidly converted to nitrate (NO_3) during the nitrification process. For the 2009–13 period, median NO_x concentration ranged between 2.5 µg/L (RBN) to 47 µg/L (PWB surface). 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. In surface waters, NO_x concentrations were highest in the mid estuary, particularly at Prince of Wales Bay, while in bottom waters NO_x was highest in the upper estuary, particularly at site U19 and U16/17.

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 5.11). As shown in Figure 5.12, median NO_x concentrations were above the ANZECC trigger level of 15 ug/L throughout most of the estuary, with the exception of lower estuary sites and Ralphs Bay.

Trend analysis over the 10-year period from 2004–13 indicates a significant increase in NO_x concentrations in surface waters of the upper and mid estuary, including sites U14 and U12 together with all mid estuary channel sites. This increase appears unrelated to benthic processes given that no significant trend was identified in bottom waters anywhere in the estuary, and suggests an increase in nutrient loads to this region of the estuary.

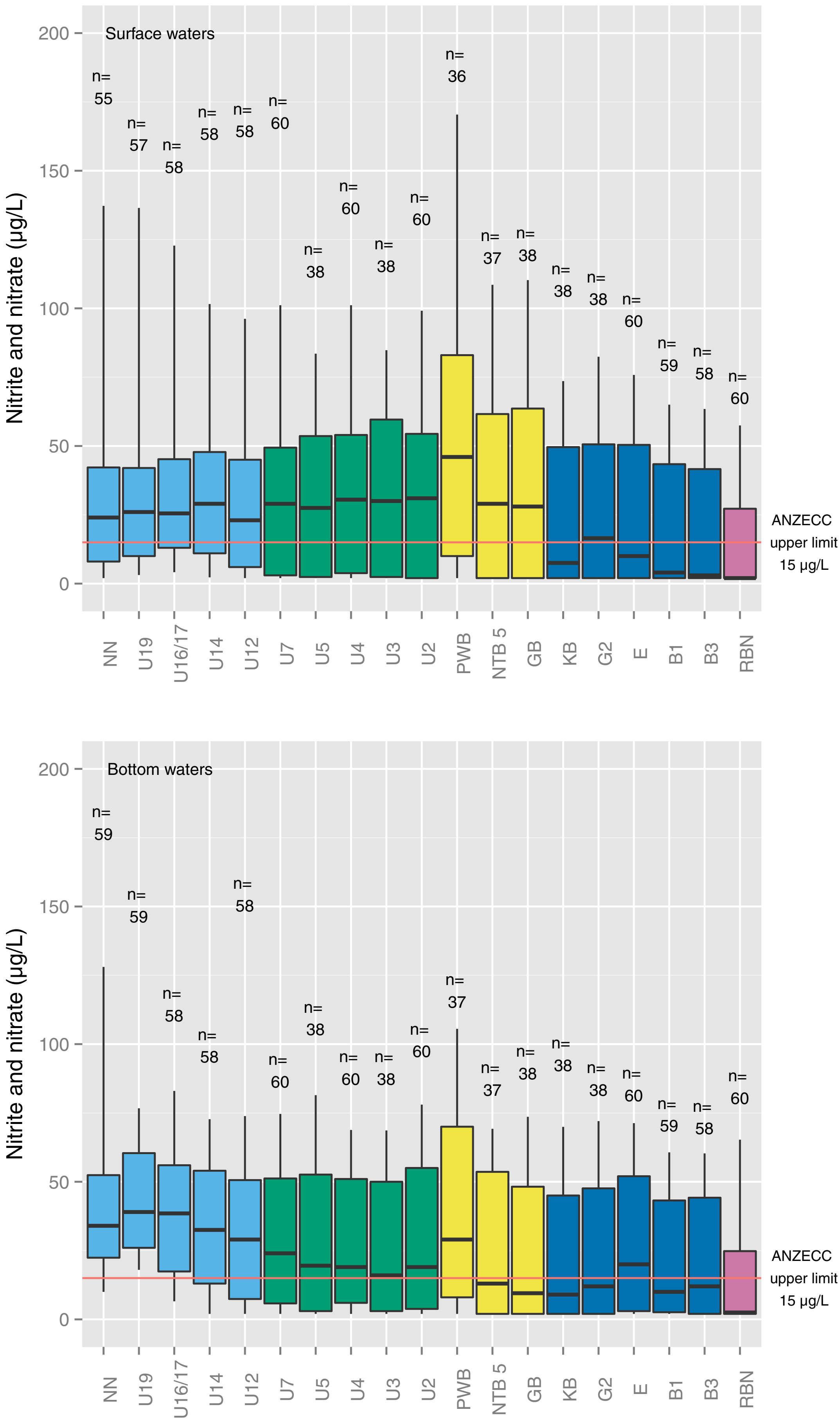
Table 5.10 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for nitrite+nitrate during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges from -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	**U14** (0.35), **U12** (0.42)
	Bottom	None
Mid-channel	Surface	**U7** (0.41), **U5** (0.28), **U4** (0.25), **U3** (0.23), **U2** (0.19)
	Bottom	None
Mid-bays	Surface	**GB** (0.22)
	Bottom	None
Lower	Surface	**G2** (0.19)
	Bottom	None
Ralphs Bay	Surface	None
	Bottom	None

Figure 5.12 Nitrite+nitrate levels in a) surface waters and b) bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



5.4.5 Total nitrogen

For the 2009–13 period, median total nitrogen (TN) concentrations ranged from 200 µg/L (surface waters of site NN) to 360 µg/L (Prince of Wales Bay) (Figure 5.14). TN in surface waters generally increased downstream from New Norfolk towards the estuary mouth, but there was no clear spatial trend at depth. TN was generally higher in bottom waters than surface waters, particularly at U19 and U7, and was particularly high at PWB. There is a strong correlation between TN at New Norfolk and River Derwent flow (R^2 = 0.8) (Eriksen et al., 2006), and riverine TN values are highest in winter months when river inputs are typically greater. Median TN concentrations at all surface water sites were below the ANZECC trigger level of 300 ug/L, with the exception of Prince of Wales Bay (PWB). However, median TN levels in bottom waters exceeded the trigger levels at 37% of sites.

Trend analysis over the 10-year period from 2004–13 indicates a significant increase in TN concentrations in the upper estuary (both at surface and at depth), as well as an increase in surface waters of the mid estuary, including Geilston Bay (Table 5.11). The observed increase at NN suggests that input from the River Derwent may be a key influence; in contrast no significant changes were observed at lower estuary sites.

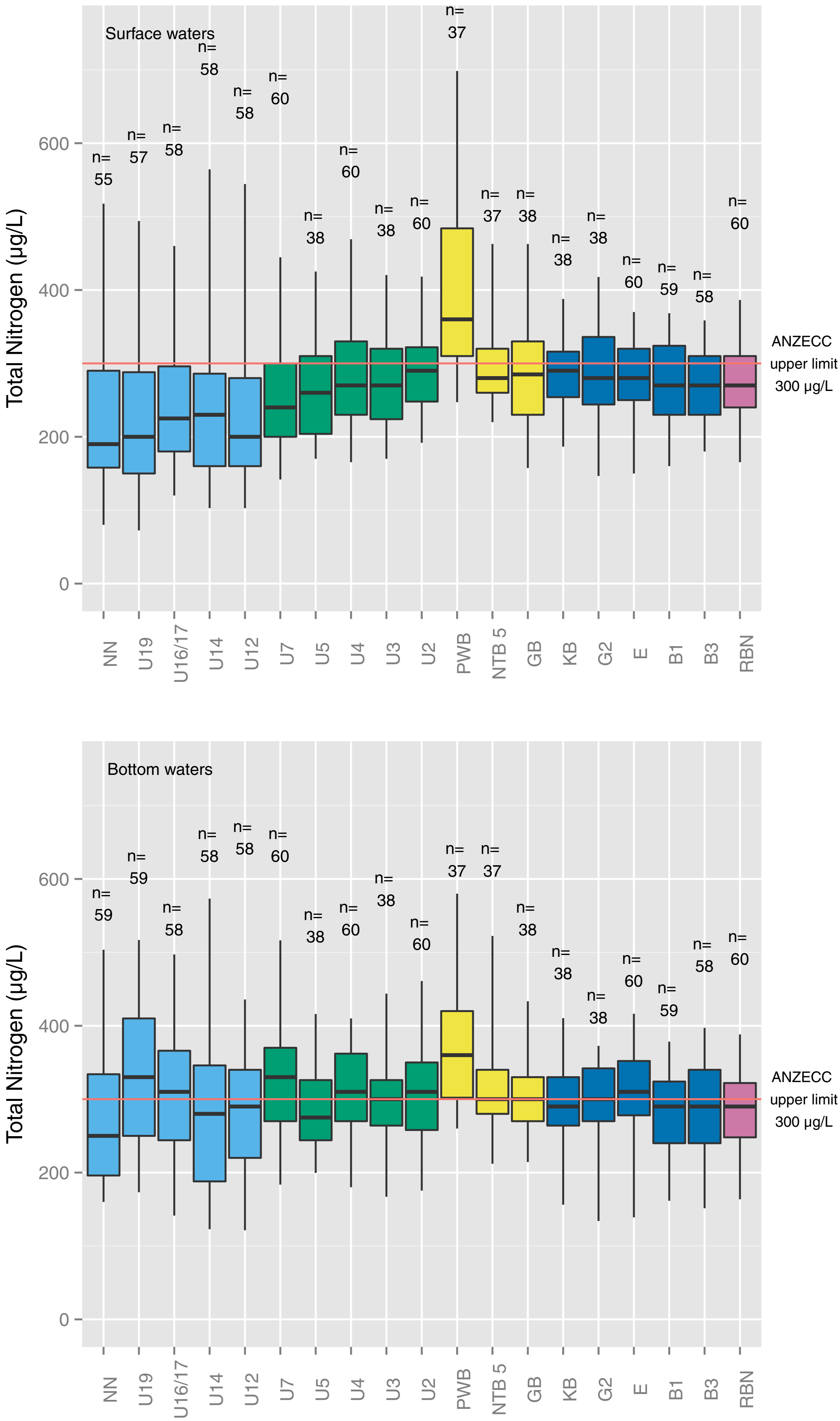
Table 5.11 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for total nitrogen during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges from -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	**NN** (0.22), **U19** (0.19), **U16/17** (0.18), **U14** (0.26), **U12** (0.35)
	Bottom	**NN** (0.22), **U19** (0.24), **U16/17** (0.36), **U14** (0.27), **U12** (0.17)
Mid-channel	Surface	**U7** (0.22), **U5** (0.2), **U4** (0.2),**U3** (0.2), **U2** (0.22)
	Bottom	None
Mid-bays	Surface	**GB** (0.19)
	Bottom	**PWB** (0.21)
Lower	Surface	None
	Bottom	None
Ralphs Bay	Surface	None
	Bottom	None

Figure 5.13 Total nitrogen levels in a) surface waters and b) bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



5.4.6 *Dissolved reactive phosphorus*

Dissolved reactive phosphorus (DRP) consists largely of the inorganic orthophosphate (PO4) form of phosphorus, which is the form that is directly taken up by algae. DRP is also referred to as soluble reactive phosphorus or filtered reactive phosphorus.

For the 2009–13 period, median concentration of dissolved reactive phosphorus ranged from 3 µg/L (NN surface) to 17 µg/L (PWB). DRP levels were relatively low in surface waters of the upper estuary, increased in the mid estuary (particularly at PWB) and declined again towards the mouth (Figure 5.14). At the majority of sites, DRP was considerably higher in bottom waters than surface waters, with no clear spatial pattern other than notably lower concentrations at NN and lower estuary sites (B1, B3 and RBN). This pattern suggests inputs from catchment and estuarine sources, rather than marine sources. Marine influences cause a seasonal flux of DRP in the lower estuary and Ralphs Bay in winter but this flux is not evident at mid and upper estuary sites, possibly due to the continuous impact of discharge from anthropogenic sources that particularly affect these zones.

Median DRP concentrations in surface waters exceeded the ANZECC guideline of 5 µg/L at all mid and lower estuary sites (74%), while median DRP in bottom waters exceeded the ANZECC guideline at all sites except NN (95%).

Trend analysis over the 10-year period from 2004–13 suggests a significant increase in DRP in the surface waters of all upper estuary sites, including NN, suggesting that inputs from the River Derwent may play a role. In contrast, DRP decreased significantly at a number of lower estuary sites, suggesting a change in marine conditions.

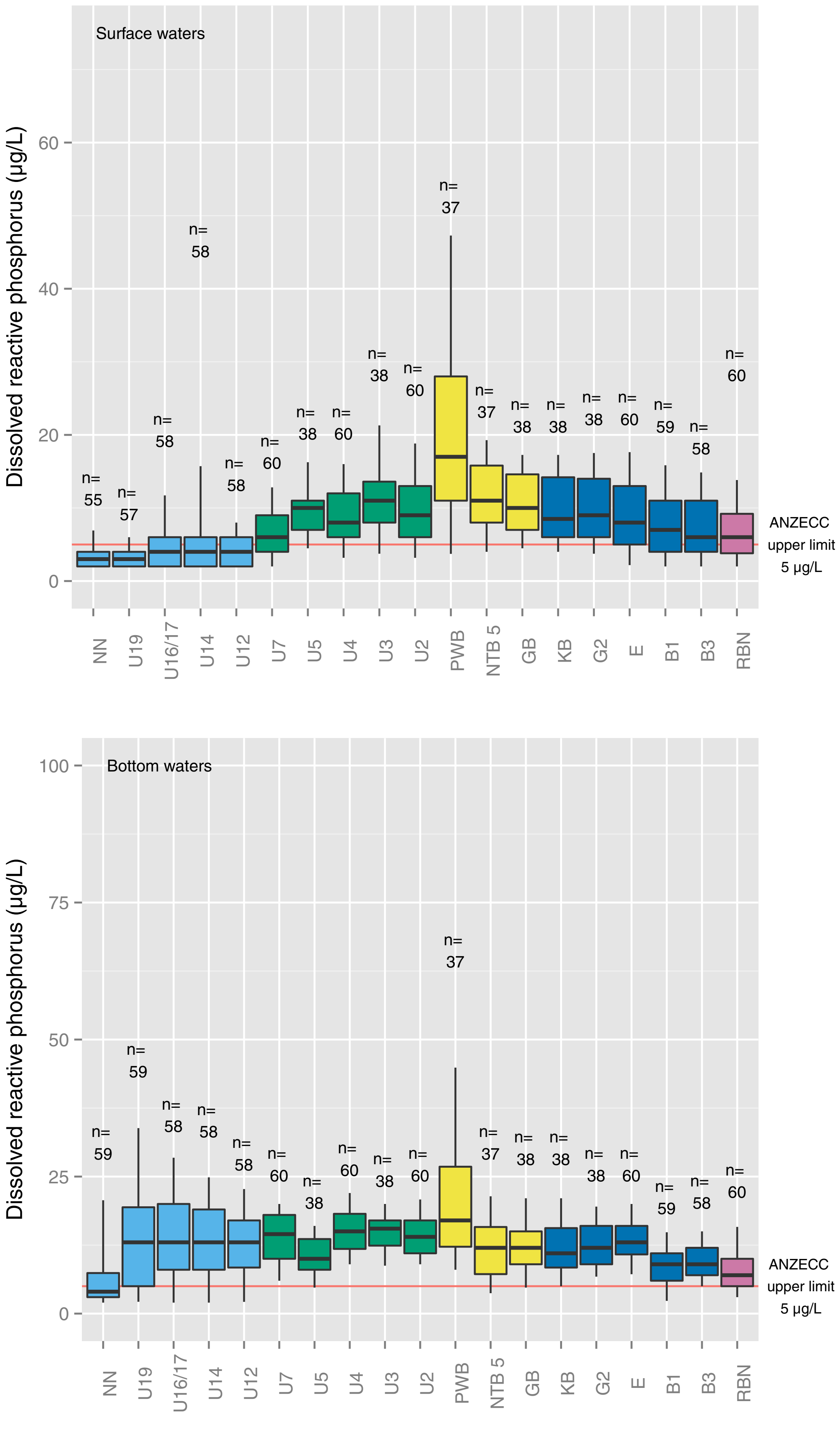
Table 5.12 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for dissolved reactive phosphorus during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges from -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	**NN** (0.41), **U19** (0.3), **U16/17** (0.18), **U14** (0.29), **U12** (0.34)
	Bottom	None
Mid-channel	Surface	**U7** (0.25), **U5** (0.22)
	Bottom	**U2** (-0.22)
Mid-bays	Surface	**PWB** (-0.19)
	Bottom	None
Lower	Surface	**G2** (-0.23), **B3** (-0.21)
	Bottom	**KB** (-0.26), **G2** (-0.25), **B1** (-0.16), **B3** (-0.3)
Ralphs Bay	Surface	None
	Bottom	None

Figure 5.14 Dissolved reactive phosphorus levels in a) surface waters and b) bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



5.4.7 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).

For the 2009–13 period, median concentration of total phosphorus ranged from 10 µg/L (NN surface) to 56 µg/L (PWB). Median TP levels were relatively low in surface waters of the upper estuary, increased in the mid estuary (particularly at PWB) and declined slightly towards the mouth (Figure 5.15). TP was considerably higher in bottom waters than surface waters, particularly at upper estuary sites. 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 levels were exceptionally high in PWB, probably as a result of WWTP discharges plus occasional runoff from the Impact fertiliser plant entering this poorly flushed bay. Median TP concentrations exceeded the ANZECC guideline of 30 µg/L at all surface water sites in the mid and lower estuary and at all bottom water sites except New Norfolk. The fact that even the lower estuary sites exceed the ANZECC guideline suggests that the guidelines may not be appropriate for southern Tasmanian estuaries.

Trend analysis over the 10-year period from 2004–13 did not suggest widespread changes other than a significant increase in TP concentrations in the bottom waters of upper estuary sites U19 and U16/17 and a decrease in bottom waters of mid estuary site U3. The increase at sites U19 and U16/17 may be linked with the observed increases in dissolved reactive phosphorus at these sites.

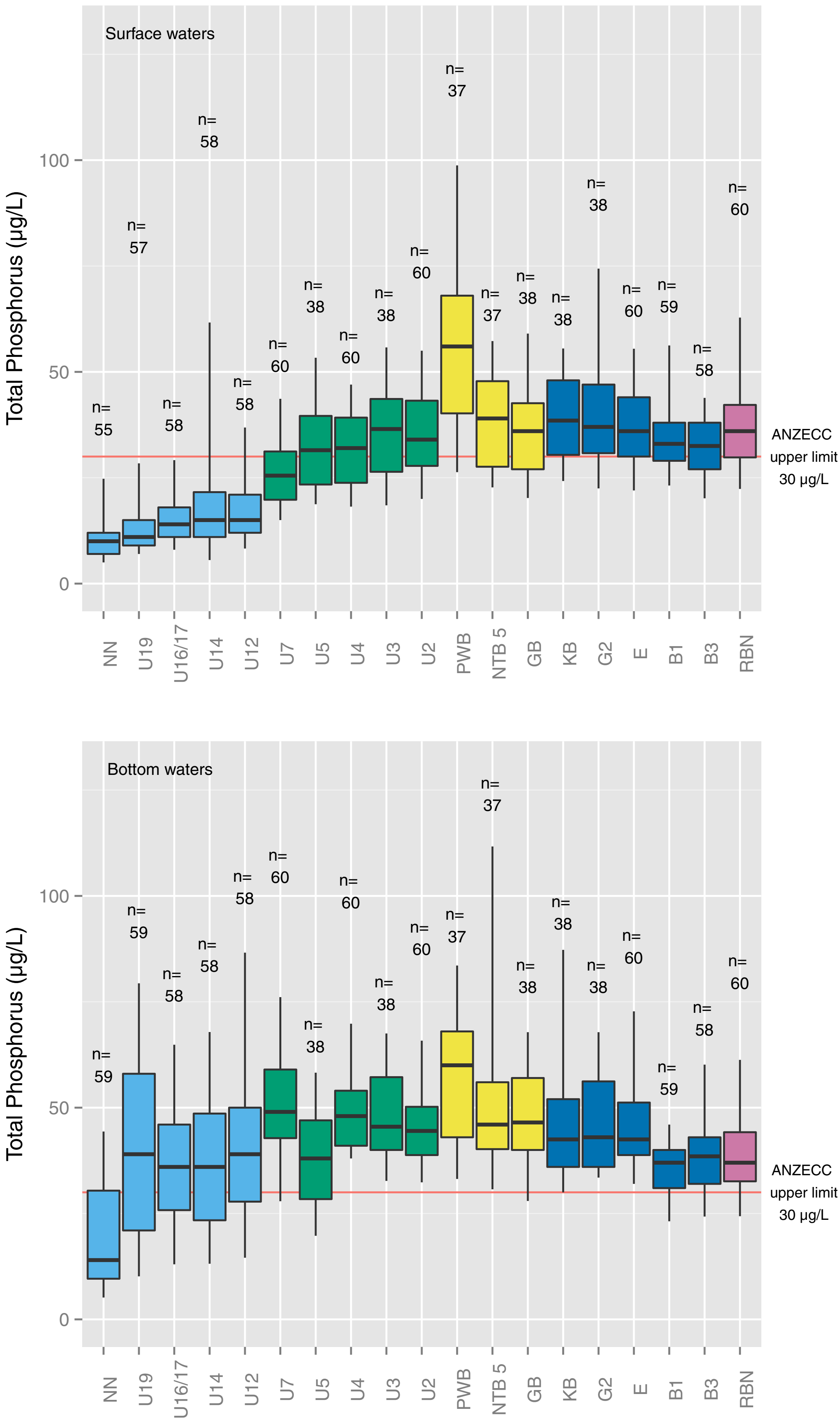
Table 5.13 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for total phosphorus during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges from -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	None
	Bottom	**U19** (0.16), **U16/17** (0.23)
Mid-channel	Surface	None
	Bottom	**U3** (-0.2)
Mid-bays	Surface	None
	Bottom	None
Lower	Surface	None
	Bottom	None
Ralphs Bay	Surface	None
	Bottom	None

Figure 5.15 Total phosphorus levels in a) surface waters and b) bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value



5.4.8 *Phytoplankton, chlorophyll-a and algal blooms*

Phytoplankton are very small single-celled algae that live in the water column and are an important component of aquatic ecosystems, forming the base of many aquatic food webs. The Derwent estuary has high phytoplankton species diversity, consisting predominantly of native species, as well as several introduced toxic or nuisance species.

As discussed in Section 5.4.1, nutrient enrichment in many estuaries leads to phytoplankton blooms and other nuisance plant growth, including macroalgae and epiphytic algae, which can smother intertidal zones and shade out or overgrow productive seagrass beds.

The amount of phytoplankton in a water body is typically represented by the amount of the photosynthetic pigment chlorophyll-a (chla). For the 2009–13 period, median concentrations of chlorophyll-a in the Derwent estuary ranged from 1.2 µg/L (U16/17) to 4 µg/L (PWB), with the highest values observed at mid estuary sites and adjacent embayments, and lower values in the upper and lower estuary. All median values were below the ANZECC trigger level of 4 µg/L, although the results of individual sampling events often exceeded the guidelines (Figure 5.16).

Figure 5.16 Chlorophyll-a data from Lund tube (integrated water column) samples (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value

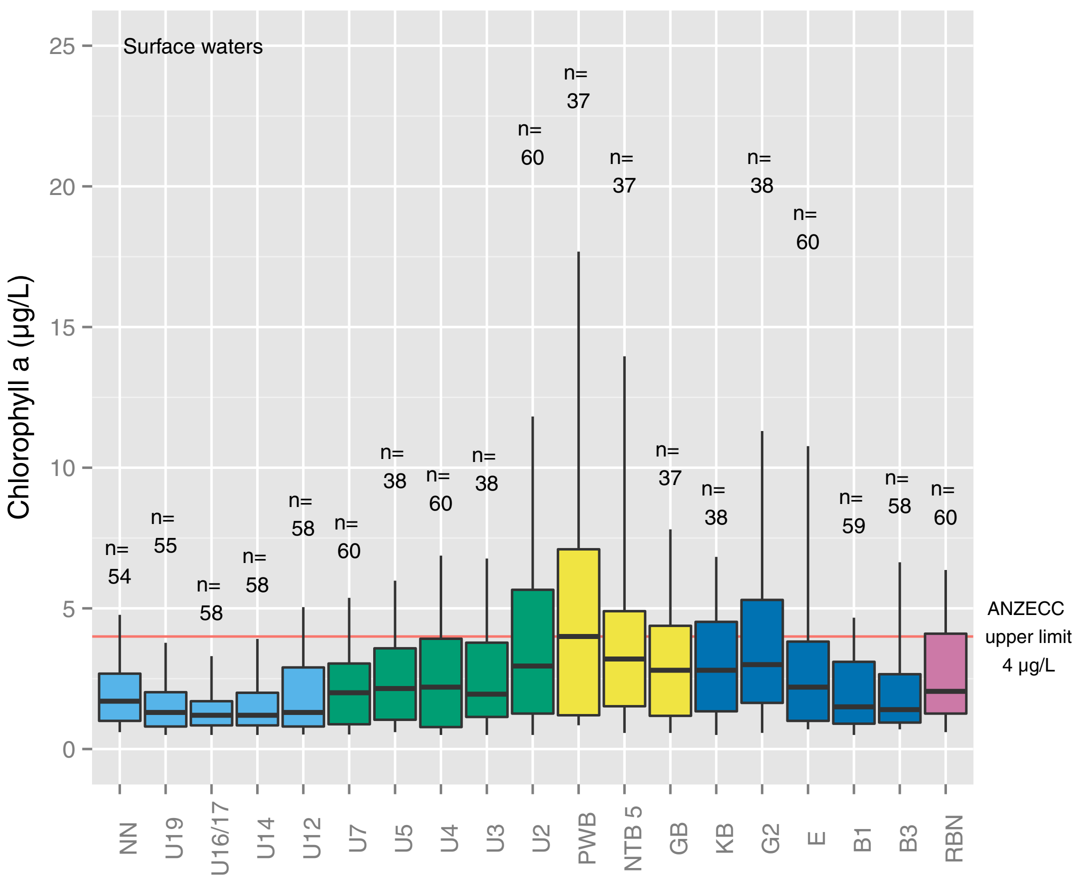
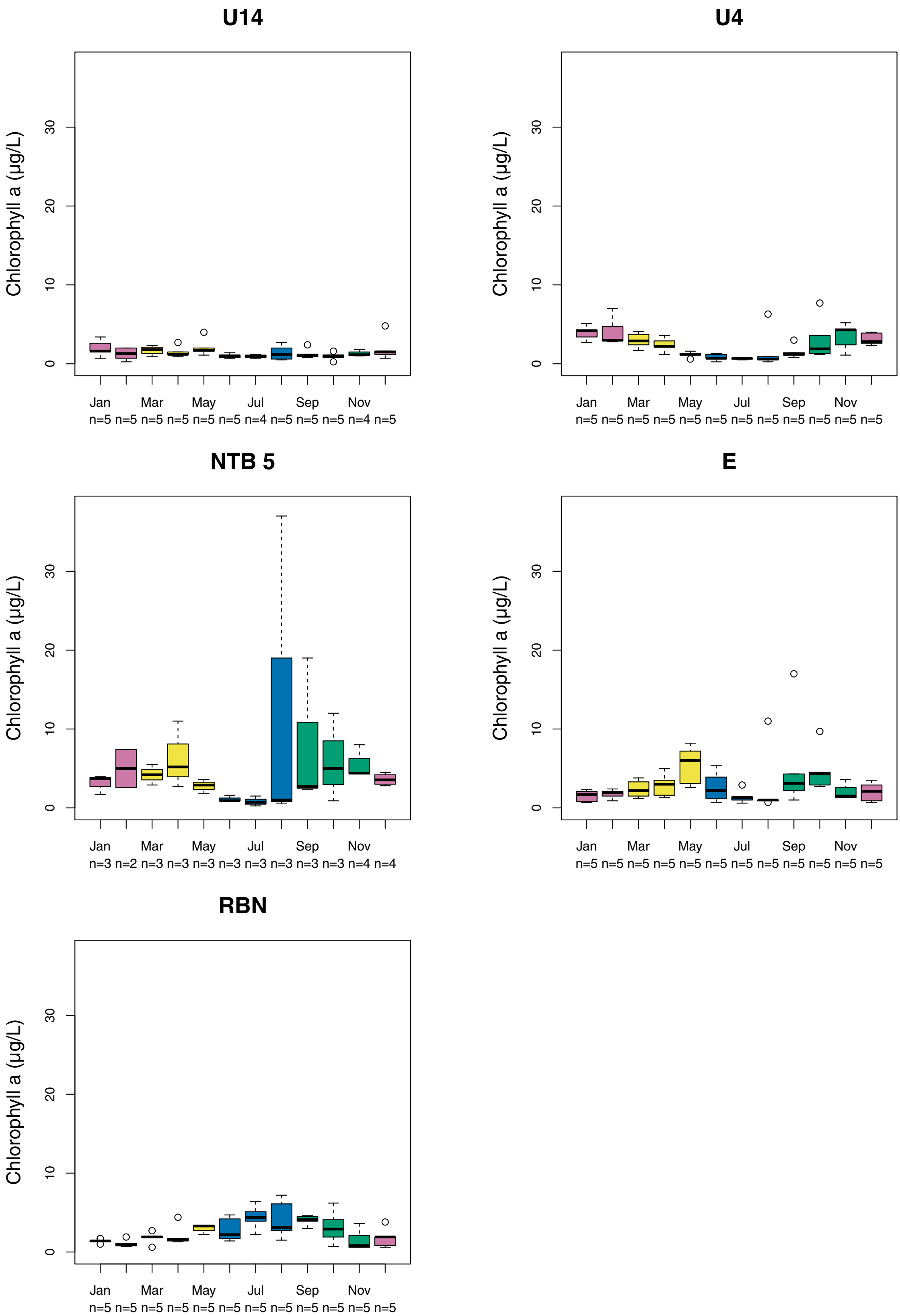


Figure 5.17 Monthly chlorophyll-a results collected between January 2004 and December 2014 at representative sites in each zone.



A more detailed analysis of the chla data in Figure 5.17 shows the occurrence of periodic algal blooms (defined as chla levels ≥4 µg/L) in different regions of the estuary. For example, late summer/autumn and spring blooms were common in the middle estuary and associated embayments, and to a lesser degree in the outer estuary, while Ralphs Bay experienced winter blooms. Algal blooms in the upper estuary were rare, with only eight samples >4 µg/L over the five-year period. The highest chla levels were observed in mid estuary bays, particularly at New Town and Prince of Wales bays, where chla levels in excess of 20 µg/L have been observed.

Trend analysis over the 10-year period from 2004–13 suggests a significant increase in chla levels in all zones except in Ralphs Bay. The lack of a significant increasing trend at New Norfolk may be due to the influence that the predominantly fresh water has on plankton species compared with more saline waters downstream of site U19. There has also been an increase in the frequency of blooms, particularly in the mid estuary and associated embayments, where the number of blooms has doubled.

Dissolved nitrogen-to-phosphorus ratios suggest that nitrogen is probably the limiting nutrient for 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 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). Experiments in the middle to lower estuary have also identified light availability as a key factor, particularly during winter months when water entering the estuary from the catchment is highly coloured with tannins (Hallegraeff & Westwood, 1995). The relatively low median chla values observed in the Derwent estuary as a whole, together with the presence of bioavailable nutrients, suggest that environmental factors other than nutrients also play an important role (e.g. water temperatures, light availability and residence time).

The observed increase in both median chlorophyll-a levels and the frequency of blooms is probably related to the increasing concentrations of dissolved nutrients discussed above. However, chlorophyll-a levels also increased at the seaward end of the system (sites B1 and B3), which suggests that changes to marine waters may also play a role. Given nutrients in the lower to mid-estuary have been declining between 2004 and 2013, it is possible that increasing water temperature may also be a factor.

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 or there is a relatively rapid rate of tidal and freshwater flushing. In these areas, 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 communities, may be more suitable. While there is little quantitative data on the distribution or biomass of nuisance macroalgae within the Derwent estuary, visual observations suggest an increase in amount and distribution of

Table 5.14 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for chlorophyll-a during the decade 2004 through 2013, at a confidence interval of p=0.05

Values in brackets represent the Kendall tau rank correlation coefficient, which ranges from -1 (100% negative trend) to 1 (100% positive trend).

Estuary zone	Sites with significant trend
Upper	**U19** (0.19), **U14** (0.38), **U12** (0.45)
Mid-channel	**U7** (0.43), **U5** (0.48), **U4** (0.32), **U3** (0.38), **U2** (0.22)
Mid-bays	**GB** (0.3), **NTB 5** (0.3)
Lower	**G2** (0.27), **E** (0.17), **B1** (0.24), **B3** (0.21)
Ralphs Bay	None

macroalgae, as described below:

- Dense filamentous and epiphytic algal growth occurs on and among the actively growing leaves of submerged aquatic vegetation (SAV) in the upper and middle estuary (Whitehead 2014, *pers. obs.*). This algal growth is concerning because in other areas where epiphytic algal growth has completely smothered seagrass meadows, catastrophic decline has occurred, which destabilises the ecosystem and dramatically reduces ecosystem productivity (Cambridge et al., 1986; Short et al., 2011). While the upper Derwent SAV still appear to be relatively healthy, further research is required to determine the sensitivity and tolerance of SAV in the Derwent estuary to different nutrient concentrations. This would be an important step toward developing refined water quality objectives for the Derwent estuary.
- In spring to early summer, a line of bright green macroalgae (*Ulva* sp.) often occurs along the rocky intertidal shorelines of the mid estuary, suggesting a significant level of nutrient enrichment. Dense algal growth can have adverse effects on intertidal community structure by restricting light availability to other autotrophic organisms. It may also impact the intertidal community by smothering and releasing a localised nutrient pulse when the algae dies back at the end of summer (Williams, 1984). At times this macroalgal growth smothers the intertidal habitat, for example in Prince of Wales Bay during the summer of 2008–09 (Whitehead pers. obs, 2009).

5.4.9 Organic carbon

Organic carbon is naturally abundant in many aquatic ecosystems and is an essential element for biological growth. However, large discharges of organic matter into an estuary may over-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. Once bound to organic matter, contaminants may then be transferred through the food web or become sequestered in sediment.

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 sewage treatment plants,

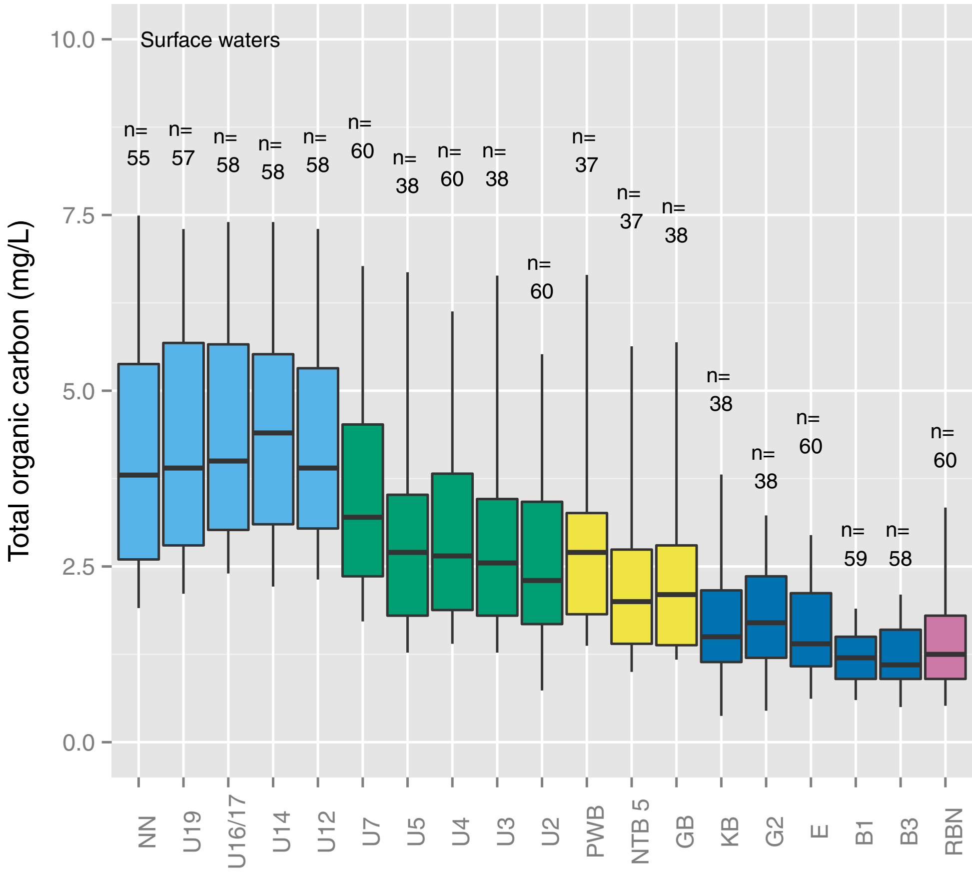
Table 5.15 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for total organic carbon during the decade 2004 through 2013, at a confidence interval of p=0.05

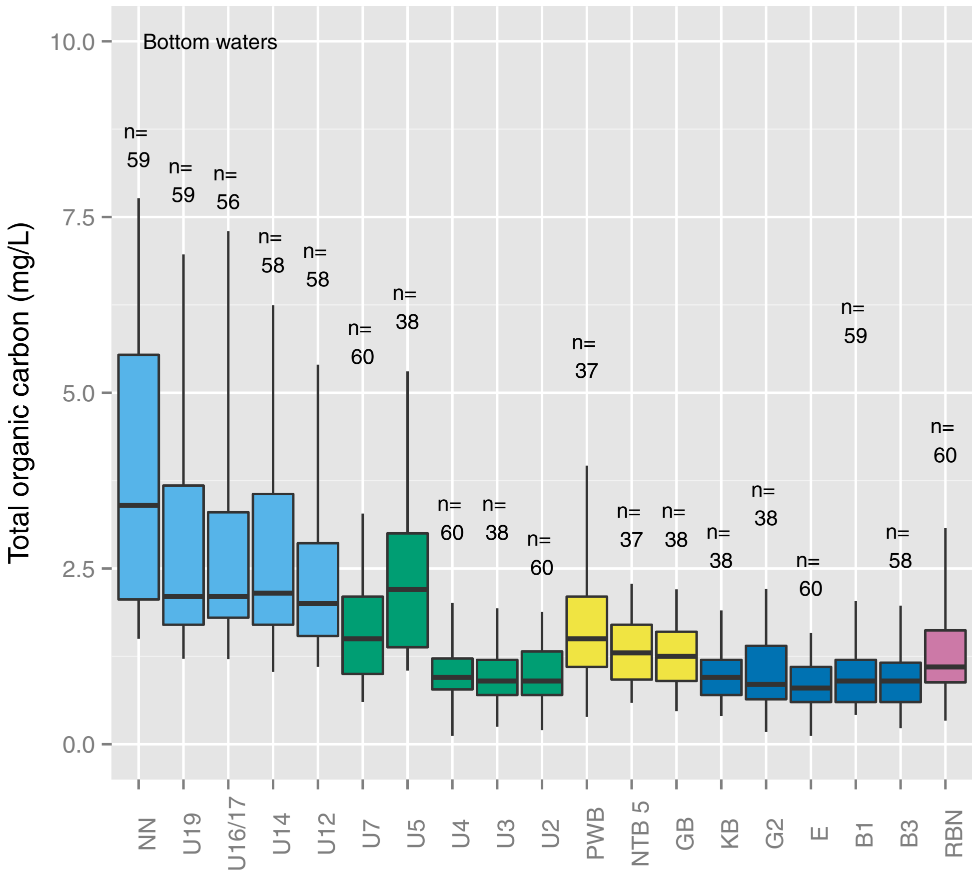
Values in brackets represent the Kendall tau rank correlation coefficient, which ranges from -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	**NN** (0.21), **U19** (0.23)
	Bottom	**NN** (0.17), **U19** (0.22), **U12** (0.21)
Mid-channel	Surface	**U2** (0.16)
	Bottom	**U7** (0.16)
Mid-bays	Surface	None
	Bottom	None
Lower	Surface	**G2** (0.22), **E** (0.17)
	Bottom	None
Ralphs Bay	Surface	None
	Bottom	None

Figure 5.18 Total organic carbon in a) surface waters and b) bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value





the Boyer paper mill and urban runoff. During this reporting period, there has been a major reduction in organic carbon loading to the Derwent, as a result of the new wastewater treatment system and other process changes at Norske Skog (see Section 4.2.2 for details).

Organic carbon in the Derwent estuary water column is measured as total organic carbon (TOC), over 97% of which occurs in dissolved form (Whitehead et al., 2010). For the 2009–13 period, median concentration of TOC ranged from <1.0 to 4.4 ug/L, with the highest values observed in surface waters of the upper estuary, generally decreasing with distance downstream (Figure 5.18).

Trend analysis over the 10-year period from 2004–13 suggests that TOC has increased at several sites, particularly at NN and U19 in the upper estuary, suggesting a change in catchment inputs (Table 5.15 for details).

5.5 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 vehicle emissions, combustion power plants, mining and industrial wastes – particularly those derived from smelting, refining and electroplating (Bloom and Ayling, 1977). 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 paper 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.

Heavy metals are persistent in the environment and are toxic if they occur above a threshold concentration which varies depending on the metal and its toxicity. As heavy metals are readily adsorbed to the surface of fine particulate matter, they tend to accumulate in the bottom sediments of aquatic ecosystems. Aquatic organisms can accumulate heavy metals from surrounding water, sediments or through their food supply.

The species of the metal is critical to biological availability and toxicity, and the relative concentration of different metal species is influenced by biological, physical and chemical properties of the environment, principally the composition and activity of bacterial communities, temperature, salinity, pH and the concentration of DO and organic matter (Ullrich et al., 2001). Species in solution are generally more bio-available and potentially more toxic than metals bound to particulate matter. Heavy metals may be divided into two categories (Kennish, 1996):

i) Transition metals (e.g. zinc, chromium, cobalt, copper, iron, manganese) which are essential to metabolism at low concentration but may be toxic at higher concentration;
ii) Metalloids (e.g. arsenic, cadmium, lead, mercury, selenium, tin) which are generally not required for metabolic function and are toxic at low concentration.

An approximate order of decreasing toxicity of common metals is: mercury>cadmium>copper> zinc>nickel>lead >chromium>aluminum>cobalt, however toxicity can vary significantly between different organisms (Kennish, 1996).

Heavy metals – particularly mercury, cadmium, lead and arsenic – also represent significant health hazards to humans and exposure can cause sensory, visual, auditory and kidney functional impairment in adults and neurotoxic effects in infants or developing fetuses (Hutton, 1987; Ullrich et al., 2001; World Health Organisation, 1976). Inorganic forms of mercury have relatively low toxicity to biota but are readily converted to more toxic forms of organomercury such as methylmercury. Methylmercury is rapidly absorbed by aquatic organisms (Koos and Longo, 1976; Ullrich et al., 2001).

Heavy metals have been monitored periodically in Derwent estuary waters since the early 1970s. Data collected up until 1997 was reviewed in the 1997 State of the Derwent estuary report (Coughanowr, 1997). The report showed high concentrations of zinc, particularly at middle and upper estuary sites, 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 below detectable levels, the analytical suite was reduced and zinc is now the only metal analysed at all sites. Cadmium, copper, lead and mercury continue to be monitored by Nyrstar at mid estuary sites, but with very few samples above detectible limits (occasional low copper values in Prince of Wales Bay).

5.5.1 Zinc

Zinc is considered to be indicative of the behavior of most other heavy metals in the Derwent (with the exception of mercury) and has previously been used as the basis for toxicant modeling and broader management recommendations (Coughanowr et al., 2009). Previous comparison of total and dissolved zinc analyses indicates that dissolved zinc accounts for the majority of the observed concentrations. Typically 85% of total zinc in surface water samples is in dissolved form, and 77% of total zinc in bottom water samples is dissolved. This suggests that the majority of zinc in the water column may be fairly bioavailable.

The National Water Quality guidelines for toxicants (ANZECC, 2000) specify trigger levels for the protection of aquatic ecosystems at four different protection levels, 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 and has been recommended for the Derwent. 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. The ANZECC (2000) trigger levels for zinc in marine waters at varying levels of protection are provided below.

- 99% protection 7 µg/L
- 95% protection 15 µg/L
- 90% protection 23 µg/L
- 80% protection 43 µg/L

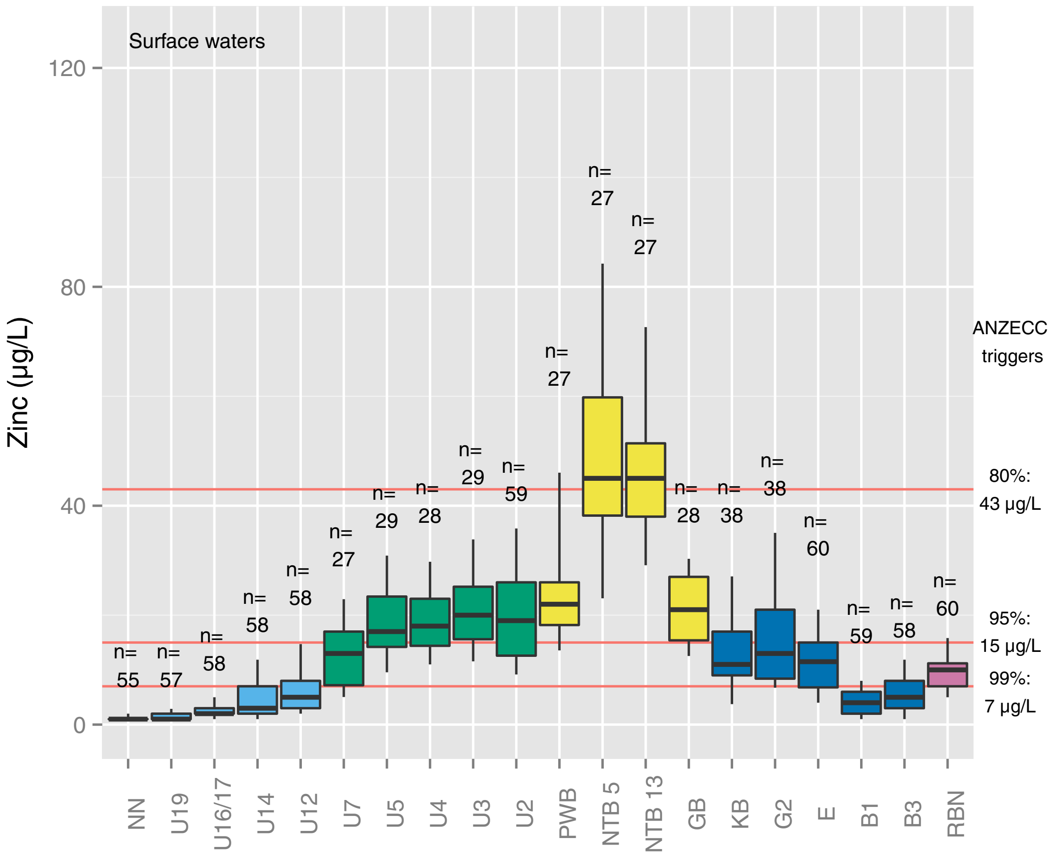
Monitoring data for the period January 2009 to December 2013 indicate that median total zinc concentration ranged from 1 µg/L (NN and U19 surface, B1 bottom) to 45 µg/L in surface waters of New Town Bay (Figure 5.19), with the

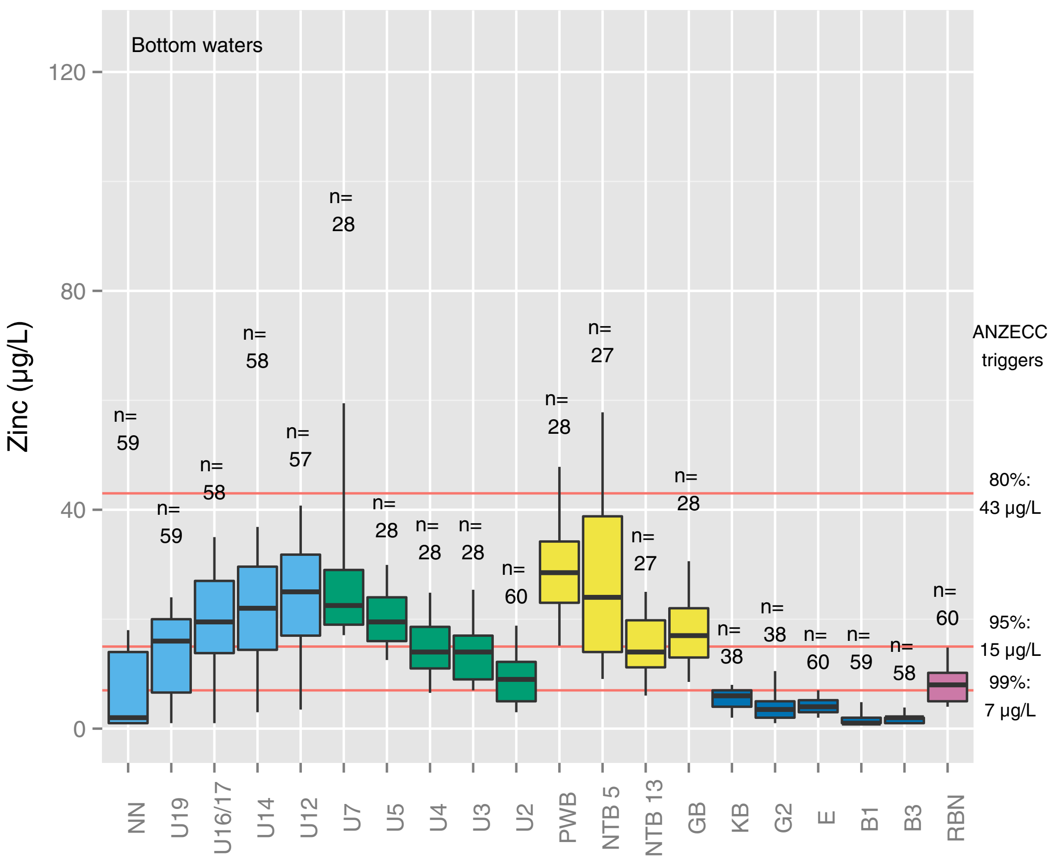
Table 5.17 Sites where seasonal Mann-Kendall trend analysis identified a significant trend for zinc during the decade 2004 through 2013, at a confidence interval of p=0.05 Values in brackets represent the Kendall tau rank correlation coefficient, which ranges from -1 (100% negative trend) to 1 (100% positive trend)

Estuary zone	Depth	Sites with significant trend
Upper	Surface	None
	Bottom	**U19** (-0.19), **U12** (-0.21)
Mid-channel	Surface	None
	Bottom	None
Mid-bays	Surface	None
	Bottom	**NTB 5** (0.21), **PWB** (-0.28)
Lower	Surface	None
	Bottom	**B3** (-0.22)
Ralphs Bay	Surface	None
	Bottom	None

Figure 5.19 Total zinc levels in a) surface waters and b) bottom waters (Jan 2009 – Dec 2013)

Where the limit of the boxes represents 20th and 80th percentiles, the whiskers extend to the 2nd and 98th percentiles, and n=(number of observations) is located at the maximum observed value





highest values observed in surface waters and embayments of the middle estuary (particularly in New Town Bay). Zinc was also elevated at depth in the middle to upper estuary, with median values peaking at nearly 30 µg/L in the vicinity of the Bridgewater Causeway (U12). This distribution pattern is related both to the location of the primary source at the zinc works, as well as the salt-wedge estuarine circulation system, whereby 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 influxes from contaminated sediments in this region of the estuary (see Section 7 for further discussion of the heavy metals in Derwent sediments). Median zinc levels exceed the ANZECC 95% trigger levels at 40% of surface water sites (with particularly high levels in New Town Bay where median levels exceed the 80% trigger level) and at 50% of bottom water sites, primarily in the middle to upper estuary.

Trend analysis over the 10-year period from 2004–13 did not identify any system-wide trends, however four sites at depth experienced a decrease in zinc levels and one site (NTB5) increased.

5.6 Discussion and recommendations

This section reviews the overall condition of the estuary with respect to ambient water quality over the reporting period (2009 to 2013) and describes how several key indicators have changed over the past ten years (2004 to 2013). Longer-term trend analysis is based on the Mann-Kendall statistical analyses presented in previous sections, together with a simple comparison of median values between the two five-year periods at representative sites. While the comparison of median values is generally in agreement with the more robust Mann-Kendall statistical trends, keep in mind that the 2004–08 data set is missing data for the 17-month period from July 2005 to September 2006 (inclusive), which would slightly skew median values towards summer conditions.

This section also recommends actions to better understand and/or manage the system where water quality indicators are well beyond recommended guidelines or have experienced a significant change over the past decade. It is important that this data be interpreted within the context of natural variability, particularly with respect interannual changes in river flows and marine waters.

5.6.1 Physico-chemical indicators

Temperature, salinity, pH and dissolved oxygen levels in the Derwent estuary have generally reflected previously reported spatial, seasonal and interannual patterns, as influenced by climate, river runoff, marine water masses and the overall circulation patterns of the estuary. DO levels remain very low at depth in the upper estuary during summer months, causing remobilisation of nutrients and adverse effects on fauna. Trend analysis suggests that there has been a general increase in water temperature at mid and lower estuary sites, but an apparent decrease in salinity. The increased temperature is in agreement with regional patterns associated with climate change (i.e. greater influence of East Australian current masses), for example as documented by Johnson et al, 2011. However the decrease in salinity at the estuary mouth is unexpected and warrants further evaluation. There has also been an apparent increase in salinity at the New Norfolk site, though this may be related to a new, more sensitive salinity sensor.

Recommendations:

- Maintain/enhance physico-chemical sensors in the upper estuary, including real-time data access;
- Undertake further statistical analysis of the longer term data records;
- Investigate options to improve summer DO levels at depth in the upper estuary;
- Monitor freshwater pulses in the upper estuary and potential impacts on fish populations.

5.6.2 Water clarity

On the whole, the Derwent estuary has relatively good water clarity, particularly toward the seaward end and in the upper estuary during summer months. Secchi depths are lowest in the middle reaches of the estuary and associated embayments. TSS levels follow a similar pattern, and are influenced by heavy rainfall and river flows, sediment resuspension and phytoplankton blooms. During winter months, water clarity is also influenced by highly coloured, tannin-rich freshwater that enters the system at New Norfolk. Trend analysis suggests that there has been a significant decline in water clarity (Secchi depth) and an increase in TSS levels across the estuary as a whole. These trends may reflect increased sediment inputs from urban and catchment sources and/or increased phytoplankton production. There has also been an apparent decline in colour over the 10-year period, particularly towards the mouth of the estuary.

5.6.3 Nutrients, chlorophyll-a and algal growth

Nutrient concentrations in the estuary over the reporting period follow previously reported spatial and seasonal patterns, with the highest levels of dissolved nutrients observed in surface waters of the mid estuary and at depth in the upper estuary. Prince of Wales Bay continues to be particularly eutrophic. The natural seasonal pattern of high NOx and DRP inputs from marine sources, and high NOx inputs from catchment sources persists.

Trend analysis suggests a significant increase in bioavailable nutrient levels, particularly in surface waters of the upper and middle estuary. While DRP levels have increased at the catchment end, there has been a decline in NH4 and DRP levels at the marine end, suggesting that the increasing levels within the estuary are related to anthropogenic and/or internal sources. Another notable change in nutrient patterns is that the drawdown in bioavailable nutrients previously observed in the vicinity of Bridgewater (U12) is less pronounced (Figure 5.20). The previous strong drawdown was probably caused by a combination of nutrient removal by seagrasses and wetlands, together with the in-river breakdown of the organic carbon load previously released by the Boyer paper mill (which would have utilised bioavailable nutrients).

Chlorophyll-a levels in the Derwent follow previously observed patterns, reflecting the distribution of bioavailable nutrients, with highest median values observed in the middle estuary and associated bays (particularly Prince of Wales Bay). While levels are still relatively low by national standards, trend analysis suggests a significant increase in chla levels at the majority of sites, together with an increase in the number of blooms (chla >4 mg/L). Phytoplankton blooms, however, may be less of a risk to the Derwent estuary than macroalgal blooms (epiphytic and filamentous), particularly with respect to the high value seagrass and wetland communities in the upper estuary. These communities play a critical role in maintaining water quality, stabilizing sediments and providing habitat for fish, birds and other fauna. While there has been little quantitative monitoring of macroalgae in the Derwent, recent observations suggest an increase in macroalgae extent and biomass.

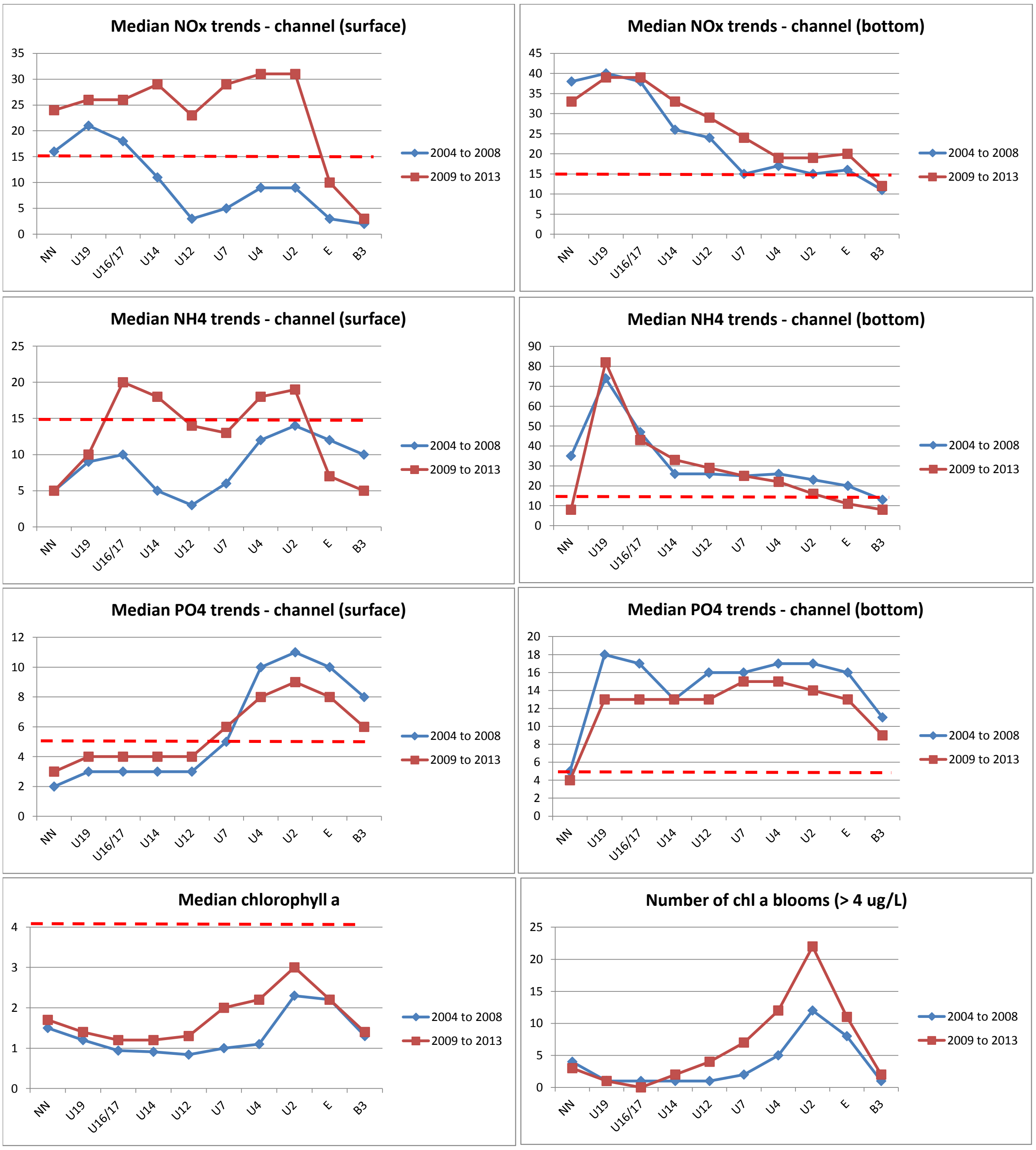
The changes described above suggest an increase in nutrient loads to the Derwent estuary, possibly combined with warming water temperatures at the marine boundary. These increased loads probably reflect a combination of:

- Increased catchment loads associated with existing and intensifying activities (e.g. cropping, dairy, fish hatcheries, recreation);
- Increased nutrient loads/reduced BOD loads from the Norske Skog paper mill associated with secondary treatment;
- Localised increases in nutrient loading at Bridgewater/ Brighton WWTP due to lower effluent reuse
- An increase in urban runoff associated with new urban and suburban developments.

Recommendations to better monitor, understand and manage nutrient loading and prevent system eutrophication include the following:

- Monitor, predict and manage nutrient loads associated with intensifying catchment and Channel/Storm Bay activities;
- Improve monitoring of phytoplankton, including species identification and blue-green algae
- Design and implement a macroalgal monitoring program;

Figure 5.20 Comparison of median values of bioavailable nutrients and chla between reporting periods (all values in µg/L)



- Further investigate the factors limiting algal growth, particularly nutrient limitation in the upper estuary
- Investigate and seek opportunities to reduce nutrient inputs associated with sewage and industrial activities, for example through expanded effluent reuse, process changes and/or more advanced treatment;
- Encourage new developments to implement WSUD and seek opportunities to retrofit existing urban and residential areas.

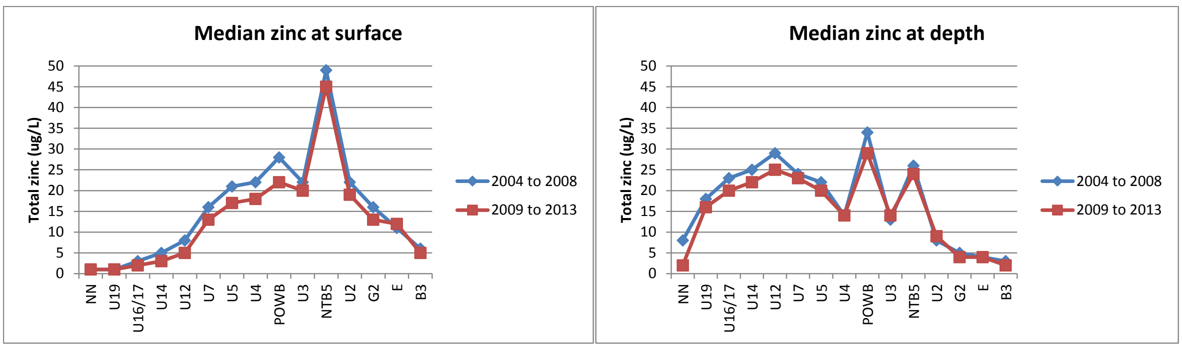
5.6.4 Zinc

Zinc concentrations in the estuary follow previously reported spatial patterns with highest levels in surface waters of the mid estuary and associated bays (particularly New Town and Prince of Wales bays), and elevated levels also observed in bottom waters of the middle and upper estuary.

Trends are difficult to determine with a high level of confidence, in part due to several missing periods of data. The Mann-Kendall analyses suggest a decline in bottom water zinc levels at several sites (U19, U12, PWB) and an increase in surface water levels at NTB. However, a comparison of median values over the two reporting periods suggests a possible reduction in zinc levels over the system as a whole (Figure 5.21).

The lack of broad-scale reductions in zinc levels for the estuary as a whole suggests that the effects of groundwater remediation works undertaken at Nyrstar may take some time to be reflected in ambient water quality observations. This may reflect both the lag time between remediation and reductions in groundwater discharges, as well as the additional remediation works to be completed at the site (see Section 4.2.1). Another potential factor is the high concentrations of zinc and other heavy metals stored in Derwent estuary sediments that could be periodically mobilised by physical disturbance such as dredging or during periods of low DO (see Section 7 for details).

Figure 5.21 Comparison of median values of zinc between reporting periods (all values in µg/L)



6.0 RECREATIONAL WATER QUALITY

Water contaminated with human and animal faeces may contain pathogenic micro-organisms (bacteria, viruses, protozoa). These organisms can cause illnesses such as gastrointestinal disorders; respiratory illnesses; eye, nose and throat infections; and skin disorders. Infection may occur if contaminated water is swallowed, inhaled or if the water comes into contact with ears, nasal passages, mucous membranes or cuts in the skin (NZ Ministry for the Environment, 2002). Full immersion or 'primary contact' activities – such as swimming, diving and water-skiing – in contaminated waters places people at greater risk of infection than do 'secondary contact' forms of recreation such as fishing, boating or wading.

6.1 Pathogens, faecal indicator bacteria and health risks

Direct detection of pathogens is not feasible for routine assessments since they occur intermittently and are difficult to recover from water. Instead, faecal 'indicator bacteria' are generally used to assess the health risks associated with pathogens in recreational waters.

Thermotolerant (faecal) coliforms and *Escherichia coli* were previously used as the recommended faecal indicator bacteria. However, studies have not demonstrated a clear relationship between the levels of thermotolerant coliforms or *E. coli* that a test subject is exposed to and the likelihood of illness. In contrast, a good dose-response relationship has been reported for enterococci which is why the World Health Organization and the National Health and Medical Research Council (NH&MRC) now recommend enterococci as the preferred faecal indicator, particularly in marine waters. See *Guidelines for Managing Risks in Recreational Water* (NH&MRC, 2008) and the 2009 *State of the Derwent Report* (Whitehead et al., 2010) for further information on indicator organisms and guidelines.

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* New Zealand Ministry for the Environment (NZMFE, 2002). Bacterial counts in water are highly skewed and are only normally distributed after logarithmic transformation. 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).

Enterococci results are reported as the most probable number of bacterial colonies in 100 mL of water (MPN/100 mL). Results are used by councils and the Department of Health and Human Services to classify each site according to long-term results, and to manage human exposure to short-term pulses in poor water quality.

6.2 Guidelines

The *Recreational Water Quality Guidelines for Tasmania (Public Health Act 1997)* (Department of Human Health Services, 2007) refer to the national guidelines (NR&MRC, 2005) as the method for assigning a long-term grade for recreational sites, but also define trigger levels for managing human exposure to short-term poor water quality events based on the New Zealand guidelines (NZMFE, 2002).

The guidelines state that a long-term grade is to be assigned to each site based on enterococci results from the preceding five years or preceding 100 samples, together with a risk-based assessment of nearby sources of faecal contamination. A three-tiered, colour-coded system has been adopted for easier interpretation, as follows:

- Green (surveillance mode) – represents good water quality (95th Hazen percentile for enterococci of <200 MPN/100 mL) and involves routine sampling to monitor bacteria levels.
- Yellow (alert mode) – reflects moderate water quality (95th Hazen percentile for enterococci of 200–500 MPN/100 mL). Conditions are generally safe for swimming, however intermittent failures are noted. If a site receives a moderate grade, an investigation into the causes of the elevated bacterial levels is recommended and increased sampling frequency may be required to better manage recreational exposure.
- Red (action mode) – represents poor water quality (95th Hazen percentile for enterococci of >500 MPN/100 mL) and a possible risk of illness if water is ingested. The water body is considered to be unsuitable for whole-body contact and follow-up investigations are required to investigate causes of elevated bacterial levels. A warning sign is required to advise the public that the water body is unsuitable for its intended use.

In addition to the long-term grade, the guidelines also prescribe trigger levels in the event of single high sample results (at designated swimming beaches only). If the results of a single sample exceed 140 enterococci MPN/100 mL, the relevant council is required to resample. If two consecutive samples exceed 280 enterococci MPN/100 mL, the council must advise the public of poor water quality at that site until the detected number falls below 140 MPN/100 ml.

The 5-year rolling 95th Hazen percentile method used to grade recreational sites is particularly sensitive to high enterococci results. Also, given it takes into account all results collected over the preceding five years, there may be a lag between recent reductions in enterococci numbers and the corresponding rolling 5-year 95th Hazen percentile value for that site. Consequently, interannual changes in the rolling 5-year 95th Hazen percentile value do not necessarily reflect changes which occurred in each corresponding year. Thus, when identifying water quality trends both the 5-year 95th Hazen percentile value and the results of individual sampling events must be considered, particularly when a site exhibits high interannual variability.

6.3 Sources of faecal contamination

Key sources of faecal contamination to coastal waters include:

- Discharges of untreated or poorly treated sewage from WWTPs and associated sewerage infrastructure (pump stations and pipes). This can occur at a number of different scales, for example:
    - Large scale spills resulting from plant or pump station malfunctions (often caused by electrical outages) or broken pipes;
    - Smaller-scale chronic leaks caused by cracked or partially-blocked pipes (tree roots are a common problem) or faulty plumbing connections (sewage connected to stormwater);
    - Rainfall-induced inflow and infiltration (I & I), whereby sewage may overflow into stormwater system and/ or stormwater may enter the sewerage system overwhelming the capacity of pipes, pump stations or the WWTP itself to transport or treat the load;
- Direct or indirect discharges of animal faeces, including ducks, gulls and other water birds, dog faeces on beaches and domestic or native animals;
- Stormwater runoff during heavy rains, which transports accumulated faecal contamination from the wider catchment;
- Resuspension of contaminated sediments may also be an issue at some beaches, for example during periods of high winds.

In the urbanised Derwent estuary catchment, stormwater and urban rivulets are often highly contaminated with faeces, particularly after rainfall. This is why primary contact recreation is not recommended near stormwater outfalls or at any location in the Derwent for several days after rain.

Rainfall events strongly influence the degree of faecal contamination of coastal waters because sewer overflows occur more often during and immediately following rainfall, and because rainfall washes faecal contamination from the wider catchment. Thus, it is important to interpret recreational water quality results in the context of the volume of preceding rainfall.

6.4 Management framework

Management of human health risks associated with contamination of public recreational waters is a shared responsibility between Tasmanian Local Governments, the Department of Health and Human Services (DHHS) and DPIPWE/EPA. TasWater is responsible for managing WWTPs and associated infrastructure, while councils manage the stormwater infrastructure. Both TasWater and councils play a role where there are cross-connections between sewer and stormwater systems, leading to contamination of recreational waters.

The DEP coordinates a quarterly monitoring taskforce meeting where representatives from councils, DHHS, EPA, TasWater and other key stakeholders coordinate water quality monitoring activities and review results, together with potential follow-up actions. Outcomes are communicated to the DEP Steering Committee which includes General Managers, CEOs and other senior managers. While the DEP encourages and supports follow-up actions to investigate or remediate sources of faecal contamination, the statutory responsibility lies with the relevant government or business bodies.

6.5 DEP Recreational water quality monitoring program

The Derwent Estuary Program coordinates recreational water quality monitoring as a cooperative initiative between the DHHS (Public and Environmental Health Services), EPA and the six councils that border on the estuary (Derwent Valley, Brighton, Glenorchy, Hobart, Clarence and Kingborough).

6.5.1 Objectives, monitoring design and methods

The principle objectives of this program are to coordinate monitoring, investigations and reporting to assist councils and the DHHS in managing human health risk associated with poor water quality at recreational sites around the estuary. The DEP's role is to:

- Coordinate and enhance recreational water quality monitoring in the Derwent;
- Compile and analyse data, including annual reports, classification of beaches and bays and analysis of longer-term trends;
- Support and facilitate site specific investigations into poor or deteriorating water quality at recreational sites;
- Report monitoring results to the public, for example through websites and signage.

This section focuses primarily on recreational water quality monitoring conducted over the past five summer seasons (1 December 2009 to 31 March 2014) but also draws on previous data to identify and understand any recent water quality changes. More detailed discussion of historical data is available in previous State of the Derwent Estuary reports (Coughanowr, 1995, 1997; Green & Coughanowr, 2003; Whitehead et al., 2010).

During the reporting period, up to 40 sites were sampled between New Norfolk and the Iron Pot (Figure 6.1). Sampling sites are categorised as either swimming sites or environmental sites as described below:

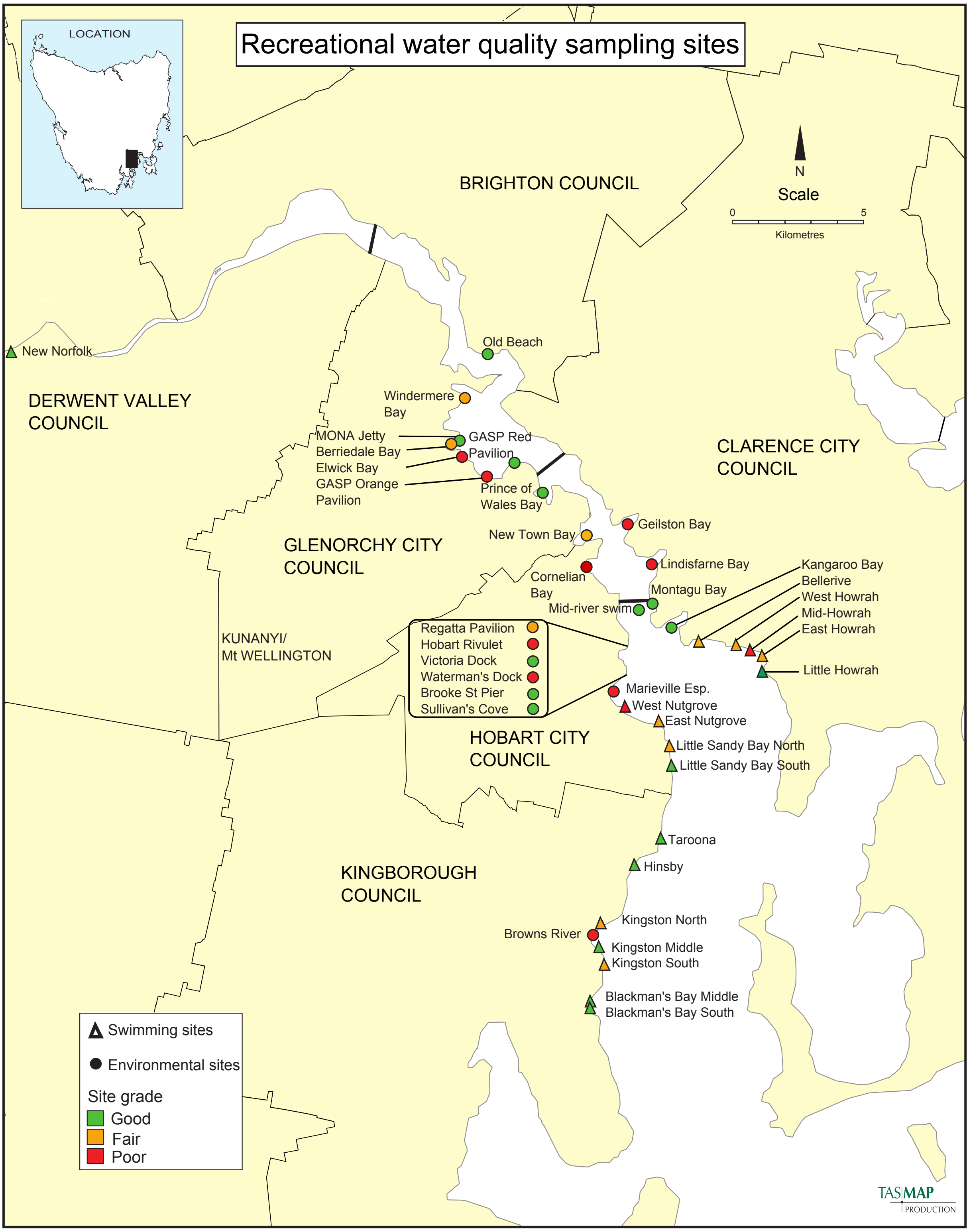
- ***Swimming sites*** are monitored and reported under the Beach Watch label. These are locations where a significant number of people conduct primary contact recreation such as swimming and these sites are sampled to provide a basis for public health information and advice. Nineteen Beach Watch sites were monitored in this reporting period. In addition to routine weekly sampling, some councils conducted additional sampling of beaches and stormwater drain outfalls to inform specific water quality investigations.
- ***Environmental sites*** are monitored and reported under the Bay Watch label. These sites were selected to provide a broader context for interpretation of Beach Watch results and to understand the extent of faecal contamination. The 21 environmental sites monitored in this reporting period were selected because they are:
  - Frequently used for water based activities such as rowing and boating and/or have foreshore parks;
  - Potentially exposed to pathogen sources including sewage and stormwater;
  - Located in the upper and middle estuary but are not likely to be exposed to pathogen sources (sampled to contextualise results from contaminated sites);
  - The location for major swimming events such as the Trans-Derwent Swim.

Every Tuesday between 1 December and 31 March, sampling teams from each of the six councils and the DEP/Environment Protection Authority collected aseptic grab samples from approximately 10 cm below the water surface. Councils conducted shore-based monitoring of beaches, while the EPA/DEP teams conducted boat-based sampling of bays and other environmental sites. Samples were stored on ice for immediate transport to Public Health Laboratories. In the laboratory, samples were analysed for enterococci using the Enterolert method (IDEXX, 2014), which provides 24-hour confirmed results.

6.5.2 Results

Results for the reporting period are presented here for the Beach Watch and Bay Watch sites, respectively. Given the significant impact stormwater runoff has on recreational water, it is important to consider these results in the context of summer rainfall. Summer rainfall records for the past ten years from the Hobart (Ellerslie Road) weather station

Figure 6.1 Recreational water quality sampling sites



are presented in Figure 6.2. This figure demonstrates that summer rainfall has been well below the long-term average (188.2 mm), particularly during the 2012–13 (105 mm) and 2013–14 (95 mm) summer seasons. Rainfall in the 2010–11 summer season (191 mm) was close to the long-term average and the highest in this reporting period.

Beach Watch sites

As shown in Figure 6.3, recreational water quality at Beach Watch sites has varied slightly over the reporting period, with the best water quality reported in 2009–10 and the worst in 2011–12 (a relatively wet summer). The improvement in water quality observed over the last two seasons at a number of sites is probably due to the influence of particularly low rainfall in the last two summers.

As of the end of the 2013–14 season, 9 sites were classified as good water, 8 were fair and 2 were poor (Figure 6.4). The five sites with the best recreational water quality were Opossum Bay, Hinsby Beach, New Norfolk, Taroona Beach and the southern end of Blackman's Bay Beach. The two sites with poor water quality were the western end of Nutgrove Beach and middle Howrah Beach (near Salacia Avenue). While Windermere Bay Beach and Bellerive Beach were still classified as fair, they were not far from the poor category.

Table 6.1 shows the recreational water quality score (rolling 5-year 95th Hazen percentile) for each Beach Watch site over the past five years. Noteworthy changes include:

- Progressive decline in water quality at Mid-Howrah Beach and Bellerive Beach since 2009–10 such that mid-Howrah is now classified as poor, and Bellerive – while still fair – is bordering on poor.
- Major improvement in water quality at Windermere Bay in 2013–14.

Figure 6.2 Total rainfall (mm) for each summer period (1 December to 31 March) recorded at Bureau of Meteorology Ellerslie Road weather station; the current reporting period is represented by darker blue bars

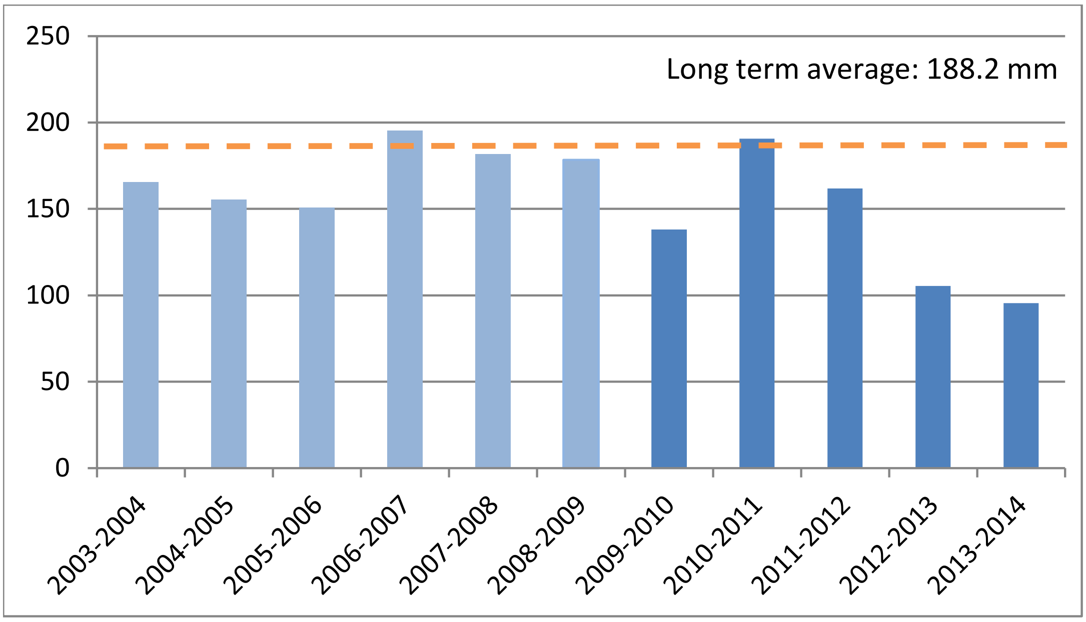


Figure 6.3 Proportion of Beach Watch sites graded as good, fair and poor throughout this reporting period

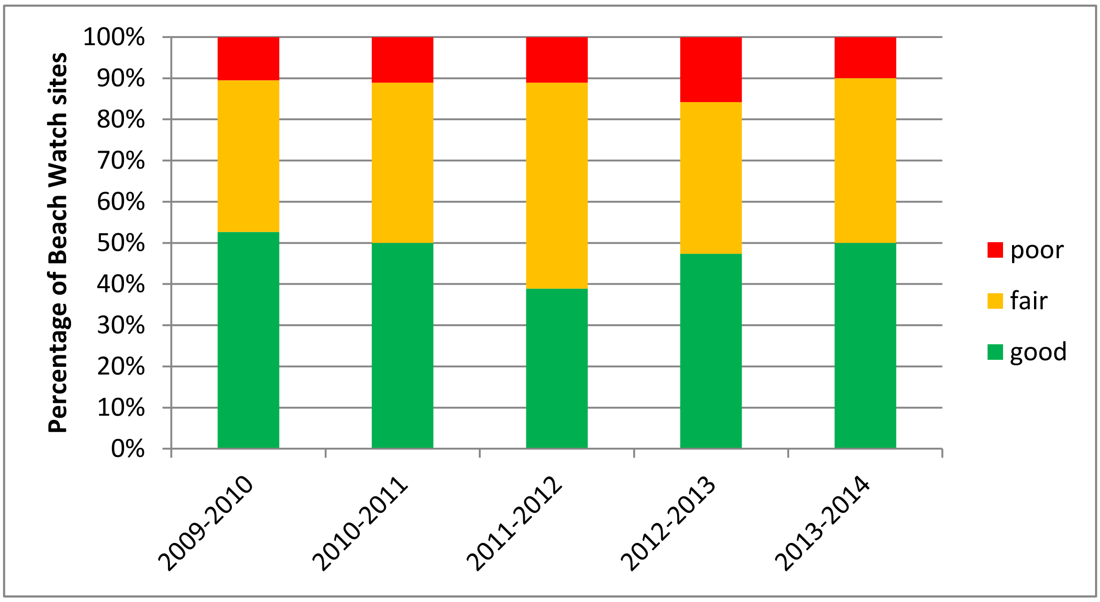
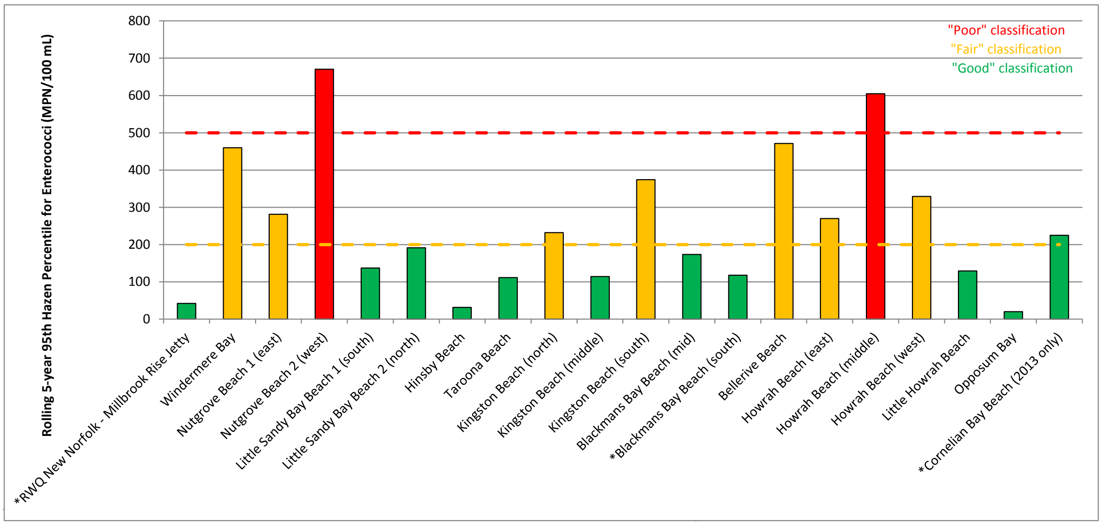


Figure 6.4 Rolling 5-year 95th Hazen percentile at Derwent beaches and other swimming sites at the end of the 2013–14 season; green = good; yellow = fair; red = poor

* means that less than 5 years' data was used



Bay Watch sites

As shown in Figure 6.5 recreational water quality at Bay Watch sites has varied over the reporting period, with a gradual improvement in water quality since 2009–10.

As of the end of the 2013–14 season, 10 of the 20 Bay Watch sites were graded as good, 3 were fair and 7 were poor (Figure 6.6). The five sites with best recreational water quality were at Doran's Road, mid-river Derwent Swim (near the Tasman Bridge), Montagu Bay, outer Cornelian Bay, Old Beach (Jetty Road) and Prince of Wales Bay (near Marina). Recreational water quality was particularly poor at Marieville Esplanade and Geilston Bay, and at the mouth of Browns River and Hobart Rivulet.

Table 6.2 shows the recreational water quality score (rolling 5-year 95th Hazen percentile) for each Bay Watch site over the past five years. Noteworthy changes include:

- Deterioration of water quality at Lindisfarne and Geilston bays over the reporting period.
- General improvement in water quality at the mouth of Hobart Rivulet and Boat Sales Wharf over the reporting period.
- Short-term improvement in water quality at a number of sites in 2013–14 (New Town Bay, Regatta Pavilion, Victoria Dock, Geilston Bay, Kangaroo Bay), probably due in part to the low summer rainfall.
- Short-term decline in water quality at Elwick Bay and Watermans Dock in 2013–14.

Table 6.1 Rolling 5-year 95th Hazen percentile at Derwent beaches and other swimming sites; green = good; yellow = fair; red = poor

NS represents "not sampled", * represents that less than 5 years' data has been used

Site	2009-10	2010-11	2011-12	2012-13	2013-14
New Norfolk (Millbrook Rise Jetty and New Norfolk Esplanade)	137*	87*	80*	38.7*	42
Windermere Bay Beach	471	980	1,051	945	460
Cornelian Bay Beach (old playground)	2005	NS	NS	NS	NS
Cornelian Bay Beach (new playground)	NS	NS	NS	NS	225*
West Nutgrove	560	587	614	784	670
East Nutgrove	324	328	332	347	281
Little Sandy Bay (north)	99	151	321	230	191
Little Sandy Bay (south)	78	79	137	137	137
Hinsby Beach	31	31	31	31	31
Taroona Beach	78	87	173	119	111
North Kingston Beach	309	327	336	228	232
Mid-Kingston Beach	119	123	168	113	114
South Kingston Beach	310	344	350	373	374
Mid-Blackmans Bay Beach	72	88	92	157	165
South Blackmans Bay Beach	NS	NS	NS	75	118
Bellerive Beach	170	207	274	439	471
West Howrah Beach	203	207	318	388	329
Mid-Howrah Beach	268	306	344	587	604
East Howrah Beach	361	344	486	483	270
Little Howrah Beach	144*	117	212	138	129
Opossum Bay	20	20	20	20	20

At sites where poor water quality has continued throughout the last two particularly dry summers, conditions may have deteriorated as lower enterococci results are generally expected during dry weather. Further deterioration may occur during summer seasons with higher rainfall.

Figure 6.5 Proportion of Bay Watch sites graded as good, fair and poor throughout this reporting period

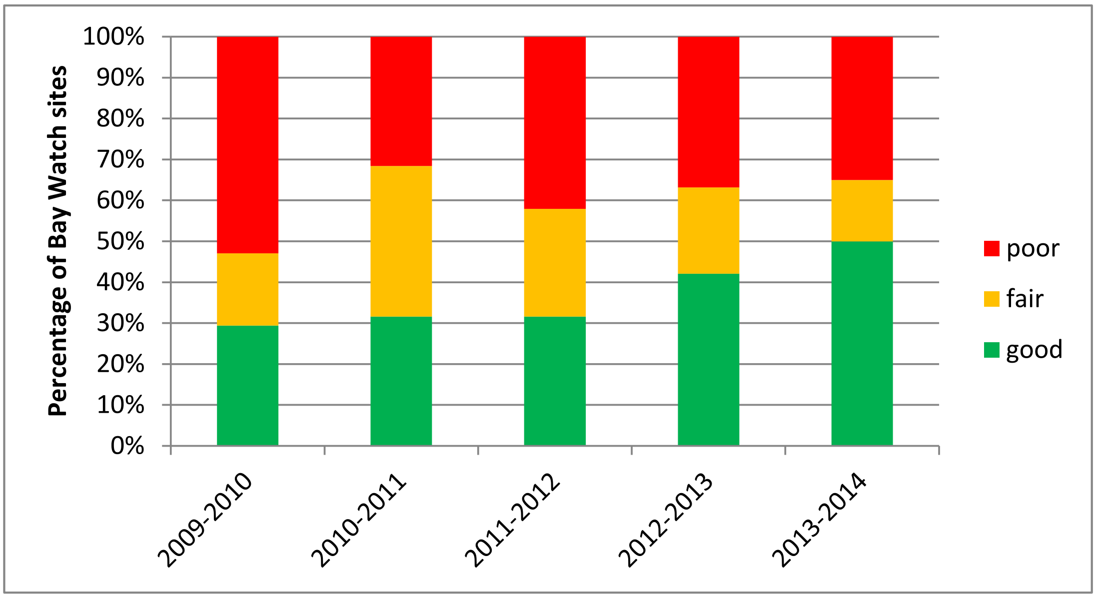
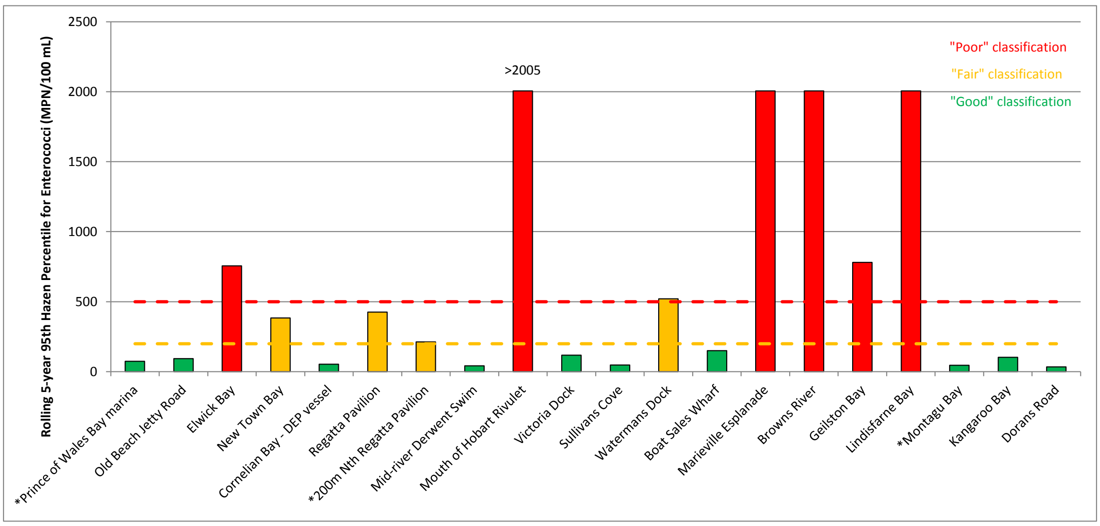


Figure 6.6 Rolling 5-year 95th Hazen percentile at Derwent bays and environmental sites; green = good; yellow = fair; red = poor and * represents that less than 5 years' data has been used



6.6 Public information and reporting

Information about recreational water quality at Derwent beaches and bays was provided in a number of formats, including websites, the regional newspaper, signage at beaches and regular media releases.

6.6.1 Websites

Weekly monitoring results are provided on the DEP Beach Watch and Bay Watch web pages (http://www.derwentestuary.org.au), together with the long-term water quality classification for each site (Figure 6.7). The weekly test result is not provided for sites with a long-term poor grade because primary contact recreation is never recommended at these sites, and a low weekly test result might suggest otherwise.

In 2013–14, a web-based recreational water quality data visualisation tool – the Marine Virtual Laboratory Information System – was developed for Derwent beaches and bays by scientists at the University of Tasmania (Roger Procter and Benedict Pasquer). This demonstration project allowed the user to explore water quality at Derwent bays and beaches, and to compare results between beaches (see www.marvlis.aodn.org.au/marvlis for details).

Table 6.2 Rolling 5-year 95th Hazen percentile at Derwent bays, coves and environmental sites; green = good; yellow = fair; red = poor; NS represents "not sampled", and * represents that less than 5 years' data has been used

Site	2009-10	2010-11	2011-12	2012-13	2013-14
Prince of Wales Bay marina	NS	NS	NS	67*	73*
Old Beach Jetty Road	42*	58*	57*	64*	94
Elwick Bay	437	413	407	490	756
New Town Bay	767	690	723	535	384
Cornelian Bay	53*	137*	133*	53*	53*
Regatta Pavilion	537	437	772	761	425
*200m Nth Regatta Pavilion	NS	222*	312*	239*	213*
Mid-river Derwent Swim	47	79	76	77	42
Hobart Rivulet (mouth)	11,492	12,865	8,414	7,249	5,523
Victoria Dock	755*	375*	311*	306*	119
Sullivans Cove	124	100	112	113	49
Watermans Dock	930	392	455	409	520
Boat Sales Wharf	571*	310*	254*	164*	150
Marieville Esplanade	2,005	2,005	>2,005	2,005	2,005
Browns River	2,005	2,005	>2,005	2,005	2,005
Geilston Bay	461	501	1,269	1,307	781
Lindisfarne Bay	591	1,471	>2,005	2,005	2,005
Montagu Bay	NS	53*	66*	49*	46*
Kangaroo Bay	209	244	644	649	102
Dorans Road	42	49	34	31	34

Figure 6.7 Samples of Beach Watch and Bay Watch weekly snapshots as they appear on the DEP website from December to March

DERWENT BEACH WATCH

Swimming water quality

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

Derwent Estuary Program

SITE	LONG TERM GRADE	WEEKLY TEST RESULT	
LITTLE SANDY BAY NORTH	GOOD	PASS	31
LITTLE SANDY BAY SOUTH	GOOD	PASS	10
NUTGROVE WEST	POOR		
NUTGROVE EAST	FAIR	PASS	10
TAROONA	GOOD	PASS	<10
HINSBY	GOOD	PASS	<10
KINGSTON NORTH	FAIR	PASS	10
KINGSTON MIDDLE	GOOD	PASS	<10
KINGSTON SOUTH	FAIR	PASS	<10
BLACKMANS BAY	GOOD	PASS	111
BELLERIVE	FAIR	PASS	53
HOWRAH EAST	FAIR	PASS	87
HOWRAH MIDDLE	FAIR	PASS	20
HOWRAH WEST	FAIR	PASS	10
LITTLE HOWRAH	GOOD	PASS	10
OPOSSUM BAY	GOOD	PASS	<10
NEW NORFOLK ESPLANADE	GOOD	PASS	10
WINDERMERE	POOR		

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

GRADE: FIVE YEAR SUMMARY
NS = NOT SAMPLED

Tuesday 28th of February, 2012

DERWENT BAY WATCH

Swimming water quality

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

Derwent Estuary Program

SITE	LONG TERM GRADE	WEEKLY TEST RESULT
SULLIVANS COVE	GOOD	87
BOAT SALES WHARF	FAIR	87
VICTORIA DOCK	FAIR	31
WATERMANS DOCK	FAIR	64
200m Nth REGATTA PAV	FAIR	10
REGATTA PAVILION	FAIR	20
HOBART RIVULET	POOR	*(278)
MID RIVER SWIM	GOOD	10
MONTAGU BAY	GOOD	<10
LINDISFARNE BAY	POOR	
GEILSTON BAY	POOR	
NEW TOWN BAY	POOR	
KANGAROO BAY	FAIR	10
DORANS ROAD	GOOD	<10
BROWNS RIVER	POOR	
MARIEVILLE ESPLANADE	POOR	
CORNELIAN BAY	POOR	
ELWICK BAY	FAIR	10
OLD BEACH	GOOD	<10

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

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

*Information for swimming event organisers

Tuesday 28th of February, 2012

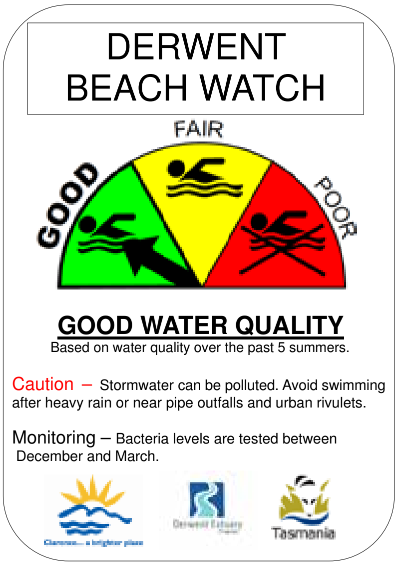
6.6.2 *Signage*

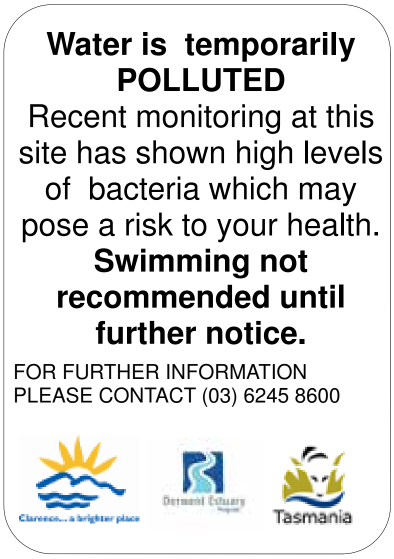
In 2009, DEP developed signage for Derwent beaches in consultation with DHHS and councils (Figure 6.8). These signs have been maintained and regularly updated by councils at all major swimming sites. The signage is intended to:

- Communicate information about the long-term water quality grade at each particular site;
- Raise awarness about the potential for poor water quality associated with stormwater drains and heavy rainfall;
- Allow for advisories to be posted in the event of short-term poor water quality incidents.

At sites with a fair or good long-term grade, a flip-down sign is installed which displays the current classification, but – in the event of short-term poor water quality – can be flipped down to advise the public against swimming. When water quality improves, the sign can be folded back up, again displaying the long-term grade. At sites with a long-term "poor" classification, a single fixed sign is displayed notifying the public that the long-term water quality at that site is poor and that swimming is not recommended.

Figure 6.8 Example of a sign advising the public of the long-term classification for a Derwent estuary recreational site, together with a flip-down sign that can be displayed in the event of short-term poor water quality





6.7 Follow-up investigations and management actions

6.7.1 Rainfall-runoff analyses

In 2013, the DEP carried out an analysis of enterococci response to rainfall, to try and identify those sites that are most (and least) influenced by stormwater runoff. Eight seasons of enterococci and rainfall data were analysed from November 2005 through March 2012. At each site, where enterococci levels exceeded 140 counts/100 ml, this was compared with rainfall records in the previous 24 hours (Table 6.3). While there is further work to be done, the initial results suggest that some sites are more sensitive to stormwater runoff and may be good candidates for more detailed stormwater investigations and management. In contrast, other sites seem to be relatively insensitive to runoff, suggesting that other factors may be at play (e.g. dry weather sewage leaks, localised contamination by waterfowl or dogs).

6.7.2 Sanitary surveys and other investigations

A number of sanitary surveys and follow-up investigations have been carried out at beaches with a poor water quality classification, as described below:

Nutgrove Beach

For a 10-week period during the summer of 2013, Hobart City Council officers collected additional water samples at Nutgrove Beach and Little Sandy Bay, as well as from the Lipscombe Rivulet outfall at the western end of Nutgrove. Samples were collected both in the morning and afternoon, allowing for an assessment of fluctuating inputs and tidal influences on beach water quality. Additional observations were also made at the time of sampling, including meteorological conditions and potential sources of contamination. No clear relationship was found between tidal stage and water quality. However, high levels of contamination were frequently observed in Lipscombe Rivulet, particularly associated with morning sampling, suggesting a sewage leak in this catchment.

Further work was undertaken by council and TasWater officers in 2014–15 to sample water quality at key points within the Lipscombe catchment stormwater system to identify the source of pollution. This investigation is still underway.

Howrah Beach

Several sanitary surveys conducted at Howrah Beach have identified the large stormwater pipes discharging to the beach as probable sources of faecal contamination, particularly during storm events. In 2014, a likely source of stormwater-to-sewage infiltration was identified at the Wentworth Park sewer pump station, which overflows to the Salacia Avenue stormwater drain at mid-Howrah Beach. Other investigations by TasWater and Clarence City Council are underway to investigate possible sewer-to-stormwater cross connections, for example through the use of dye testing. Dye is added to parts of the sewer network and if any dye is visible in nearby stormwater pipes or outfalls, this helps identify that there is a cross-connection in that part of the network. Further investigation is then required to identify the specific location of the leak which, when found, can be repaired. TasWater has also committed funds in the 2014/15 financial year to conduct a broader investigation into the capacity of the Wentworth Park to Rosny WWTP sewer system and has tentatively budgeted some funding for repair works. The full investigation may take some time to complete, as will any resultant infrastructure repair works.

Windermere Beach

Sanitary surveys conducted in the immediate vicinity of Windermere Beach did not identify major stormwater or sewerage leaks within the catchment, and current investigations are focusing on adjacent sources of contamination, including nearby Faulkners Rivulet. Water quality in Faulkners Rivulet is frequently poor, with high enterococci levels observed even during periods of low rainfall. Given the poor flushing in this part of the Derwent, it is possible that Faulkners Rivulet discharge is influencing the adjacent Windermere Beach. In 2014 Glenorchy City Council comenced a sampling program extending throughout Faulkner's Rivulet and from the mouth of Faulkner's Rivulet to Windermere Beach to identify potential sources of faecal contamination.

Table 6.3: Rainfall-runoff analyses for Derwent beaches, bays and environmental sites

	n	Number of samples >140	% of samples affected by rain events
Beaches			
Little Sandy Bay South	144	5	40%
Kingston Beach North	153	12	42%
Kingston Beach Middle	152	7	42%
Kingston Beach South	158	25	55%
Nutgrove West	175	24	58%
Nutgrove East	136	13	62%
Little Sandy Bay North	156	11	65%
Bellerive Beach	167	19	70%
Blackmans Bay	148	5	80%
Little Howrah Beach	110	6	82%
Howrah Beach Middle	151	17	88%
Howrah Beach East	156	21	90%
Hinsby Beach	138	2	100%
Taroona Beach	151	6	100%
Opossum Bay	145	1	100%
Bays			
Cornelian Bay*	124	32	30%
Marieville Esplanade	134	62	40%
Windermere Bay	147	24	60%
Elwick Bay	135	25	60%
New Town Bay	132	20	75%
Lindisfarne Bay	125	20	75%
Geilston Bay	124	17	82%
Kangaroo Bay	131	7	85%
Montagu Bay	100	2	100%
Rivulets			
Hobart Rivulet mouth	134	107	40%
Browns River	153	69	58%
Waterfront			
Watermans Dock	144	22	45%
Sullivans Cove	133	4	75%
Victoria Dock	79	7	85%
Boat Sales Wharf	85	8	88%
Swimming event sites			
Regatta Pavilion	134	33	52%
200m north Regatta Pavilion	101	11	72%
Mid river Derwent Swim	133	3	66%
Other			
New Norfolk Esplanade	99	3	0%
Old Beach jetty	76	1	0%
Dorans Road	142	1	100%

6.8 Summary and recommendations

Recreational water quality in the Derwent estuary is relatively good for an urbanised area, with majority of swimming sites, as well as environmental sites, in any given year having fair or good water quality. However, several sites stand out as having poor water quality, specifically:

- The western end of Nutgrove beach, central Howrah beach, and Windermere beach;
- Several mid-estuary sites, particularly Lindisfarne Bay and Marieville Esplanade;
- The mouths of Hobart Rivulet and Browns River (and urban rivulets more widely – see Section 4.4 for details).

Over the past five years recreational water quality at Derwent beaches has been relatively steady, while there has been an apparent improvement at bays and other environmental sites. However this trend needs to be taken in the context of rainfall patterns during this time, which have been much lower than average.

It is recommended that further work be undertaken to:

- Predict recreational water quality at swimming beaches in response to rainfall, as the current monitoring and advisory program is based to a large degree on retrospective information;
- Review and trial more rapid and diagnostic indicators of faecal pollution to better identify and manage pollution sources (e.g. human vs bird);
- Complete the beach classification process per the NH&MRC guidelines. In addition to the microbiological score, sanitary surveys should be completed at all beaches to enable a complete risk assessment;
- Identify, track and fix pollution sources, starting with designated swimming sites with a poor water quality classification. In order of priority, this would include:
  - dry weather sewage leaks, discharged via stormwater pipes
  - wet weather sewer/stormwater cross connections
  - managing stormwater runoff at a broader catchment scale;
- Raise community awareness about actions they can take to prevent pollution (e.g. picking up dog faeces, not feeding the ducks).

7.0 SEDIMENT QUALITY

Most estuaries are depositional areas. They trap and retain sediments and organic matter from their catchments, along with associated contaminants such as heavy metals, nutrients, hydrocarbons, pesticides, herbicides and other organic compounds. These sediments may be transported and redistributed by floods, tides and currents, and eventually settle out in lower energy environments. The contaminants associated with estuarine sediments may be reprocessed 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 geochemistry. Previous State of the Derwent reports have summarised sediment surveys and investigations carried out up until 2009. 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 (Edgar and Samson, 2004).

During the period from 2003–09, the DEP's main focus was on heavy metal sediment process studies, sediment toxicity and effects on benthic invertebrate communities. Much of this work was carried out in the context of the *Derwent Estuary Water Quality Improvement Plan (WQIP) for Heavy Metals*. 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 a number of sediment investigations were carried out. These investigations were reviewed in the previous State of the Derwent Report (Whitehead et al., 2009) and can be sourced there. See the full WQIP report (DEP, 2004) for details.

The following sections provide an overview of our current knowledge concerning heavy metal impacts on sediment quality in the Derwent estuary, together with a summary of investigations carried out since 2009. Several related investigations into food chain pathways and geochemical processes, are described in Sections 8 and 10.

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 application including numerical rounding and inclusion of several additional chemicals (ANZECC, 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 contamination on the basis of geochemistry, toxicity and biological communities. In the Derwent, it has been demonstrated that the total heavy metal concentrations in sediment are not necessarily the major environmental parameter influencing the distribution of the benthic biota in the estuary (Macleod and Helidoniotis, 2005). Further work is recommended to better understand the distribution of biologically available heavy metals in Derwent estuary sediments, as well as the relationship between biota distribution and heavy metal toxicity, in order to develop meaningful sediment quality guidelines. For the purposes of this report metal levels in Derwent estuary sediments will be compared to the ISQG values in Table 7.1.

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 guidelines adopted by ANZECC (2000)

7.2 Heavy metal contamination of Derwent sediments

Heavy metal contamination – particularly by zinc, mercury, cadmium, lead, copper and arsenic – is one of the Derwent estuary's most severe and persistent problems, with metal concentrations in sediments among the highest in Australia and indeed the world, as illustrated in Table 7.2. Past heavy metal contamination of the Derwent estuary has been primarily associated with the zinc smelter (established in 1917) and the Boyer newsprint mill (established 1941). Other current and historical sources of heavy metals include former industries (e.g. foundries, tanneries, textile dying, munitions), urban runoff (particularly during the era of leaded petrol), 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 and lead still greatly exceed the ANZECC (2000) sediment quality guidelines throughout most of the estuary, while copper and arsenic are also significantly elevated.

7.2.1 Surface sediment heavy metal concentrations

A number of major sediment surveys have been carried out in the Derwent since the 1970s, as outlined in Table 7.2. The first comprehensive study of heavy metals in the 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 estuary in 1996 by Pirzl (1996), in 1996–97 by Jones et al. (2003) and in 2000 by the DEP and Tasmanian Aquaculture and Fisheries Research Institute. 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; Whitehead et al., 2009).

Table 7.2 Heavy metal concentrations in Derwent estuary surface sediments compared to other Australian and international estuaries

Estuary	Year collected	# of samples	As max (avg)	Cd max (avg)	Cu max (avg)	Hg max (avg)	Pb max (avg)	Zn max (avg)	Ref
Derwent									
Derwent[a]	2011	123	421 (56)	128 (18)	580 (130)	48.3 (8.5)	1880 (509)	14,600 (2557)	DEP (this report)
Derwent[a]	2000	136	1400 (84)	477 (31)	1490 (164)	130 (10)	8120 (748)	59,000 (4228)	DEP: Whitehead et al., 2003
Derwent	1996	69	657 (51)	180 (14)	1182 (106)	36 (6)	3866 (580)	22,593 (2103)	Jones et al., 2003
Derwent	1996	40	20.9	134	530	55.7	2078	19,201	Pirzl,1996
Derwent	1975	102		1400	10,050	111	41,700	104,000	Bloom & Ayling, 1977
Other Tasmanian estuaries									
Tamar									
	1974-2002	4 to 44	370	16.5	472	2.5	1750	6050	Aquenal and DEPHA, 2008
Macquarie Harbour	1975-93	4 to 12			1980				DoE, 1975; Koehnken, 1996
Huon	1996	18	25 (16)	<10	32 (17)	<5	48 (25)	66 (40)	Jones et al, 2003
Other Australian estuaries									
Spencer Gulf SA				267	122		5270	16,667	Ward & Young, 1981 cited in Birch, 2000
Sydney – Port Jackson	1995	~ 1700					3604	7622	Birch & Taylor, 1999
Newcastle - Port Hunter				8	283		843	5161	Birch, 1997 cited in Birch, 2000
Port Phillip Bay			30	5.8	62	0.5	197	1600	Fabris et al., 1991
Other international									
Hudson River, NY, USA				2.3	149		177	257	Feng et al., 1998
Acushnet, MA, USA				76	7,500		560	2,300	Forstner & Wittman, 1981
Corpus Christi, TX, USA				130				1,100	Forstner & Wittman, 1981
Thames, UK									
Mersey, UK			(42)	(1.1)	(84)	(3)	(124)	(379)	Bryan & Langston, 1992
Restronguet/Fal, UK			(1740)	(1.5)	(2398)	(0.5)	(341)	(2821)	Bryan & Langston, 1992
Golden Horn, Turkey					3900		702	8750	Ergin et al., 1991
Izmir Bay, Turkey	1995	100					(100)	(640)	Atgin et al., 2000
Rio Tinto, Spain				4.1	1400		1600	3100	Forstner & Wittman, 1981
Sorfjord, Norway				850	1200		30,500	118,000	Forstner & Wittman, 1981
Tokyo Bay, Japan				1.7	112		74	501	Fukushima et al., 1992
Victoria Harbour, Hong Kong	2004				111		93	246	Yim & Fung, 1981
Sediment Quality Guidelines									
ISQG - low			**20**	**1.5**	**65**	**0.15**	**50**	**200**	
ISQG - high			**70**	**10**	**270**	**1**	**220**	**410**	

All concentrations as mg/kg (dry sediment); all surface samples unless otherwise noted

a – average is for 77 sites sampled in 2000 and 2011 surveys

2011 Derwent sediment survey

During 2011, the DEP re-surveyed Derwent estuary surface sediments. Samples were collected at 123 sites throughout the estuary in November 2011, at the locations shown in Figure 7.1. Sample sites were selected to include good overlap with the previous 2000 sampling survey (77 sites in common). At most sites a multi-corer was used to obtain triplicate cores in a single deployment. The upper 5cm of core material was extruded and mixed to provide an integrated surface sample. As triplicate cores were collected, these provided a sample for:

i) metals and % organic carbon analysis
ii) grain size
iii) archived samples for future analyses.

At sandier locations an Ekman or VanVeen grab sample was obtained. All samples were kept cool and then frozen within several hours of collection. The sediment samples were analysed for metals (As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn), and percentage organic carbon at Analytical Services Tasmania (AST). Grain size analysis was undertaken at Geosciences Australia in Canberra, however results were not comparable to previous surveys due to different preparation techniques (i.e. oven drying prior to grainsize analyses) and are not presented here. (See Whitehead et al., 2013 for details.)

Contour maps showing the distribution of each metal compared to the national sediment quality guidelines were developed using *Surfer 8* software, based on the full suite of 123 samples collected in 2011. To compare metal distributions between the 2000 and 2011, ArcGIS 9.0 software was used to create maps based on the 77 sites that were shared between the 2000 and 2011 surveys. These maps were created to illustrate those areas with possible decreases and increases in metal level between the 2000 and 2011 surveys. These spatial changes should be considered as indicative, given the relatively short time period between surveys and possible discrepancies in site locations between the two surveys.

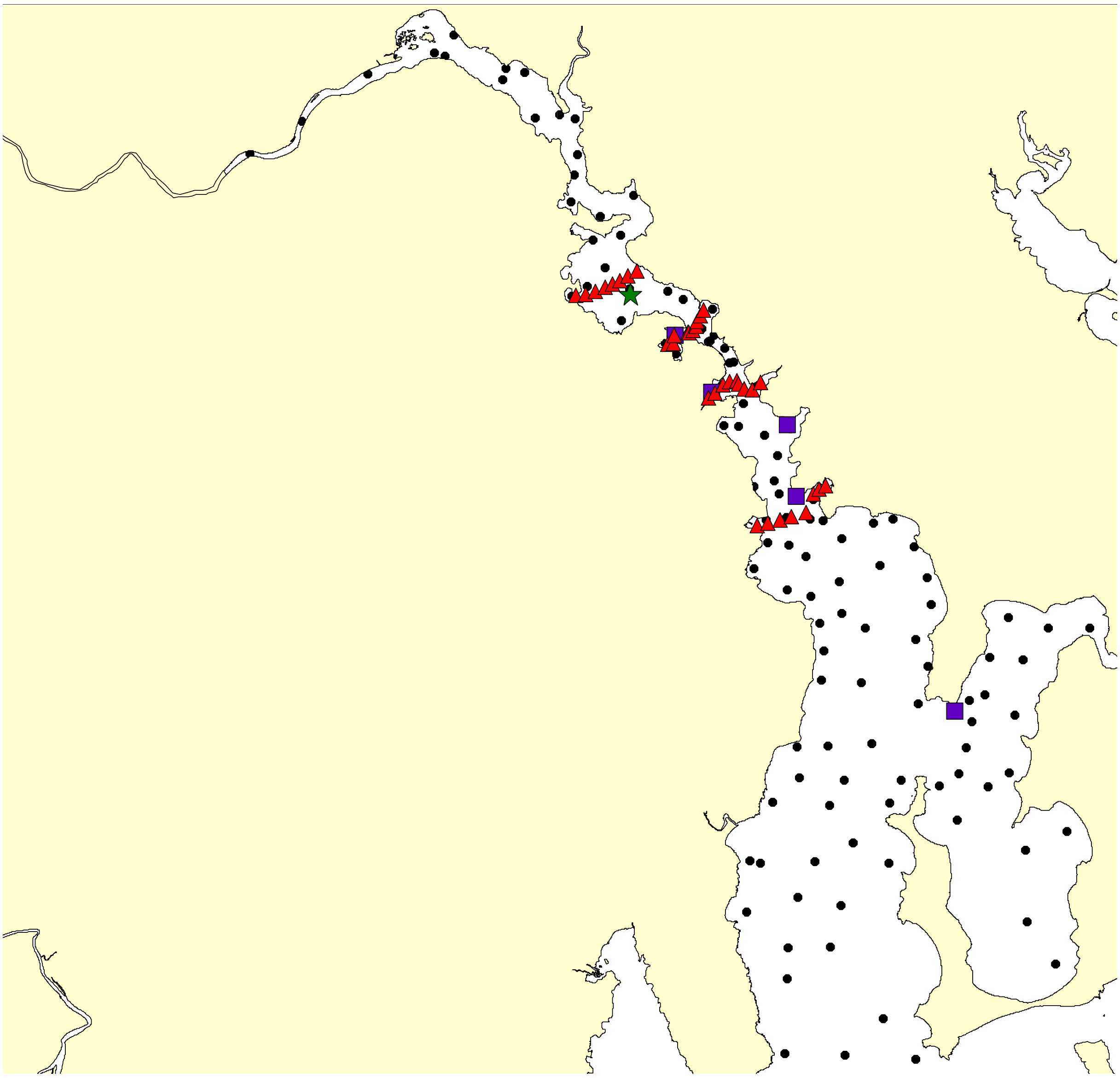
Figures 7.3 to 7.9 illustrate the distribution of heavy metals in Derwent estuary surface sediments based the 2011 survey, as well as a comparative snapshot between the 2000 and 2011 surveys . Distribution maps for % organic matter are also provided.

The 2011 sediment survey showed similar spatial distributions of heavy metals across the estuary as compared to previous studies, with highest levels in the middle estuary, particularly in the vicinity of the smelter site. Concentrations of zinc, mercury, cadmium, lead, copper and arsenic remain well above the ISQG guidelines over large areas of the estuary.

The middle reaches of the estuary are particularly contaminated with heavy metals and in this area can be 10 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). Heavy metal concentrations decrease towards both 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 estuary's salt-wedge circulation;
- The sediment types in the estuary (i.e. grain size and organic content).

Figure 7.1 Sample locations from the 2011 surface sediment survey (DEP) and core locations from other recent investigations. Where • = DEP 2011 samples; ★ = Townsend & Seen (2012); ■ = Gregory (2013) and ▲ = Hughes (2014)



Comparison of the 2000 and 2011 data sets (Figure 7.2) shows a significant reduction in some of the extremely high metal values previously recorded, particularly with respect to zinc and lead. Average values also decreased across the estuary as a whole, however median values have not changed substantially. The comparative maps for the 2000 and 2011 surveys indicate slight shifts in contaminant distributions with some reductions in contaminant levels at upper and lower estuary sites (including Ralphs Bay), and an apparent increase in contaminant levels in Elwick Bay. This increase could be due to redistribution or re-exposure of more contaminated sediments, but is based on a limited number of samples and merits further investigation. (See Whitehead et al., 2013 for further discussion.)

Figure 7.2 Comparison of heavy metal levels (mg/kg) in Derwent estuary sediments between 2000 and 2011 surveys (based on 77 samples/survey) where limit of boxes represents 25th and 80th percentiles, whiskers extend to maximum values and n=number of samples.

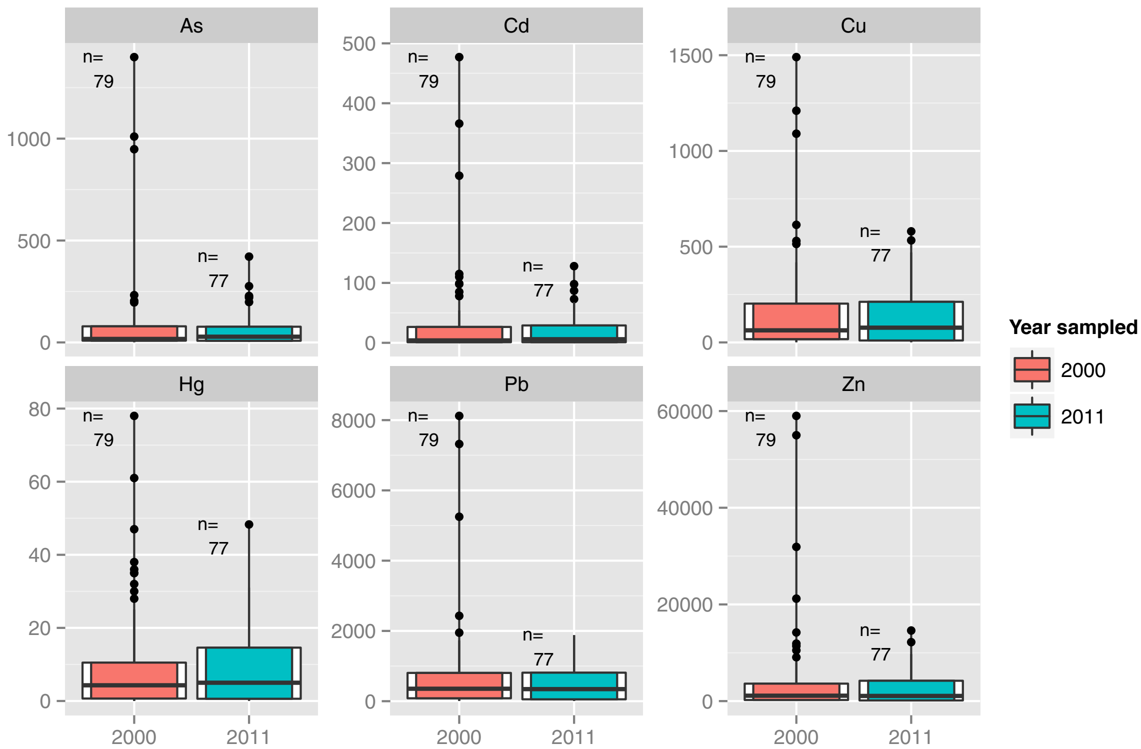


Figure 7.3 Distribution of arsenic in Derwent estuary surface sediments based on 2011 survey (123 samples) and comparison of 2000 and 2011 survey results (77 samples). Dashed blue line = ISQG Low; Red line= ISQG High

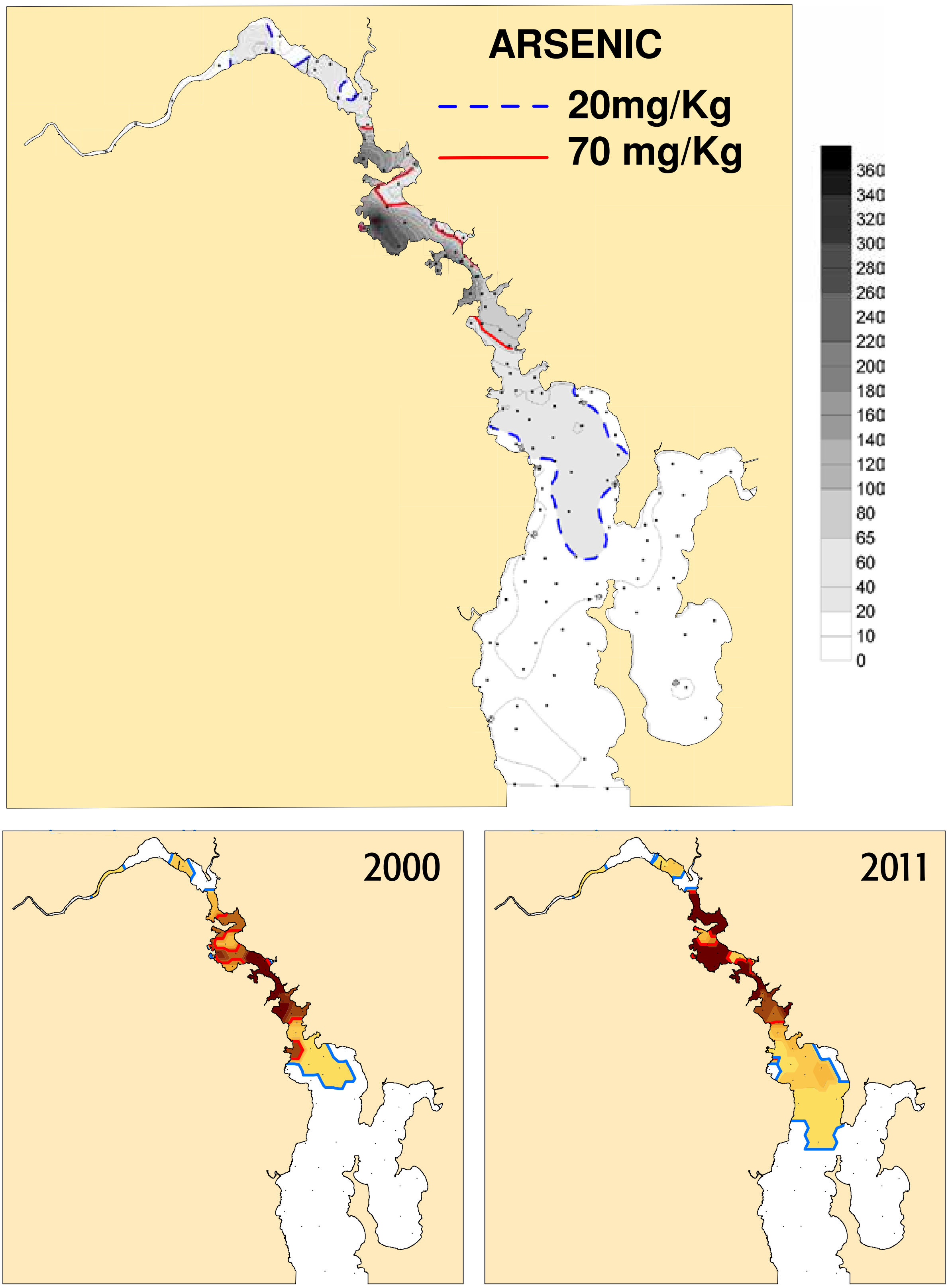


Figure 7.4 Distribution of cadmium in Derwent estuary surface sediments based on 2011 survey (123 samples) and comparison of 2000 and 2011 survey results (77 samples). Dashed blue line = ISQG Low; Red line= ISQG High

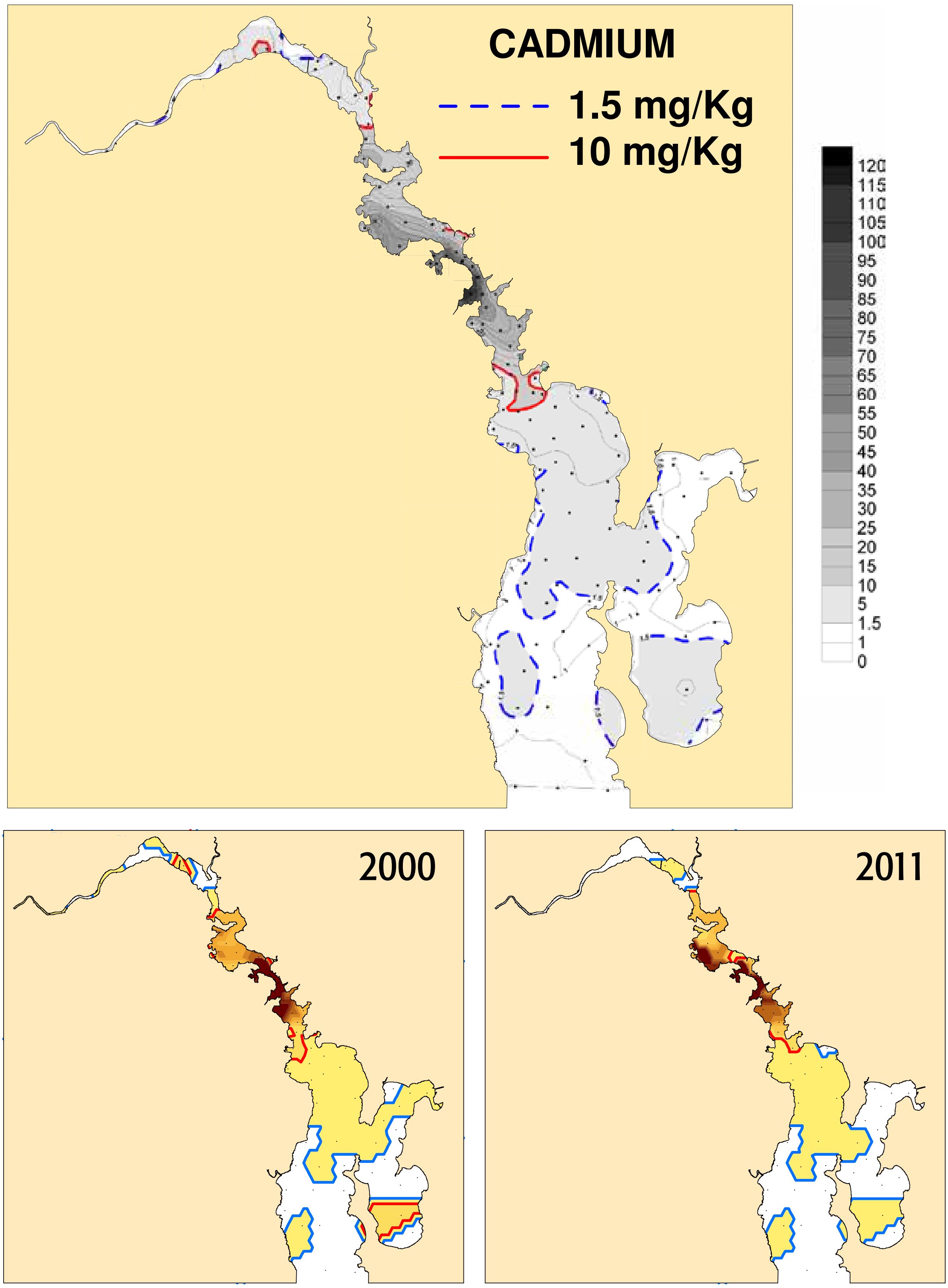


Figure 7.5 Distribution of copper in Derwent estuary surface sediments based on 2011 survey (123 samples) and comparison of 2000 and 2011 survey results (77 samples). Dashed blue line = ISQG Low; Red line= ISQG High

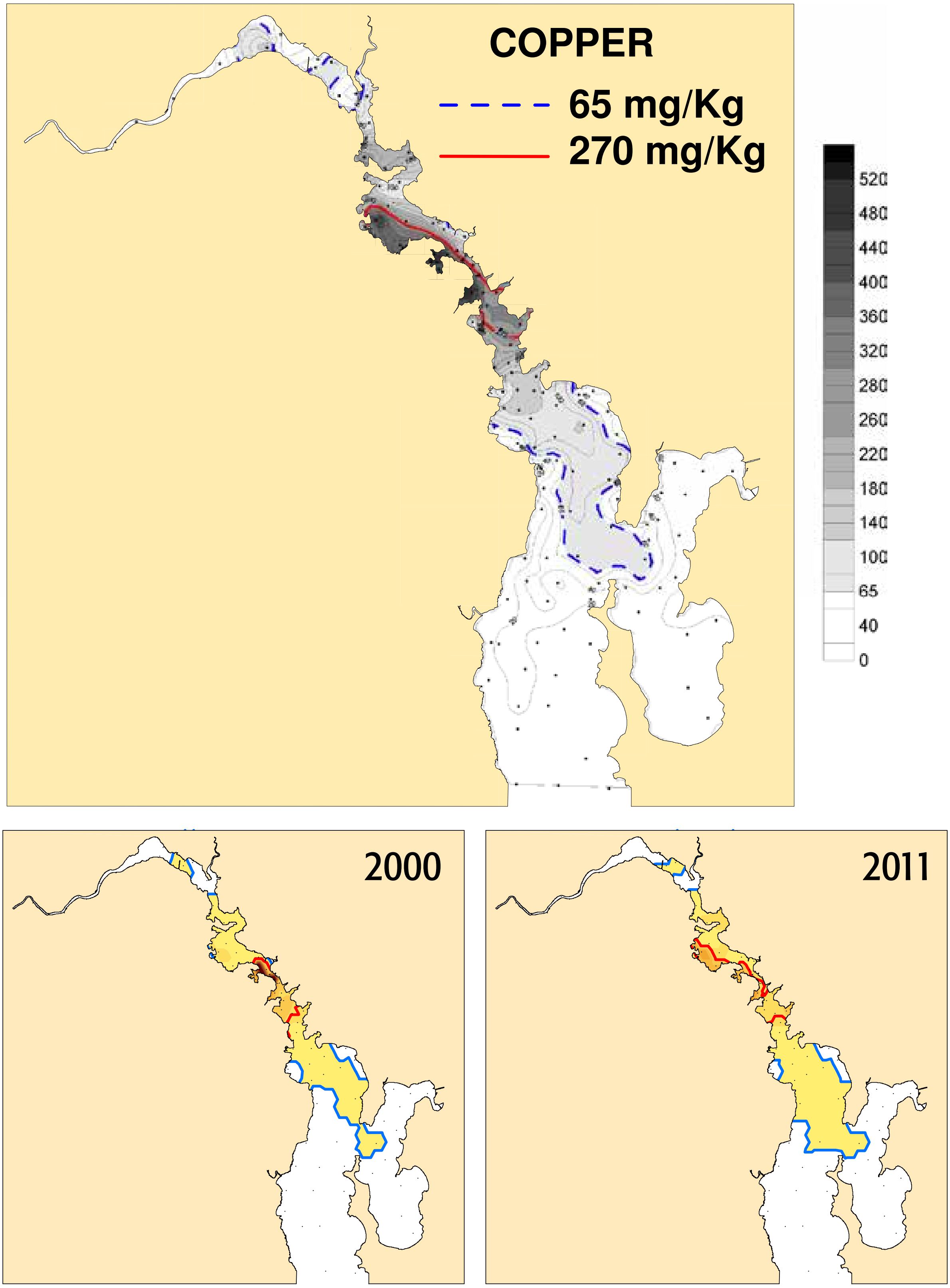


Figure 7.6 Distribution of mercury in Derwent estuary surface sediments based on 2011 survey (123 samples) and comparison of 2000 and 2011 survey results (77 samples). Dashed blue line = ISQG Low; Red line= ISQG High

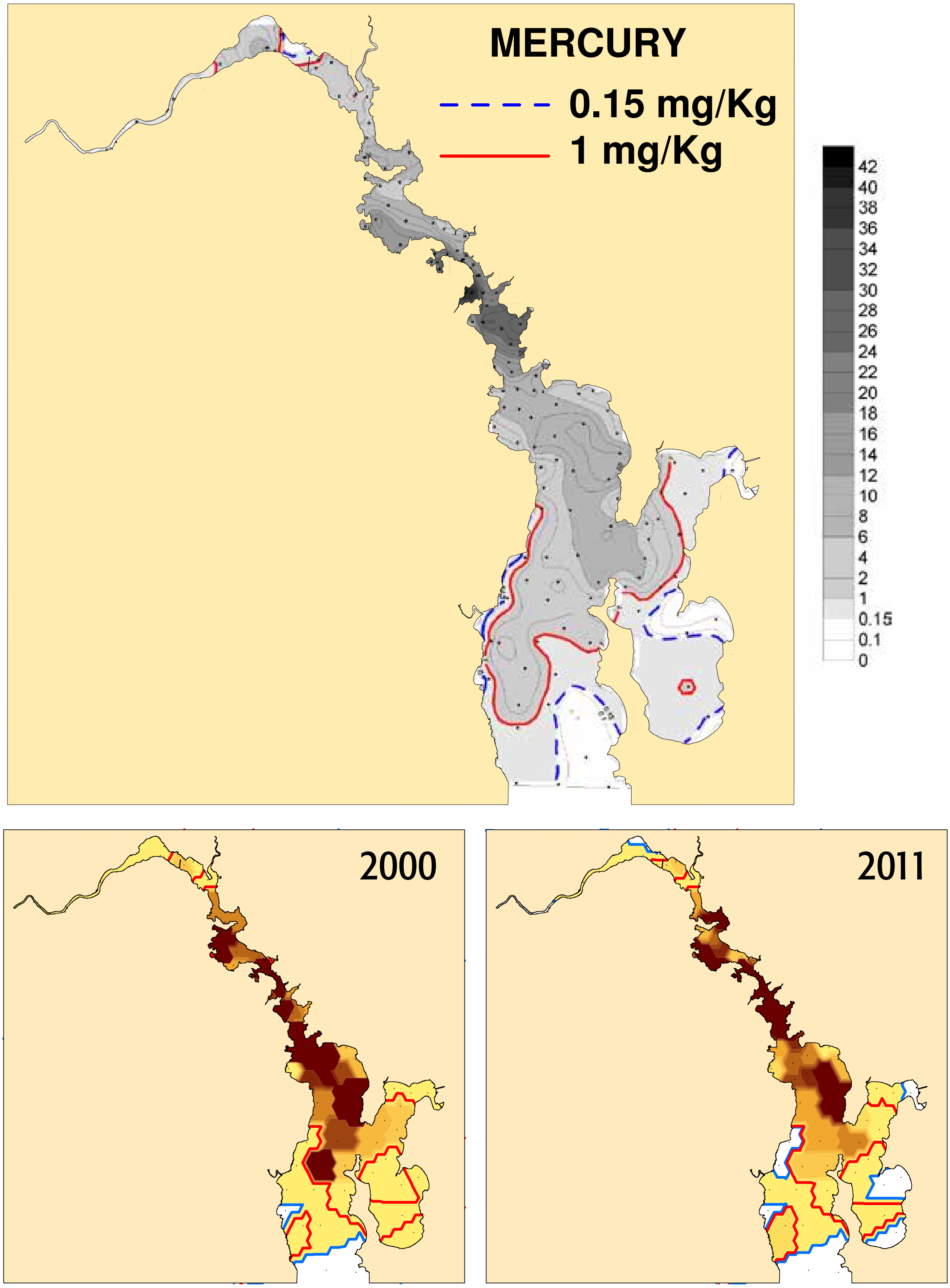


Figure 7.7 Distribution of lead in Derwent estuary surface sediments based on 2011 survey (123 samples) and comparison of 2000 and 2011 survey results (77 samples). Dashed blue line = ISQG Low; Red line= ISQG High

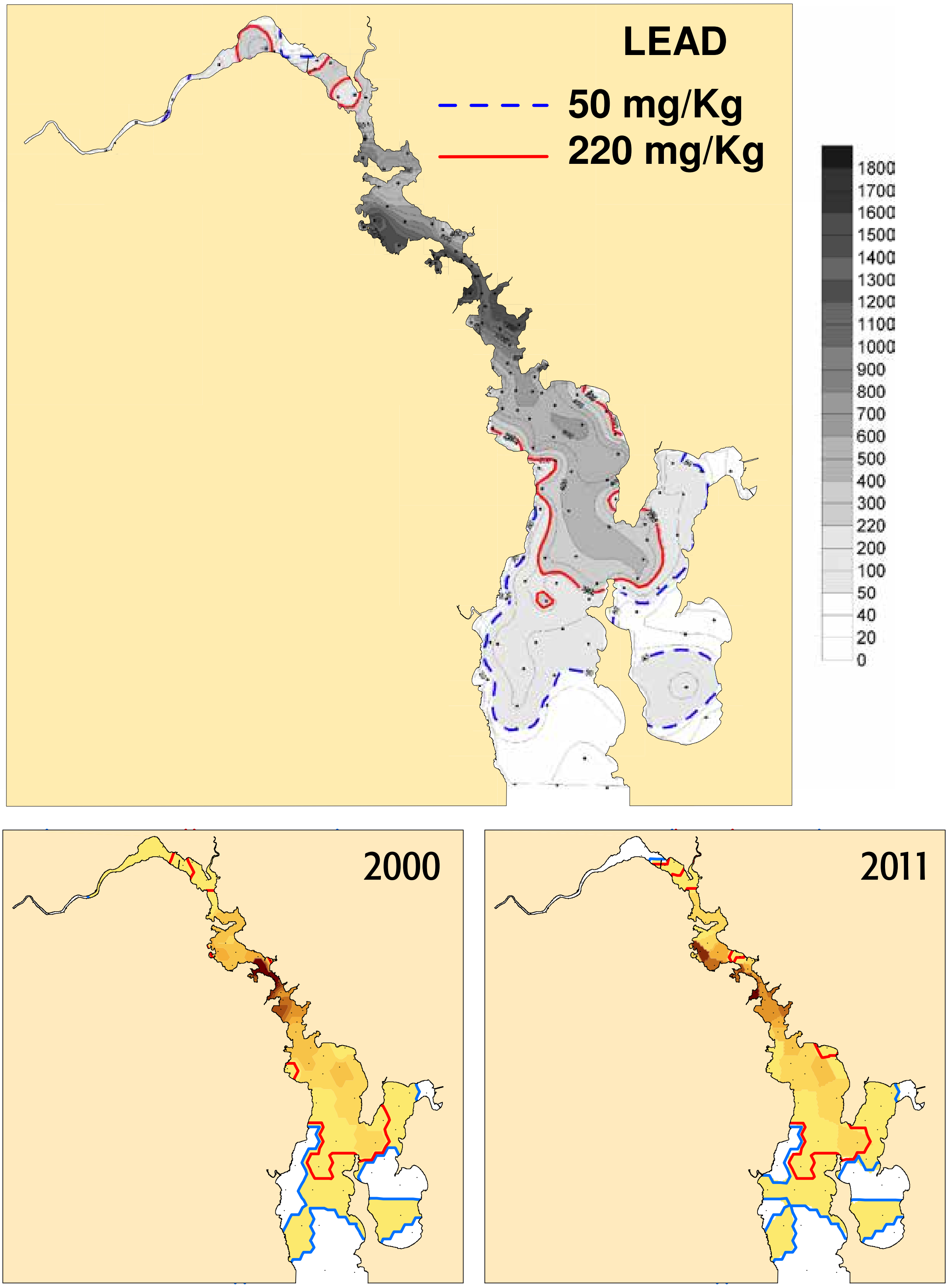


Figure 7.8 Distribution of zinc in Derwent estuary surface sediments based on 2011 survey (123 samples) and comparison of 2000 and 2011 survey results (77 samples). Dashed blue line = ISQG Low; Red line= ISQG High

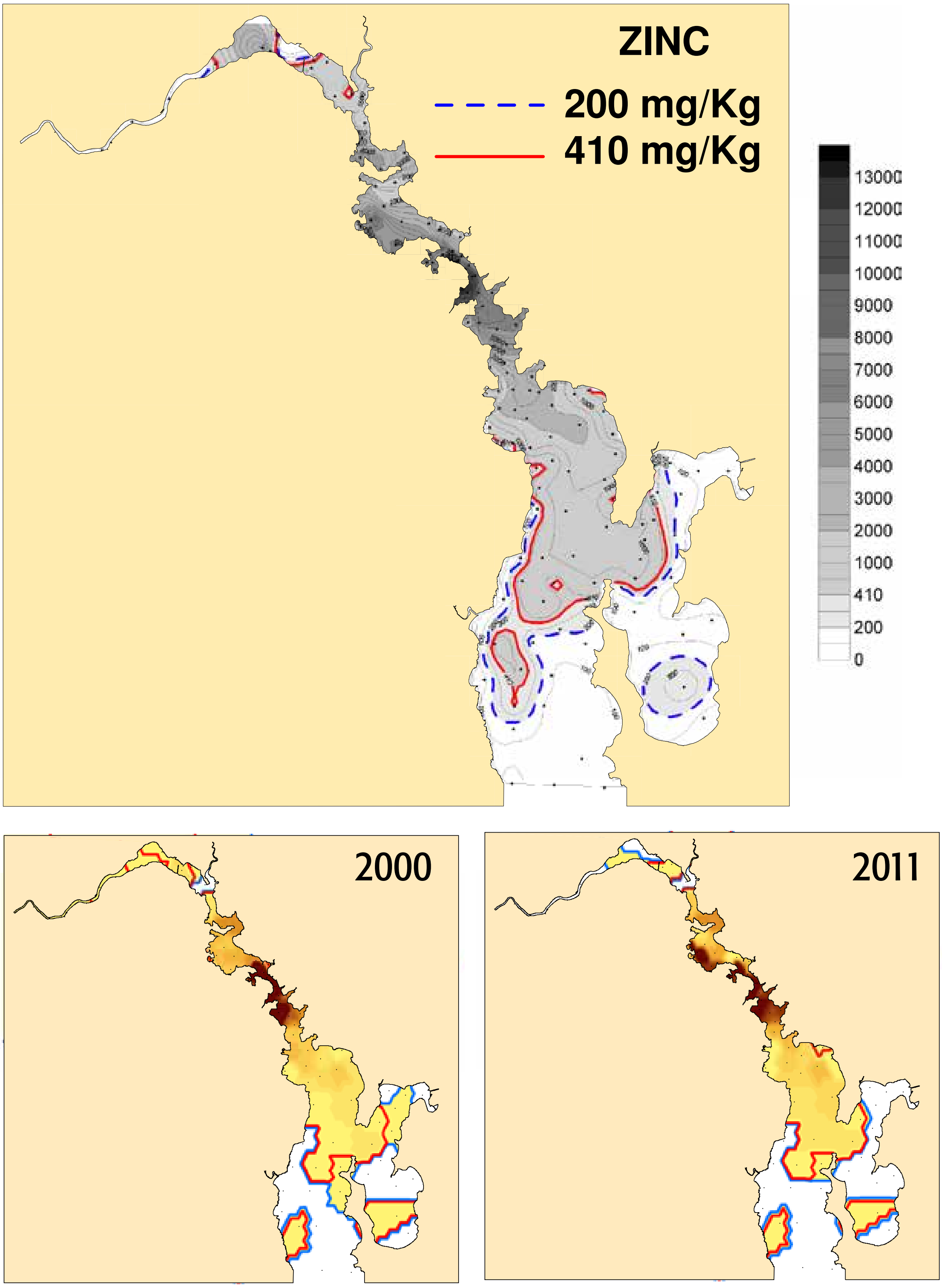
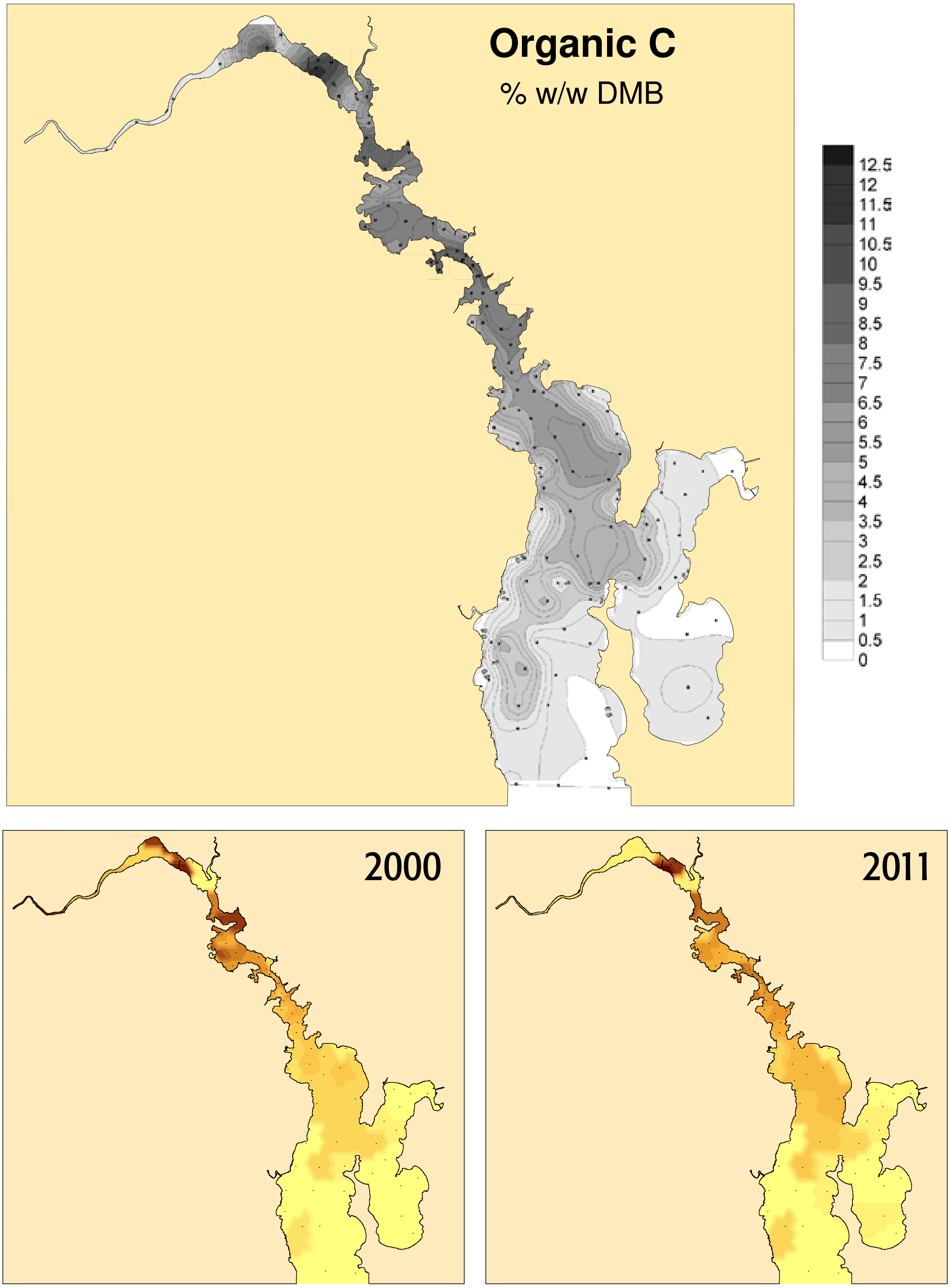


Figure 7.9 Distribution of organic carbon in Derwent estuary surface sediments based on 2011 survey (123 samples) and comparison of 2000 and 2011 survey results (77 samples).



7.2.2 *Past heavy metal concentrations in Derwent estuary sediments*

Several recent studies have collected and analysed short cores (up to one metre) from the Derwent to better understand how metal levels have changed over time, and to estimate sediment accumulation and recovery rates. The location of the cores collected since 2009 are shown in Figure 7.1.

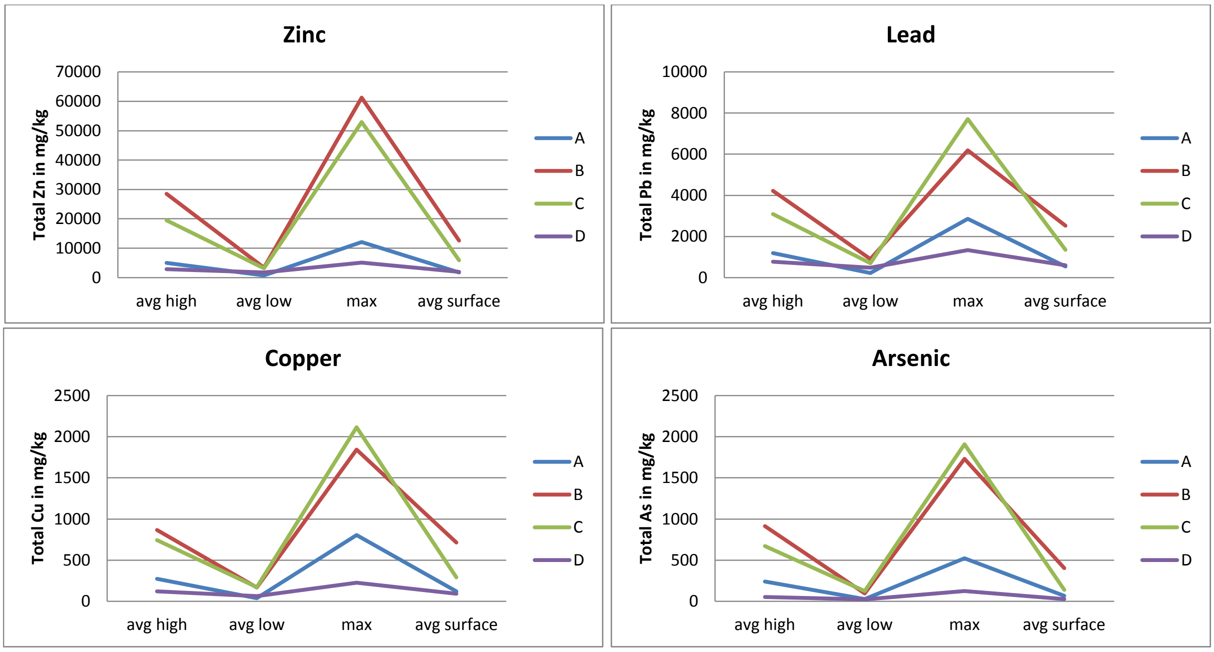
Townsend and Seen (2012) analysed a core collected in Elwick Bay for physical properties (grainsize, loss on ignition), heavy metal concentrations, lead isotopes and lead 210 (a dating technique). The onset of metal contamination occurred at a depth of about 45 cm, with maximum levels of Zn (4500 mg/kg), Pb (1090 mg/kg), Cd (31 mg/kg) and Cu (141 mg/kg) observed at about 20 cm. Mercury was not analysed in this study. Sedimentation rates in the upper 50 cm of the core ranged from about 0.4 to 0.5 cm/yr in the upper and lower sections, with a higher rate (0.7 cm/yr) in the middle section, possibly corresponding to a major flood or erosional event. Lead isotopes were successfully used to track the different ore types used at the nearby zinc smelter through the sedimentary record. Lead and zinc levels in the Elwick Bay core were compared to levels in a number of other Tasmanian, Australian and international estuaries.

Another recent study (Gregory et al., 2013) investigated the mineralogical siting of heavy metals in Derwent estuary sediments, and the degree to which this controls metal mobility. Five cores were collected from mid estuary bays and at the entrance to Ralphs Bay (Figure 7.1) and metal concentrations were measured using a mobile X-ray fluorescence (XRF) device as well as lab based methods. Sequential leach extractions were used to determine metal mobility, and mineralogy was investigated using x-ray diffraction and electron microprobe methods. Maximum metal concentrations in the Prince of Wales Bay and New Town Bay cores occurred at depths of 40–60 cm below the surface. The mineral franklinite (a zinc ferrite, found in the iron rich residue discharged to the estuary prior to 1975) was found to be the main repository of zinc, while much of the lead and copper is hosted by sulphides, organic matter and iron oxides. The sequential leach extractions showed that zinc and cadmium were the most tightly bound, followed by copper, and then lead.

In 2013–14, Hughes collected a series of 37 cores along four transects at the locations shown in Figure 7.1. Each core was frozen and divided into 5 cm sections that were freeze dried and analysed for heavy metal content using a portable XRF device. Lab-based heavy metal analyses were also run on samples from two of the cores at Nyrstar (for comparative purposes), while additional mercury analyses were carried out on several cores from transects B and D at AST. Some additional mineralogical analyses were also carried on a subset of samples as described in Hughes (2014). This study found a peak in metal concentrations in nearly all cores at a depth of about 10 to 70 cm, with a double peak observed in some samples particularly in the vicinity of New Town Bay. A summary of heavy metal concentrations in cores along each transect is provided in Figure 7.10. The highest metal concentrations were observed in transects B and C (Prince of Wales Bay and New Town Bay), followed by transect A (Berridale) and D (Sullivans Cove). Heavy metal concentrations in surface sediments were found to have declined to between 10 and 40% of peak values along transects A, B, and C, but have declined more slowly in the less contaminated lower estuary (transect D). Mercury levels in two New Town Bay transect cores ranged from 14 to 72 mg/kg, while levels in three cores from the Sullivans Cove transect ranged from 0.05 to 20 mg/kg.

Figure 7.10 Heavy metal/metalloid levels in cores along four transects across the Derwent

(A = Berridale to Otago; B = Prince of Wales to Risdon Cove; C = Newtown to Geilston Bay; D = Sullivans Cove to Kangaroo Bay (source: Hughes, 2014)



The average thickness of the contaminated layer was 63 cm, ranging from 30 to 110 cm. Sedimentation rates were estimated based on the onset of heavy metal contamination (1917) and peak values (1970), and typically ranged from 0.5 to 1 cm/yr. It was estimated that 123 years (+/- 88 yrs) would be required for surface sediments to reach low levels of contamination (ISQC-low) based on these sedimentation rates, noting the high degree of uncertainty. An estimate of the total amount of heavy metals that have accumulated in Derwent estuary sediments was also attempted with the following approximate values: 122,000 tonnes of zinc, 20,000 tonnes of lead, 5,100 tonnes of copper and 2,200 tonnes of arsenic. See Hughes (2014) for details.

8.0 CONTAMINANTS IN FISH, SHELLFISH AND OTHER BIOTA

Photo: N. Barrett TAFI

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 a million 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 some metals, polycyclic aromatic hydrocarbons (PAHs) and other organic compounds, and because they are sessile may reflect local contaminant concentrations more accurately than mobile crustacean or fish species (USEPA, 2000). Bottom-dwelling fish, such as bream or 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). Contaminants such as heavy metals also accumulate in other biota such as birds and marine mammals, with adverse impacts on their health and reproduction.

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 Contaminants in seafood

Toxicants in seafood include heavy metals, organochlorine pesticides, organophosphate pesticides, chlorophenoxy herbicides, PAHs, 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 was also historically used as a slimicide in the pulp and paper industry, including at the Boyer mill. 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 fetuses (USEPA, 2000). Bottom-feeding fish and predatory 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 may still be 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).

Polychlorinated biphenyls (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 refineries, paper mills and other industrial sites (USEPA, 2000). PCBs are extremely persistent in the environment and bioaccumulate through 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).

8.1.3 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, 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 organism, can cause paralytic shellfish poisoning. In extreme cases, paralytic shellfish poisoning causes muscular paralysis, respiratory difficulties, and can lead to death (Ochoa et al. 1998).

8.1.4 Faecal pathogens

Human derived faecal pathogens can also accumulate in shellfish and other filter-feeding organisms, causing gastrointestinal and other more serious illnesses. In urbanised areas, it can be risky to harvest and consume local shellfish due to the numerous potential sources of faecal contamination associated with sewerage and stormwater infrastructure. Faecal indicator bacteria are not monitored in Derwent estuary shellfish, as it is not recommended to eat shellfish from the Derwent due to heavy metal pollution.

8.2 Food Safety Guidelines

Results for the most recent seafood surveys for the Derwent estuary 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). This code uses a combination of maximum permitted levels (MLs) and generally expected levels (GELs). Maximum levels 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. It should be noted that some GELs (particularly for zinc) did not incorporate Tasmanian data and may not be entirely appropriate to this region. Also note that 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 such as billfish, shark, orange roughy and catfish as these species accumulate higher levels of mercury in their flesh. 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 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 three population groups: women of childbearing age, the general population and young children (pers. comm. J. Baines, FSANZ, 2007). This method has been used as the basis for the health advice issued for Derwent estuary seafood by the Tasmanian DHHS.

8.3 Heavy metals in Derwent estuary seafood

Numerous investigations of heavy metal concentrations in Derwent estuary seafood 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 & Eustace (1973a; 1973b), Ratkowsky et al. (1974), Bloom (1975), and Dineen & Noller (1995). All of these 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 have been reviewed in previous State of the Derwent reports, while more recent studies are discussed here.

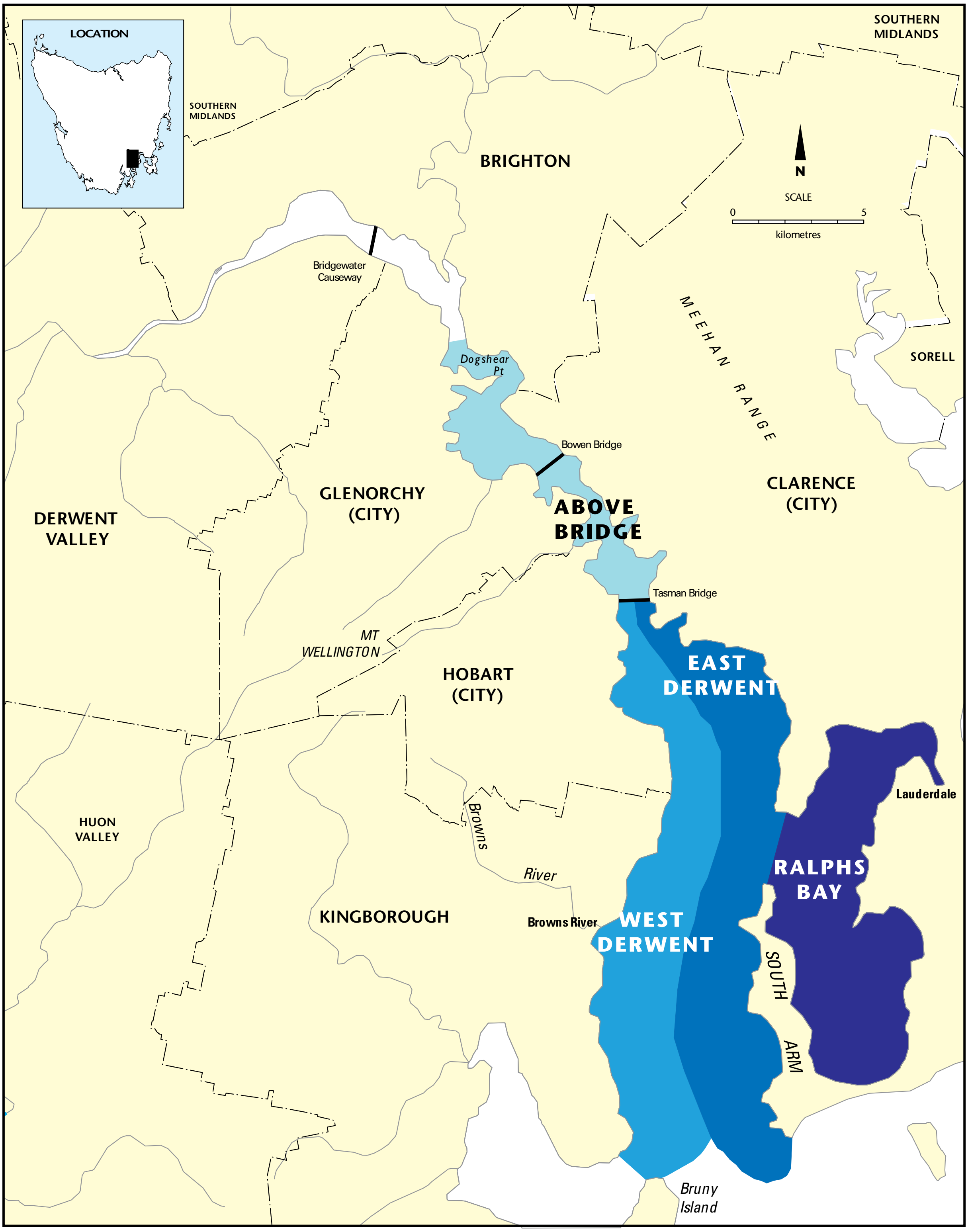
The most comprehensive and continuous seafood monitoring program in the Derwent has been carried out by current and previous operators of the Hobart zinc smelter. This program has monitored mercury levels in flathead since 1984, and heavy metal levels in oysters and mussels since 1992. In addition, caged oyster experiments have been carried out annually since 2004 to evaluate uptake rates of heavy metals in different regions of the Derwent.

Table 8.1. National food guidelines for heavy metal levels in seafood (FSANZ, 2002)

	Maximum levels (mg/kg)				Generally Expected Levels (median/90 percentile) (mg/kg)	
	As (inorganic)	Cd	Hg	Pb	Cu	Zn
Fish	2	no set limit	0.5 for most fish (1.0 for sharks and other specified fish)	0.5	0.5 / 2	5 / 15
Molluscs	1	2	0.5*	2	3 / 30	130 / 290
Crustacea	2	no set limit	0.5*	no set limit	10 / 20	25 /40

*Note: GELs are from the FSANZ Standard 1.4.1 Amendment dated February 2013; where * represents a mean value from the minimum number of fish required to be sampled*

Figure 8.1 Derwent estuary flathead and shellfish sampling regions and sites



8.3.1 Mercury levels in flathead

Flathead (*Platycephalus bassensis*) are considered to be a good bio-indicator 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 and previous managers of the zinc smelter site. Sampling of flathead is conducted in the period from August to November every year to minimise potential seasonal variations in hydrology and life cycles.

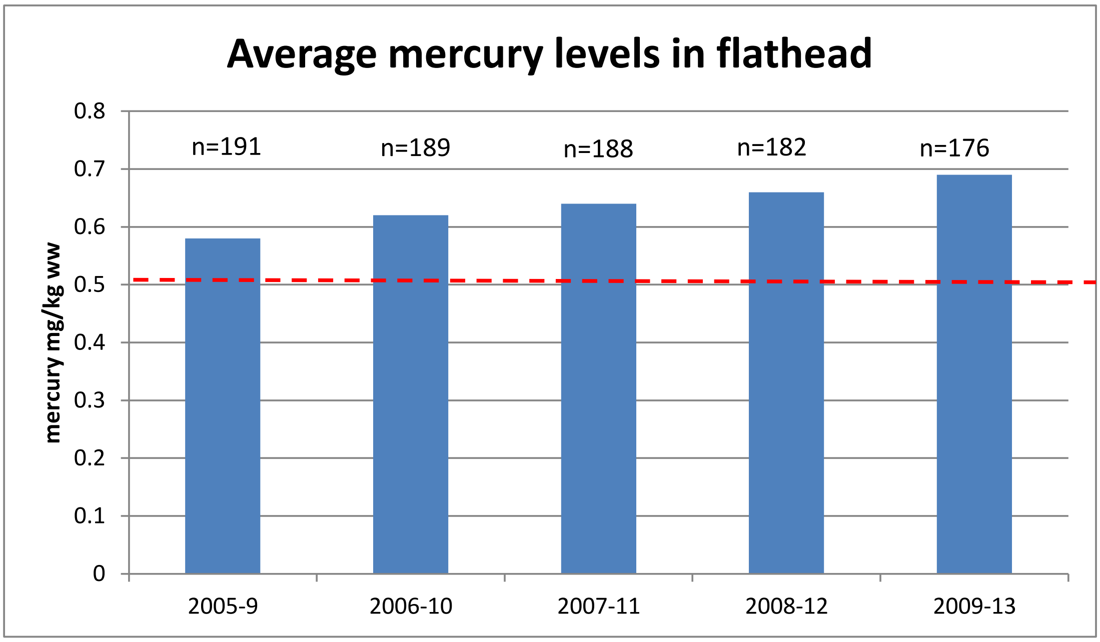
The monitoring program divides the estuary into four regions, as illustrated in Figure 8.1:

i) upstream of the Tasman Bridge
ii) eastern shore
iii) western shore
iv) Ralphs Bay

Additional sampling is also undertaken for background comparison in the D'Entrecasteaux Channel (Mickeys Bay). Twenty flathead are caught by handline within each region and analysed for total mercury. A range of different fish sizes is targeted to allow for an assessment of size versus mercury concentration; typically about 30–40 of the fish in a given year are of legal size (i.e. ≥ 300 mm in length). The discussion below is based on mercury levels in legal-sized fish only.

Mercury levels in flathead for the estuary as a whole are presented in Figure 8.2 for the period from 2009 through 2013. Results are presented here as rolling five year averages, as the number of legal sized (>300 mm length) fish in a given year can be relatively small, and there is considerable interannual variability. Monitoring data indicate that average mercury levels in legal-sized flathead are above the recommended FSANZ guideline of 0.5 mg/kg for the estuary as a whole, with higher levels in the Ralphs Bay sampling area and lower levels along the western shore (Figure 8.3). Average mercury levels at the control site (0.23 mg/kg) were well below the guideline. For the Derwent as a whole, the 5-year rolling median (2009 to 2013) was 0.67 mg/kg, with 77% of legal-sized flathead above the guideline. This value has been used in developing public health advice to recreational fishermen, presented in Section 8.6. While Figures 8.2 and 8.3 suggest an increasing trend in mercury

Figure 8.2. Mean mercury levels in Derwent estuary legal sized flathead (5-year rolling average) as compared to FSANZ guidelines (dashed red line)



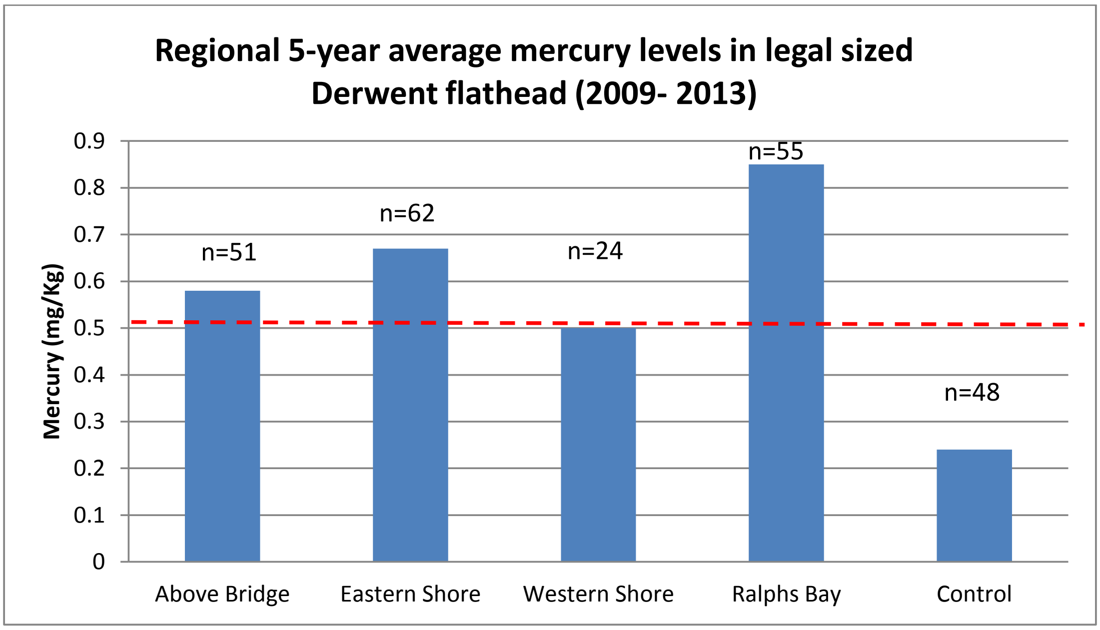
concentrations and considerable variability between regions, these results need to be considered in the context of fish biometrics (e.g. size and age) and sampling design, as discussed in the following section. It should be noted that the data summarised in this section and the associated figures is based on legal-sized fish only (i.e. greater than 300 mm), while the analyses by Jones (2013) are based on a wider population distribution, including a large proportion of <300 mm fish.

Temporal trends and regional variations in mercury concentrations in Derwent flathead have recently been investigated as part of a PhD study at IMAS (Jones, 2013; Jones et al., 2013), with interesting results. A detailed analysis of the full 37-year data set using linear and polynomial models found no statistically significant decline in mercury levels in any region of the estuary, as illustrated in Figure 8.4, with previously reported declines (Langlois et al., 1987) attributed to analysis of a shorter-term data set. Strong curvilinear relationships between fish length, fish age (derived from otoliths) and mercury concentrations were established for each region. Analyses of fish length-to-age ratios demonstrated significant differences in growth rates between different regions of the estuary, with the highest growth rates observed in Ralphs Bay, and lowest rates on the western shore. When mercury levels were corrected to a standardised fish length (300 mm), there were again no significant trends over time within the different regions (see Figure 8.5).

While mercury levels in Ralphs Bay flathead were higher than other Derwent estuary regions, this was attributed in large part to their greater size and faster growth rates. It was also determined that flathead size only explained about 50% of the observed mercury concentration fluctuations in a given year, indicating that other factors also play an important role. These may include:

- Feeding differences between flathead in different regions;
- Water temperature differences (e.g. warmer water in Ralphs Bay may increase growth rates);
- Spatial and temporal differences in mercury methylation and bioavailability;
- Possible bias resulting from sampling design (e.g.

Figure 8.3. Average mercury concentrations in legal sized Derwent flathead by region, as compared to control site (Mickeys Bay/D'Entrecasteaux Channel) and FSANZ guidelines (dashed red line)



number and location of sampling sites within each region);

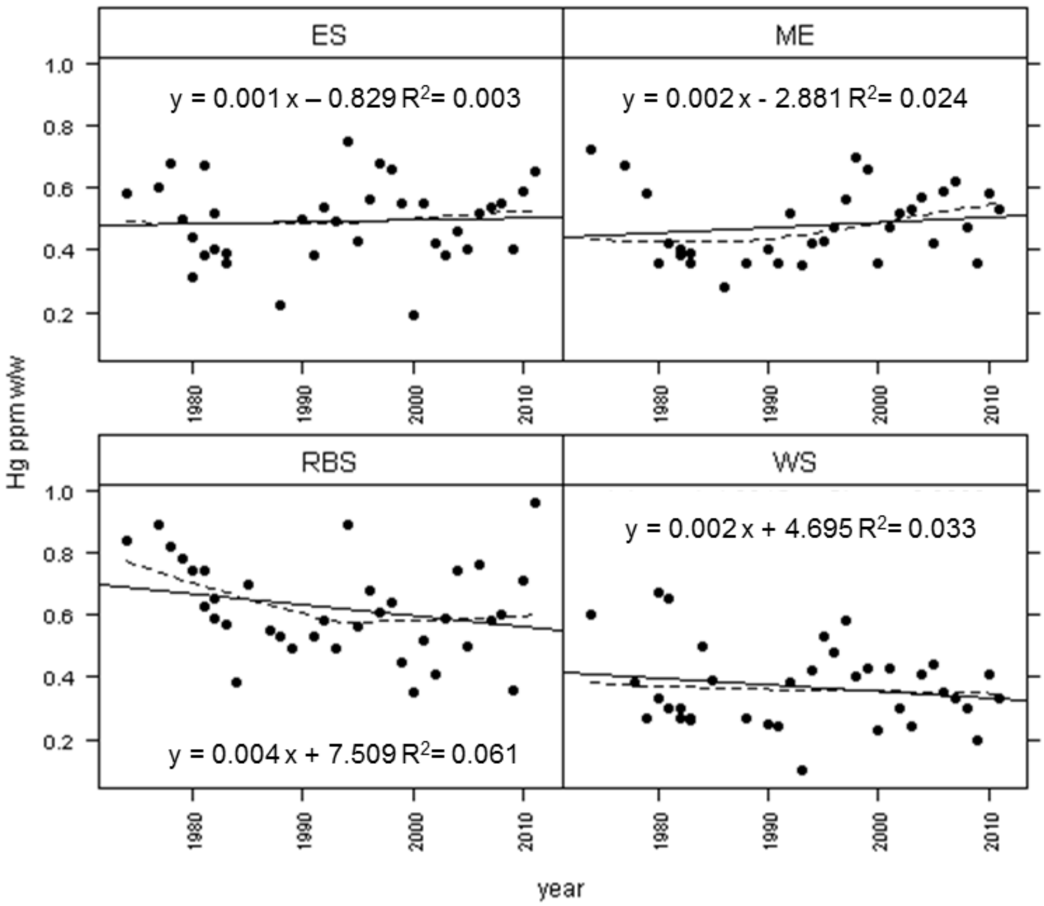
- Differential fishing pressures between regions.

Jones 2013 recommended that the flathead monitoring program continue and that it be supplemented by the collection of biometric data on the fish sampled, principally fish age and growth rate, to improve data reliability for future trend analysis.

In summary, Jones (2013) demonstrated that there has not been a significant decline in flathead mercury concentrations over the past 30 years, despite a reduction in inputs. This is atypical of other studies, where mercury levels have declined over shorter time frames, but is similar to the situation in San Francisco Bay (Greenfield et al., 2005). These results suggest that mercury within the system continues to be biologically available, probably associated with contaminated sediments. Given that methylation of mercury in sediments can continue for extended periods, it is important to understand current spatial and temporal methylation processes and how system changes could affect these. Further study is required to determine the methylation/demethylation rates

Figure 8.4 Mean Hg concentration in sand flathead muscle tissue in four Derwent regions from 1974–2011

Solid line = linear regression with intercept and slope and regression coefficient (R2); dotted line = LOESS (locally weighted polynomial regression) smoothed fit (source: Jones, 2013). ES = eastern shore; ME = mid estuary; RBS = Ralphs Bay south; WS = western shore



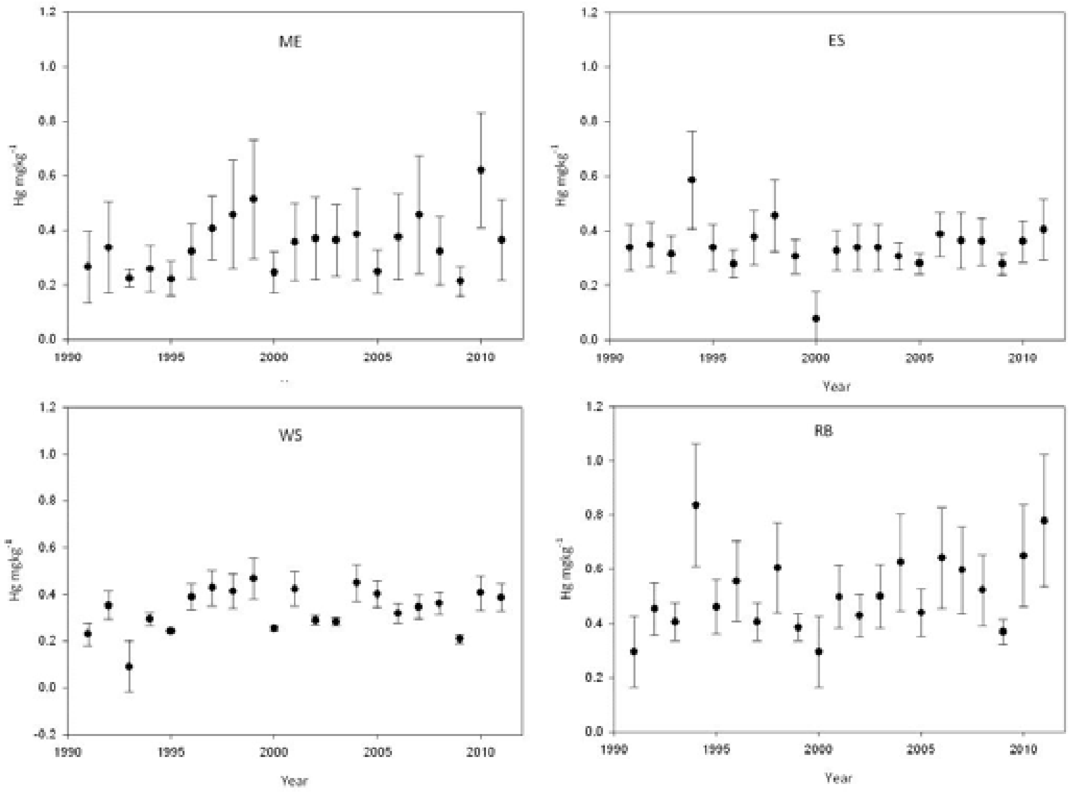
and the proportional representation of mercury species in sediment of the Derwent estuary, as well as clarifying the interrelationships between mercury and other elements, such as selenium, in sediments (Jones et al., 2013; 2014).

The presence of selenium in mercury contaminated environments may play a key role in mitigating mercury accumulation and provides significant protection against the toxicity of methylmercury in fish flesh, however selenium is not currently reflected in the food safety guidelines (Yang et al., 2008). Current research recommends considering the health benefits of selenium in seafood, and Jones (2013) found evidence in Derwent flathead data to recommend that a single value representing the selenium health benefit may not be appropriate for species with a limited range. Rather, the ratio of selenium: mercury and the Selenium Health Benefit Value would be the most appropriate method of assessing the health risk associated with mercury exposure from fish consumption and that this should be determined based on assessment at small spatial scales (Jones 2013).

8.3.2 Mercury levels in other recreationally-targeted fish

In 2007–08, heavy metals in a variety of recreationally-targeted fish from the Derwent estuary were investigated in a University of Tasmania Honour's project by Verdouw (2008). This study measured levels of mercury and other metals 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*).

Figure 8.5 Muscle Hg concentration with 95% probability threshold for sand flathead of standardised fish length (300 mm) from 4 Derwent regions over 21-year sample period (1991–2011). Vertical lines represent the confidence interval (95%) around the estimated mean level; overlap of confidence intervals suggests a lack of temporal change in Hg concentrations across this period (source: Jones, 2013)

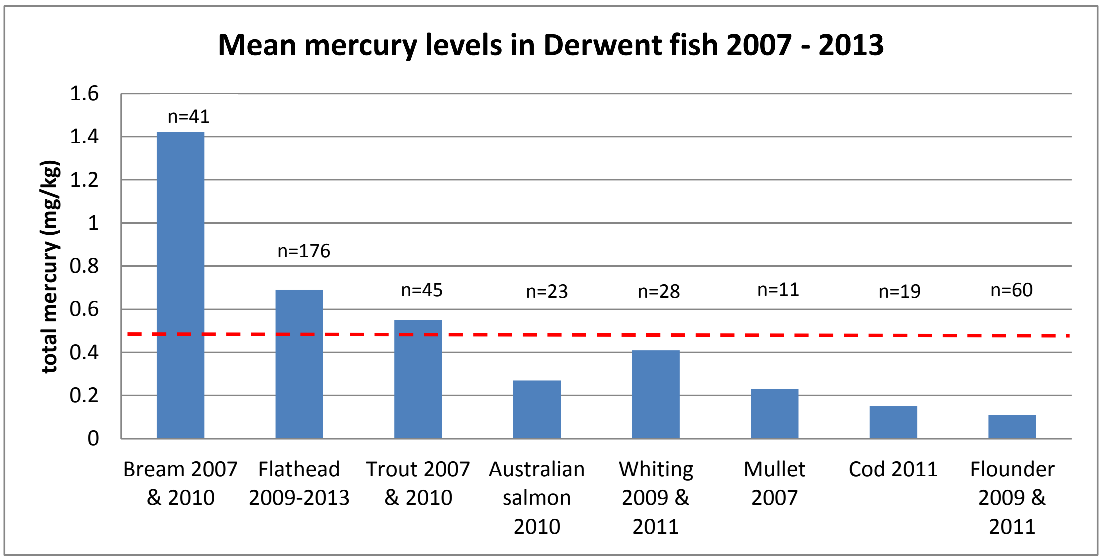


The effects of diet, age, length, gender and region on metal levels were examined for each species and levels were compared to Australian food standards to examine potential human health risks. Mean mercury levels in the muscle tissue of black bream (1.57 mg/kg), sea-run trout (0.68 mg/kg) and sand flathead (0.53 mg/kg) exceeded the maximum permitted level of 0.5 mg/kg for mercury in seafood as prescribed by FSANZ, while mean mercury levels in mullet (0.23 mg/kg) were well below. Mean levels for all other metals were below the FSANZ guidelines for all species and therefore pose little threat to human health. Diet and age were found to have the largest influence on mercury levels, with the particularly high levels in bream attributed to their diet (bottom feeders, including mussels) and age (bream can live for more than 20 years). These results were used as the basis for a precautionary health advisory by the Tasmanian Director of Public Health, until more extensive surveys were carried out.

In 2010 and 2011, the DEP extended this pilot study, incorporating further analyses of mercury in black bream, trout, Australian salmon, whiting, cod and flounder over a wider area. Much of this work was supported by an Australian Government *Caring for our Country* grant in collaboration with the University of Tasmania/IMAS, Nyrstar Hobart Smelter, DHHS, Inland Fisheries Service, Fishcare and TARfish. Average mercury levels in bream were again found to be significantly higher than other species, followed by flathead and trout both of which were close to or above the 0.5 mg/kg FSANZ guidelines. Other species were generally below this level, as indicated in Figure 8.6. Some reductions in mercury levels were noted in bream and trout samples analysed between 2007 and 2010 (Figure 8.7), however given the relatively small sample size, the results for these two sample sets were combined for the purpose of public health advice. Mercury levels in bream from Browns River were also lower than fish from the upper estuary, but given the relatively small sample size (n=18) and the tendency for

Figure 8.6. Mean mercury concentrations(mg/kg) for recreationally-targeted fish collected from the Derwent estuary during the period 2006 to 2011 (legal-sized fish only) as compared to FSANZ guidelines (dotted red line). Data compiled from Verduow (2007), DEP, Nyrstar and Low (2011). Notes:

- Bream data from upper and mid-Derwent only (not Browns River)
- Flathead data from all areas
- Trout data from upper and mid-Derwent
- Australian salmon data from mid- and lower estuary
- Whiting data from lower estuary
- Mullet data from Rose Bay only
- Flounder data from Ralphs Bay only



bream to migrate within the estuary, consumption of bream from Browns River is not recommended.

More recently, in 2010–11, a University of Tasmania Honour's project further investigated heavy metal levels in greenback flounder collected from three sites in Ralphs Bay, as compared to a control site at Pipeclay Lagoon (Lo, 2011). Results for larger sized flounder showed that mean values for all metals were below FSANZ guidelines, with an average mercury concentration of 0.12 for flounder collected in Ralphs Bay (49 samples). Total arsenic levels were found to be slightly above FSANZ guidelines in 18% of samples, however, given that inorganic arsenic (the toxic component) is typically about 10% of total arsenic, this is unlikely to present a health concern.

Results for all mercury analyses on fish collected between 2007 and 2013 are presented in Figure 8.6. In interpreting this data, it is important to keep in mind the relatively small sample sizes for some species and that fish size and age were not been considered in this study. Mercury levels in fish generally increase with size, age and trophic level.

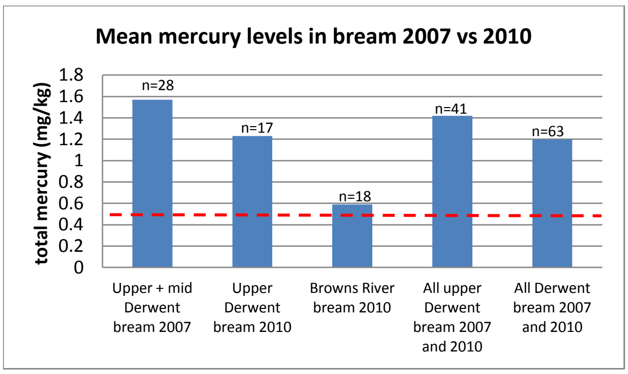
8.4 Heavy metals in Derwent estuary shellfish

Shellfish are often used as good indicators of heavy metal pollution because they are sedentary filter feeders and readily accumulate heavy metals. The two shellfish types tested in the estuary – oysters and mussels – exhibit different responses to heavy metal uptake. Oysters (*Crassostrea gigas*) accumulate zinc and copper to a higher degree than mussels (*Mytilus edulis*), while mussels preferentially accumulate lead. Two long-term shellfish monitoring programs are carried out in the Derwent, one focusing on metal levels in wild-growing oysters and mussels throughout the estuary, and the other using caged oysters, deployed at specific sites for a set period of time. Sample locations for both surveys are shown in Figure 8.1.

8.4.1 Wild oyster and mussel surveys

Routine surveys of heavy metal levels in wild growing Derwent estuary oysters and mussels have been carried out since 1991 by Nyrstar Hobart and the previous managers of the smelter site. Surveys were done annually from 1991 to 2002, and every three years since 2002. Oysters and mussels samples are collected from about 20 established sites throughout the estuary and analysed for zinc, cadmium, copper, mercury and lead. A control site is also monitored outside of the estuary (Mickeys Bay, D'Entrecasteaux Channel) to provide a basis for comparison. Median heavy metal levels for oysters and mussels have been calculated

Figure 8.7. Comparison of mercury levels in bream and trout collected in different sampling programs and regions as compared to FSANZ guidelines (dotted red line)



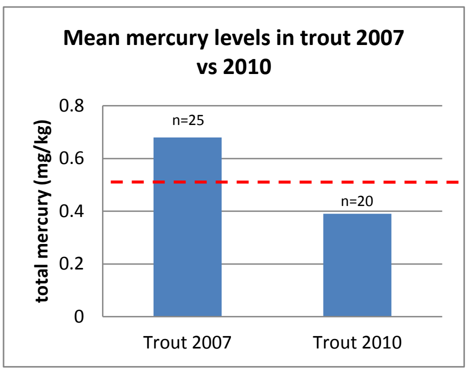


Table 8.2. Median metals levels in Derwent estuary shellfish (2002–11) in mg/kg ww

	Cadmium	Mercury	Lead	Copper	Zinc
Oysters (n=81)	1.8	0.11	2.1	54	2910
Mussels (n=84)	1.1	0.08	9.6	0.9	46
FSANZ Guidelines		*Maximum levels*		*Generally Expected Levels*	
	2	0.5	2	3	130

for the estuary as a whole based on data from the past four surveys (2002, 2005, 2008, 2011), and are summarised in Table 8.2. As indicated, lead levels in Derwent mussels are well over the FSANZ guidelines, as are copper and zinc levels in oysters.

Median lead concentrations observed in mussels over the past four surveys within the different regions of the Derwent are illustrated in Figure 8.8, as compared to the control site and FSANZ guideline. Lead levels are generally highest in the area above the Tasman Bridge followed by Ralphs Bay. Lead levels were considerably higher in mussels than in oysters, as has previously been observed.

Figure 8.9 illustrates regional differences in cadmium, copper, lead and zinc levels in Derwent estuary oysters for the past four surveys, as compared to background levels and FSANZ limits. As in previous surveys, median zinc levels remain well above the generally expected levels (GELs) of 130 mg/kg throughout the estuary – particularly in the area above the Tasman Bridge. However, even the control site had zinc levels above the GELs, suggesting this value may not be appropriate for Tasmanian waters. Similarly, copper levels are also well above the GELs of 3 mg/kg throughout the estuary (and the control site). 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. There are some indications of a declining trend in some heavy metal levels in oysters in a few regions, particularly above the Tasman Bridge and Ralphs Bay. Median mercury levels in oysters from all areas were well below the FSANZ guidelines.

Figure 8.8 Median lead levels in Derwent wild mussels observed in the past four surveys, by region, as compared to Channel control site and FSANZ guideline (red dashed line)

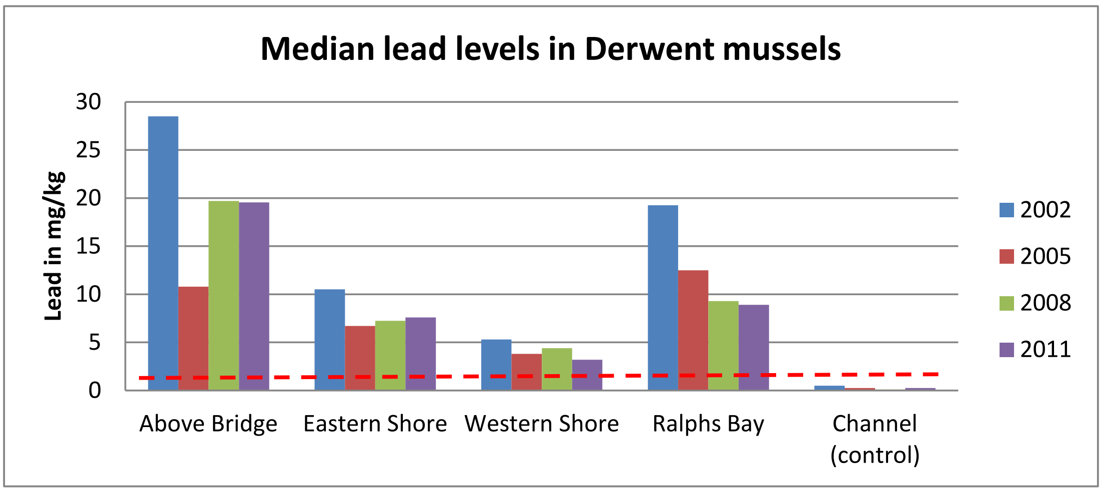
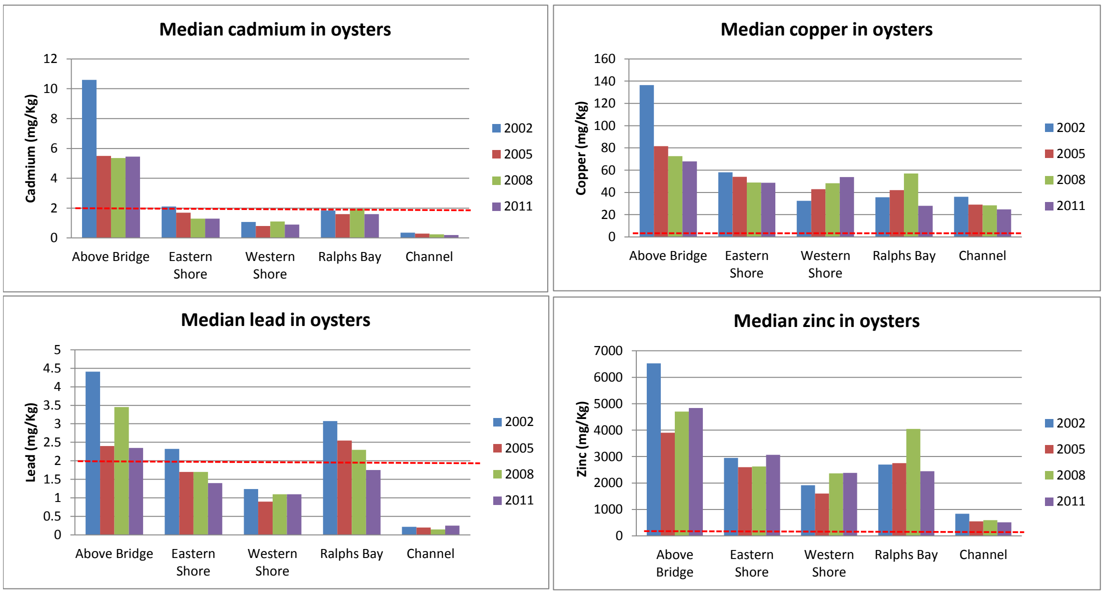


Figure 8.9. Cadmium, copper, lead and zinc levels in Derwent wild oysters (2002 to 2011)
Red dashed line = FSANZ guideline for Cd and Pb, and general expected level for Cu and Zn



8.4.2 Heavy metals in caged oysters

Nyrstar has conducted 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 (see Figure 8.1), with a focus on the middle estuary. The aim of the deployment exercise 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 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 subtidally as close to the seafloor as possible. After six weeks, the oysters from each site are retrieved, 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 experiments have been trialled over the years, including staged oyster retrieval, deployment of cages at different depths and analyses of individuals to assess

Table 8.3. Metals in oysters deployed on the Derwent seafloor (2009 through 2013)

	Cadmium	Mercury	Lead	Copper	Zinc
Heavy metal levels in oysters pre-deployment (baseline levels)					
Median	0.2	0.02	0.2	6.4	101
Heavy metal levels in oysters after 6 weeks (n=44)					
Median	0.7	0.04	3.0	14	493
Oysters deployed 6 weeks minus baseline levels					
Median	0.45	0.02	2.4	6.7	313
FSANZ Guidelines		***Maximum levels***		***Generally Expected Levels***	
	2	***0.5***	***2***	***3***	***130***

variability (see Nyrstar EMP Reviews for further details). Table 8.3 provides a summary of results of annual deployed oyster experiments over the five year period from 2009–13.

As illustrated in Figure 8.10, the caged oyster experiments carried out since 2009 indicate that within six weeks, clean oysters deployed at mid-estuary sites are able to accumulate levels of zinc, copper and lead in excess of FSANZ guidelines. Copper levels were above FSANZ guidelines in virtually all samples, including baseline and control sites, suggesting that the 3 mg/kg GEL may not be appropriate for southern Tasmanian conditions. Uptake patterns for zinc and cadmium are very similar with a progressive decrease in levels with distance from Nyrstar, while uptake of copper and lead seems to be more broadly distributed. There is a high degree of variability from year to year, suggesting that broader environmental conditions within the estuary play an important role.

There is also considerable interannual and spatial variability in metal uptake with water depth, between deployments at near-surface, middle and bottom. At the Nyrstar wharf site for example, oysters in surface waters tend to accumulate more zinc and cadmium, while those at depth accumulate more copper, lead and mercury. The Elwick Bay site showed little difference in accumulation rates at different depths, while Beltana Point showed increased uptake of zinc and cadmium in surface water but little variation in other metals.

8.4.3 Heavy metals in other species and food-web pathways

Since 2009, several investigations of heavy metals in other species and their implications for food-web pathways have been undertaken, including studies of metal levels in algae, invertebrates and birds.

Figure 8.10 Heavy metal concentrations in oysters following 6-week deployment (2009–13)

University of Tasmania Honour's student Jess Miller (2010) assessed three algal morphotypes (green, red, brown) at three sites in the Derwent and two in the Channel/Huon region to evaluate their potential as bioindicators for metal pollution. She observed a gradient of decreasing metal concentrations with distance from the zinc smelter site, and identified green foliose macroalgae such as Ulva spp as the best overall bioindicators. She also investigated the bioremediation potential of Ulva to uptake metals, with a particular focus on copper.

Jones (2013) investigated mercury, selenium and stable isotopes in flathead and their prey to determine how mercury and selenium biomagnify through estuarine foodwebs. Samples of flathead and their prey (based on stomach contents) were analysed from two sites in the Derwent (mid estuary and Ralphs Bay) and a control site in the Channel (Mickeys Bay) for total and methylmercury, selenium and carbon and nitrogen isotopes. Nearly all of the mercury measured in flathead was found to be in methylated form, and crustaceans made up over 80% of the flatheads' diet. The study found that food web differences can have a significant effect on biomagnifications of mercury within benthic fish (see Jones, 2013; and Jones et al., 2014).

In 2014, the DEP commenced a study of heavy metal concentrations in bird feathers, which have been shown to be good indicators of environmental contamination. The study targeted eight different bird species, including swans, ducks, oystercatchers, little penguins, cormorants and sea eagles. Samples were analysed for a broad range of metals plus stable isotopes. Preliminary results suggest elevated mercury levels in cormorants and eagles, and low levels in swans and ducks.

These investigations, together with previous studies (see for example Hunt, 2008; Swadling and Macleod, 2008) highlight the importance of research into the bioavailability of heavy metals and the food-web pathways through which 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. Furthermore, there is an ongoing health advisory against the harvesting or consumption of any wild shellfish from the Derwent estuary (see Section 8.6).

8.5.2 Organic contaminants

There have been no recent surveys of organic contaminants in biota from the Derwent. Previous surveys have included:

- A pilot survey in 2001 which analysed a selection of fish and shellfish (flathead, bream, trout, mullet, oysters and mussels) for PCBs and organochlorine pesticides (such as DDD, DDE & 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 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). Levels of dioxins in the Derwent samples were moderate to low, compared to samples from other urbanised estuaries around Australia.

8.6 Public health advice

The information discussed in the previous sections has been used as the basis for public health advice issued by the Director of Public Health. Recommended consumption limits for fish are based on mercury and were calculated using the FSANZ method as set out in on the Food Standards website (www.foodstandards.gov.au/scienceandeducation/factsheets/factsheets2004/mercuryinfish). Based on this information, the following seafood safety advice has been issued by the Director of Public Health regarding the human consumption of seafood from the Derwent estuary. This information has also been incorporated into signage and regular media releases to improve public awareness of this issue.

Do not consume shellfish caught from the Derwent estuary, including Ralphs Bay.

Do not consume black bream caught from the Derwent estuary, including Browns River

Limit consumption of other Derwent-caught fish as follows:

- Fish from the Derwent should not be eaten more than TWICE a week.
- Some people should further limit their consumption to no more than ONCE a week.
    - Pregnant and breastfeeding women
    - Women who are planning to become pregnant
    - Children aged six years and younger

8.7 Discussion and recommendations

As discussed in Section 4, mercury and other heavy metals historically discharged to the Derwent have been derived from multiple 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 zinc smelter site, which is undergoing further remediation (see Section 4.2.1). The significant reductions in heavy metal loads discharged to the estuary are not yet 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;
- Estuarine chemistry such as sediment remobilisation, acid volatile sulphide levels, and organic components.

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

- Review and refine the biota monitoring program at Nyrstar, including collection of biometric data;
- Resurvey mercury levels in wider range of recreationally targeted seafood every 5 to 10 years;
- Further investigate the role of selenium, both with respect to mercury uptake and human health implications;
- Investigate sediment sources of mercury and how methylation rates could potentially be minimised.

9.0 ESTUARINE HABITATS AND SPECIES

The natural character and human values of the Derwent estuary are ultimately underpinned by the condition of its estuarine habitats and their associated flora and fauna. The estuary contains a wonderful diversity of habitats, including sandy beaches, wetlands, seagrasses, rocky reefs and tidal flats. These habitats in turn support thousands of different species of flora and fauna, ranging in size from microscopic phytoplankton to whales. Several species, such as the spotted handfish, are found nowhere else.

9.1 Derwent estuary habitats

The Derwent estuary supports a wide variety of habitat types in both subtidal and intertidal environments, as listed in Table 9.1. Of these, unvegetated subtidal sand and silts are the most abundant habitat type, occupying over 86% of the estuary area. Next most abundant are aquatic macrophytes (6.6%, primarily in the upper estuary), followed by intertidal sands (5.8%, mostly in Ralphs Bay). Other habitats (wetlands, saltmarshes, seagrasses, kelp forests, reefs and rocky shores) occupy the remaining 1.5% of the estuary area and, while collectively small in area, are critical for sustaining many species found within the estuary. These different habitats types are discussed in more detail in the following sections, as is the fringing coastal vegetation that borders much of the estuary.

Information on estuarine habitats and their distribution has previously been compiled by the DEP into a GIS-based Derwent Estuary Habitat Atlas. The major estuarine habitat types in the upper, middle and lower estuary are illustrated in Figures 9.1–9.3. These maps, together with additional information about each habitat, are available on the DEP website (Derwent Habitat and Species section). The habitat maps were created using data from Lucieer et al. (2007), DPIPWE and North Barker (2008).

There has been extensive pressure on these habitats from urban and industrial development, climate change, and changes in catchment use and River Derwent flow. These pressures have contributed to the deposition of silt and organic matter 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. This is particularly so 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. There are, however, significant areas of habitat remaining within the Derwent estuary that supports healthy functioning ecosystems, with abundant and diverse populations of native species, as described below.

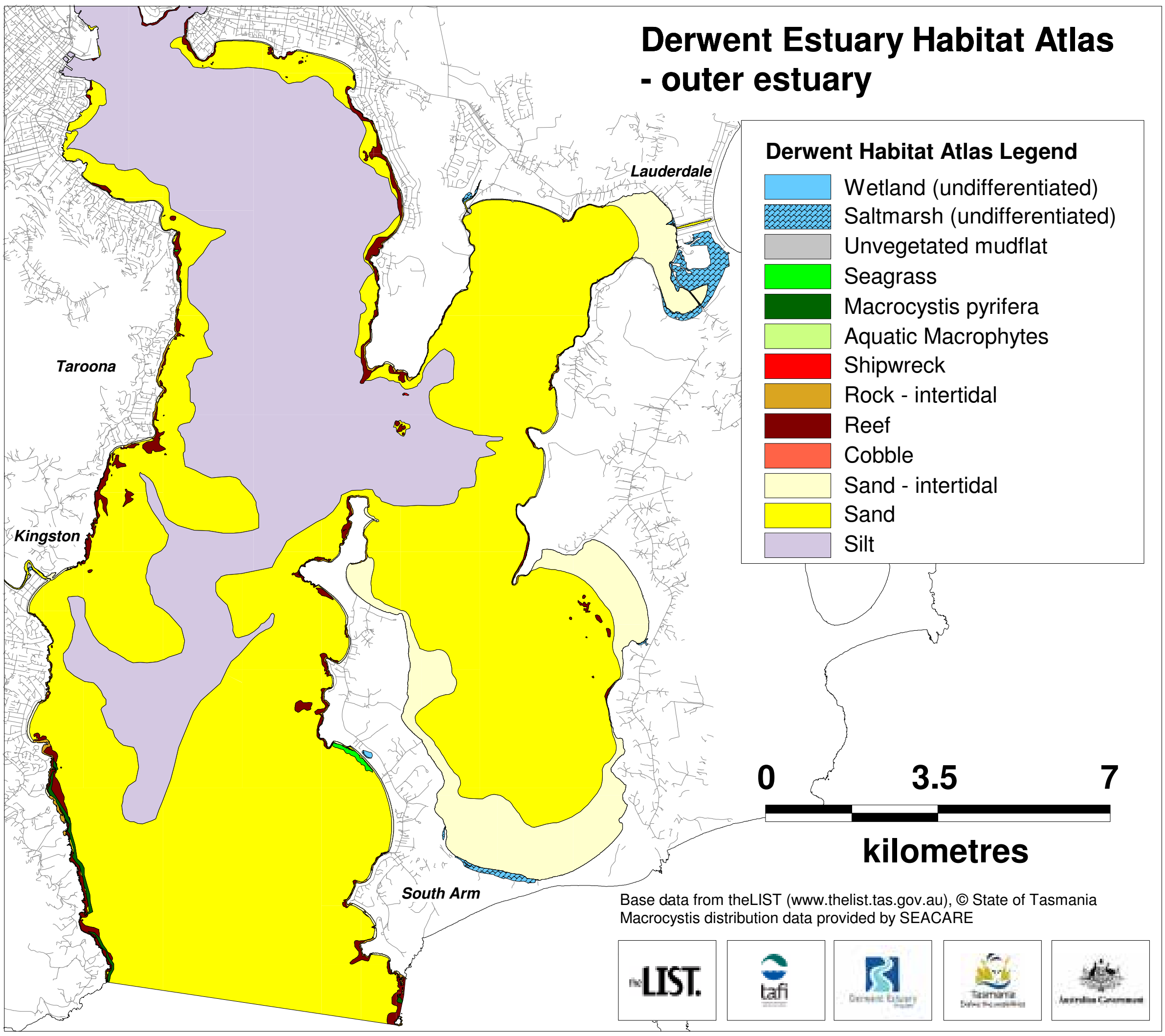
Table 9.1 Summary of habitats in the Derwent estuary

Habitat	Area (km^2)	Percent
Subtidal	***174.0***	***88%***
Sand	93.0	47%
Silt	77.6	39%
Rocky reef	3.0	1.5%
Cobble Reef	0.3	0.1%
Kelp forest	0.3	0.1%
Seagrass	0.2	0.1%
Shallow subtidal to intertidal	***6.6***	***3.3%***
Aquatic macrophytes	6.6	3.3%
Intertidal	***13.2***	***6.7%***
Intertidal sand (sand flat / beach)	11.4	5.8%
Unvegetated mud flat	1.0	0.5%
Rocky shorelines	0.9	0.5%
Intertidal to supratidal	***3.5***	***1.8%***
Saltmarsh	2.2	1.1%
Wetland	1.3	0.7%
TOTAL AREA OF ESTUARY	**198**	

9.1.1 Subtidal soft sediments

Subtidal sands and silts are the dominant habitat types in the Derwent estuary. Sand predominates at shallower depths, covering 93 km^2 (47%) of the estuary, while silt predominates in deeper areas, covering 78 km^2 (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 Sullivans 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

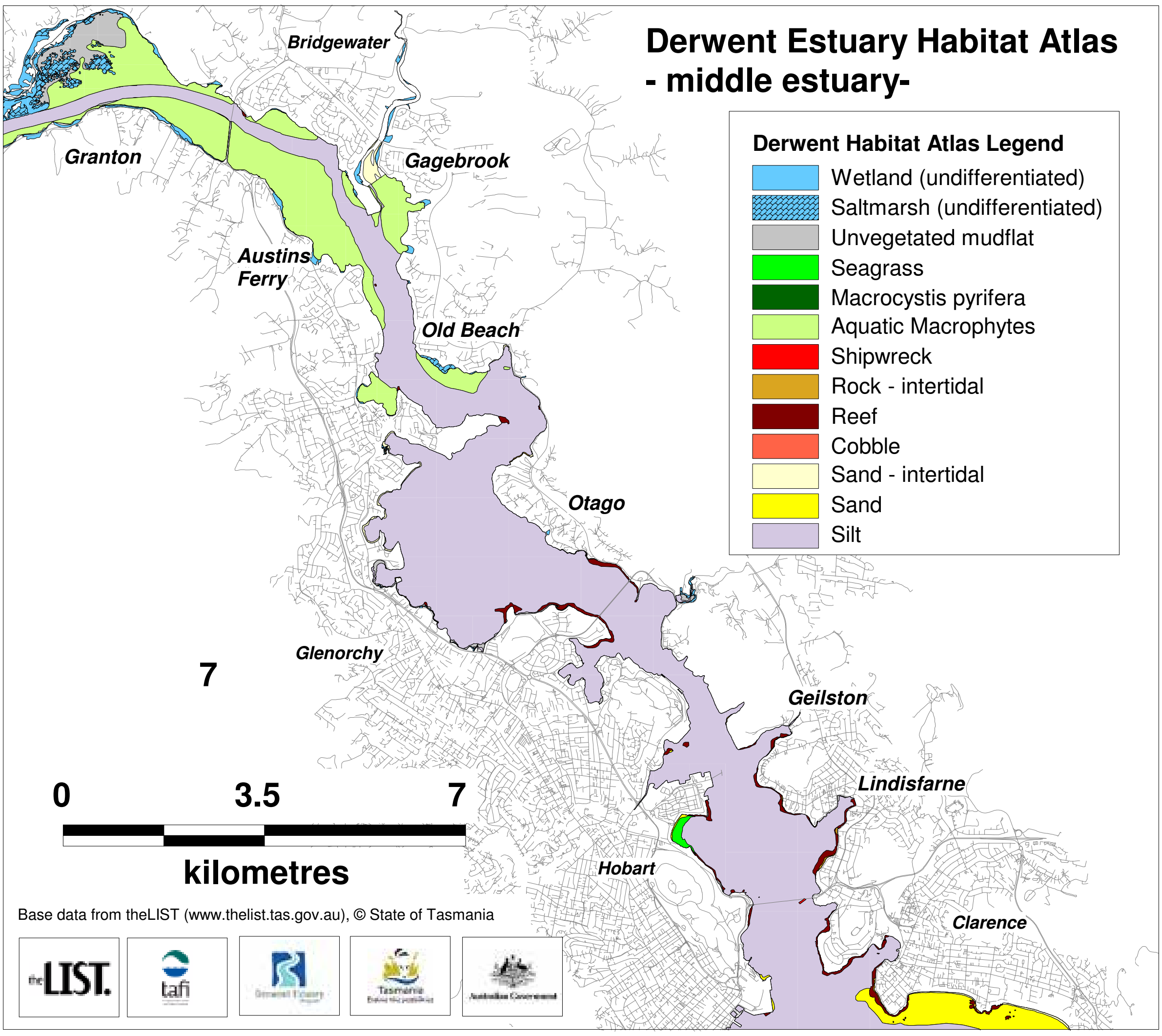
Figure 9.1 Distribution of habitat types in the lower reaches of the Derwent estuary



functions that maintain the overall health of the estuary, such as denitrification.

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 ecological values of these areas. These habitats have also been heavily impacted by historical discharges of heavy metals and organic matter. 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 matter, and mud (versus sand) concentrations and changes in benthic invertebrate species. 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.

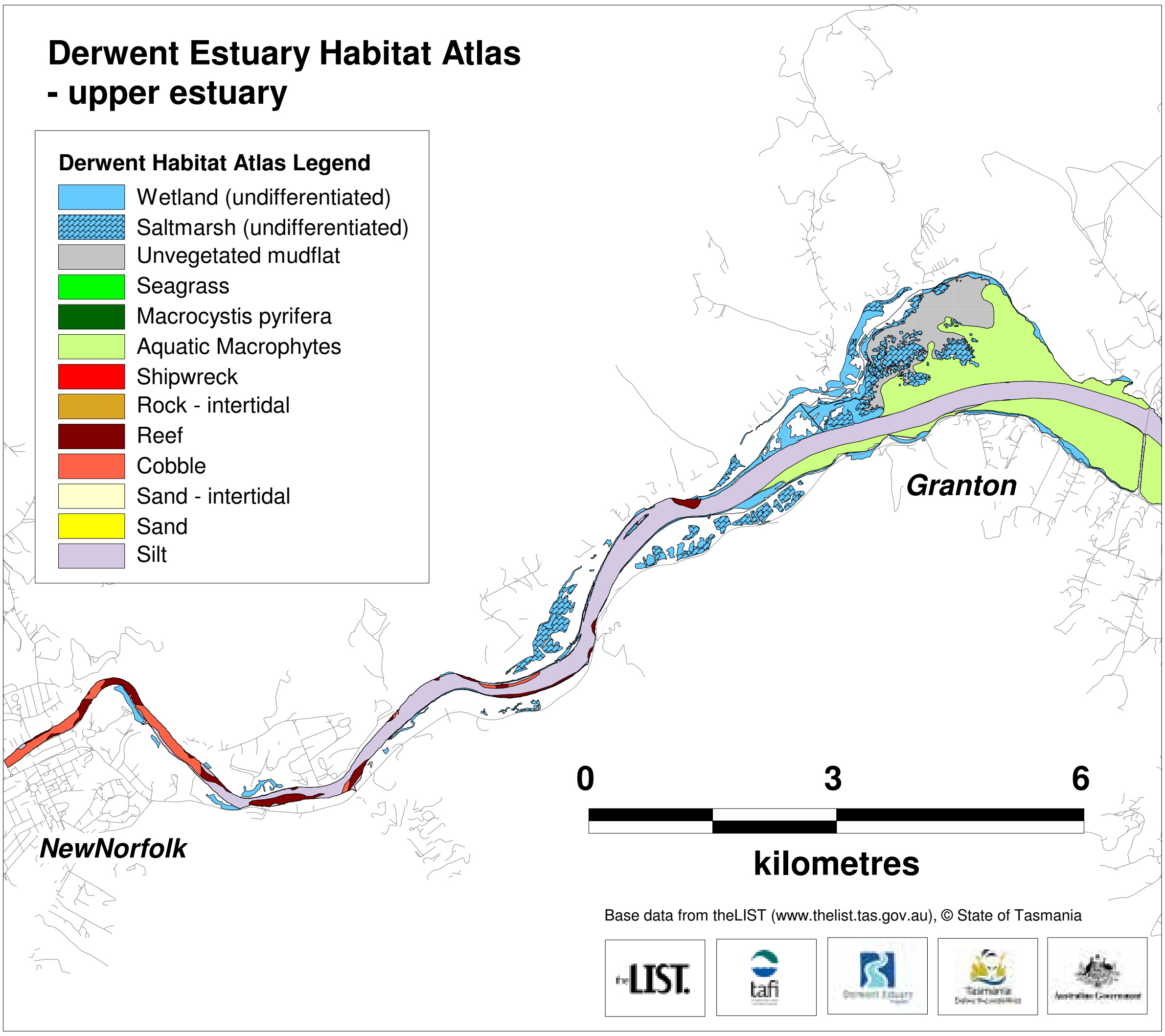
Figure 9.2 Distribution of habitat types in the middle reaches of the Derwent estuary



Overfishing during the past century has altered the structure and biology of subtidal sedimentary habitats in the Derwent estuary, most notably the loss of previously abundant 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 that have modified this habitat into shelly gravel, as described by Macleod and Helidoniotis (2005).

There have been several recent studies of soft sediment habitats, including the DEP's 2011 sediment quality survey (Section 7), sediment process studies by Ross et al. (2013; section 10) and a comparative survey of macroinvertebrates in the Derwent & Huon estuaries by Macleod and Helidoniotis (2005).

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



9.1.2 Rocky reefs and macroalgal communities

Subtidal rocky reefs collectively cover about 3 km^2 (1.5%) of the estuary. Despite this relatively small area, rocky reefs 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, surrounded by soft sediments. In the middle estuary, rocky reefs are narrow extensions of the rocky shoreline (Lucieer et al., 2007). There have been several major surveys of Derwent estuary rocky reefs since 2009; one undertaken by Barrett et al. (2010) and a second by the Reef Life Survey Foundation, also in 2010.

Barrett et al. (2010) examined patterns of diversity and abundance of fish, invertebrates and algae on intertidal to subtidal rocky reefs and their adjacent sediments within the Derwent estuary. A total of 24 sites were surveyed along a gradient from Cadburys Point to Tinderbox (Figure 9.4), using two quantitative survey methods (standard belt transects and timed swims). The survey was primarily undertaken between February to April 2010. Both survey methods showed that fish, invertebrate and algal diversity generally increased from northern to southern sites within the estuary, in a pattern typical of estuarine diversity gradients. The timed swim surveys (which cover a wider range of depths and habitats) documented 74 species of fish, 147 species of macroinvertebrates and 46 species of brown and green algae. There was a clear break in biological assemblages between Rosny Point and Bellerive Bluff, with a change from silty, tubeworm-matting dominated reefs upstream, to reefs with increasing cover of encrusting corraline algae and encrusting sponges downstream. Introduced species were also more abundant at upstream sites, both with respect to mobile and sedentary invertebrate fauna, such as the piecrust crab, green shore crab and Pacific oyster. Several species of introduced algae were found at the more seaward sites, including *Undaria pinnatafida* between the Grange and Alum Cliffs. Despite thorough searching, none of the threatened Derwent river seastars Marginalis littoralis were found. Overall, this survey provides a comprehensive quantitative snapshot of the current distribution of much of the biodiversity associated with reef systems in the Derwent estuary, providing a robust baseline from which to measure and assess future change. This project was supported by the DEP, through an Australian Government Community Coastcare grant.

In addition to the work completed by Barrett et al. (2010), the Reef Life Survey Foundation monitored Derwent rocky reefs at an additional 30+ sites during the summer of 2009–10. This work is being written up by PhD student Amelia Fowles at IMAS/University of Tasmania. Similar surveys were carried by Reef Life Survey in Port Phillip Bay and Sydney Harbour, with comparative results soon to be published (Stuart-Smith et al., in press).

In 2012, as part of a PhD dissertation on rare marine algal species endemic to southern Australia, Fiona Scott discovered a new family and probable new order of marine algae in the Derwent estuary off Blackmans Bay. This new species of red algae (*Entwisleia bella* gen. et sp. nov) is an exciting first for the Derwent (see Scott, 2012 for details).

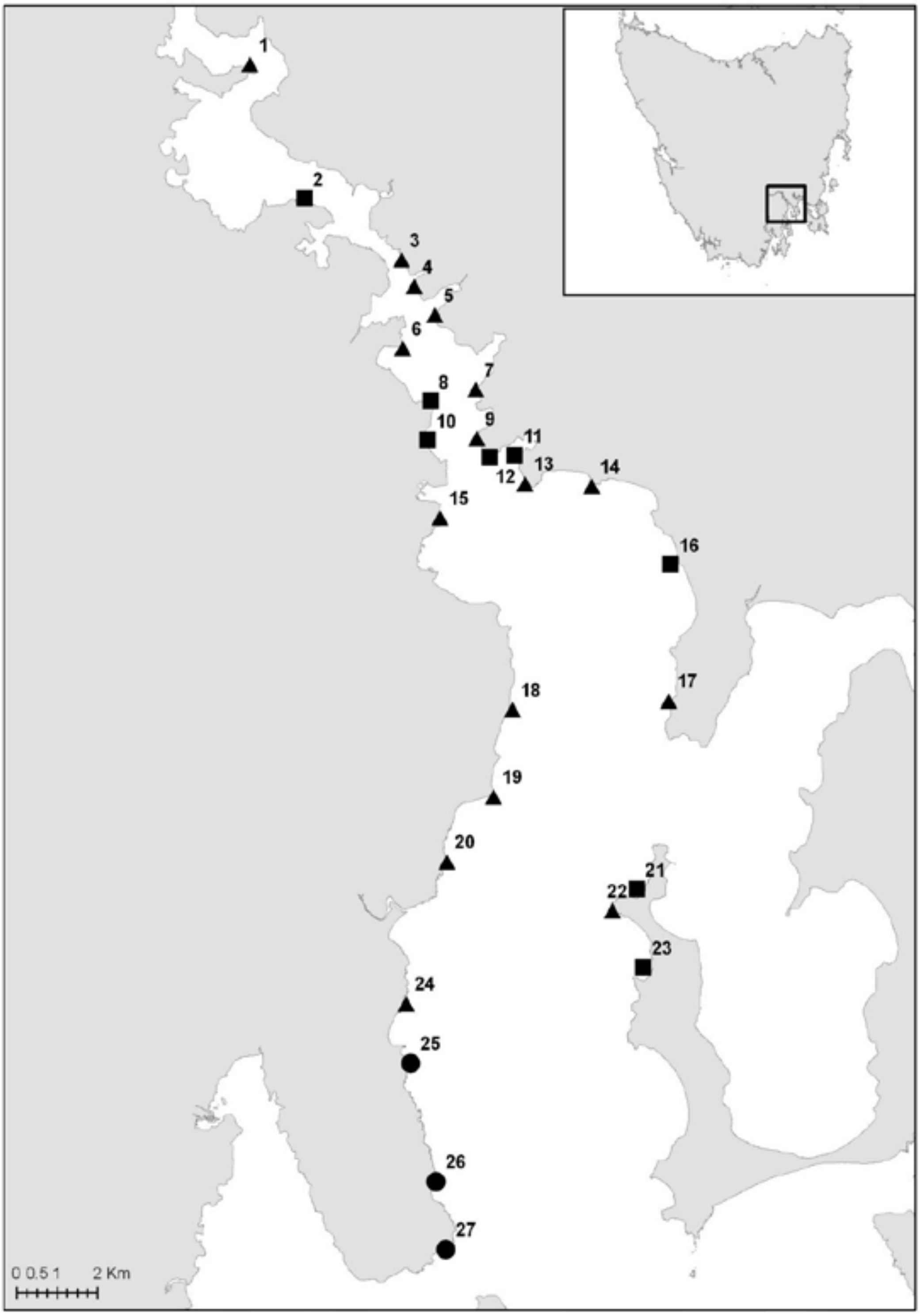
Several areas of the lower Derwent, between Blackmans Bay and the Tinderbox Peninsula, contain giant string kelp forests (*Macrocytis pyrifera*) with brown algae (*Lessonia corrugate*) as a dominant species in the understory (Jordan et al., 2001). Giant kelp often grows to lengths of 30 m or more and 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 km2 of the Derwent estuary (Sanderson, 2000). Declines in kelp beds have been reported since the 1950s, particularly along the estuary's eastern shore. 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. Giant kelp communities have been listed as endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) since August 2012.

9.1.3 Seagrasses and aquatic macrophytes

Seagrasses and aquatic macrophytes 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.

Seagrasses and macrophytes are flowering plants adapted for life submerged in water; seagrasses grow in marine or estuarine environments, while macrophytes are adapted to fresh or brackish water. The dominant seagrass species in the Derwent estuary is *Heterozostera nigricaulis* (formerly *Heterozostera tasmanica*), with smaller areas of Zostera mulleri. Aquatic macrophytes occur in the upper estuary, typically in water depths of less than 1.5 m, and are dominated by *Ruppia* spp. (typically *R. megacarpa*), and in some places abundant *Lepilaena cylindrocarpa*,

Figure 9.4. General map showing location of rocky reefs surveyed in the Derwent in February-April 2010
● standard surveys; ■ timed surveys; ▲ standard and timed species surveys – sites 26 and 27 were surveyed in March 2009 (source: Barrett et al., 2010)



Lamprothamnium spp. and *Myriophyllum salsugineum* (NSR, 2001). The area around the Bridgewater Causeway is characterised by a mix of species, predominantly *R. megacarpa*, but with some seagrass *H. nigricaulis*.

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). Some of the larger *Heterozostera* beds are found at Halfmoon Bay, Cornelian Bay, Wilkinsons Point, the northern end of Dogshear Point, Woodville Bay and Old Beach (Jordan et al., 2001). Small amounts of *Zostera mulleri* have been recorded in Cornelian Bay and Prince of Wales Bay (Lucieer et al., 2007). Many intertidal areas within middle estuary bays also support seagrass (including *Z. mulleri*), but were not monitored in previous boat based surveys as they were too shallow. Analysis of historic aerial photographs suggests that seagrass beds were formerly abundant throughout Ralphs Bay (Rees, 1993). 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.

Since 2009, several surveys and investigations have been carried out to better understand the extent, condition and variability in Derwent estuary macrophyte and seagrass communities, and to investigate factors that influence growth, as described below.

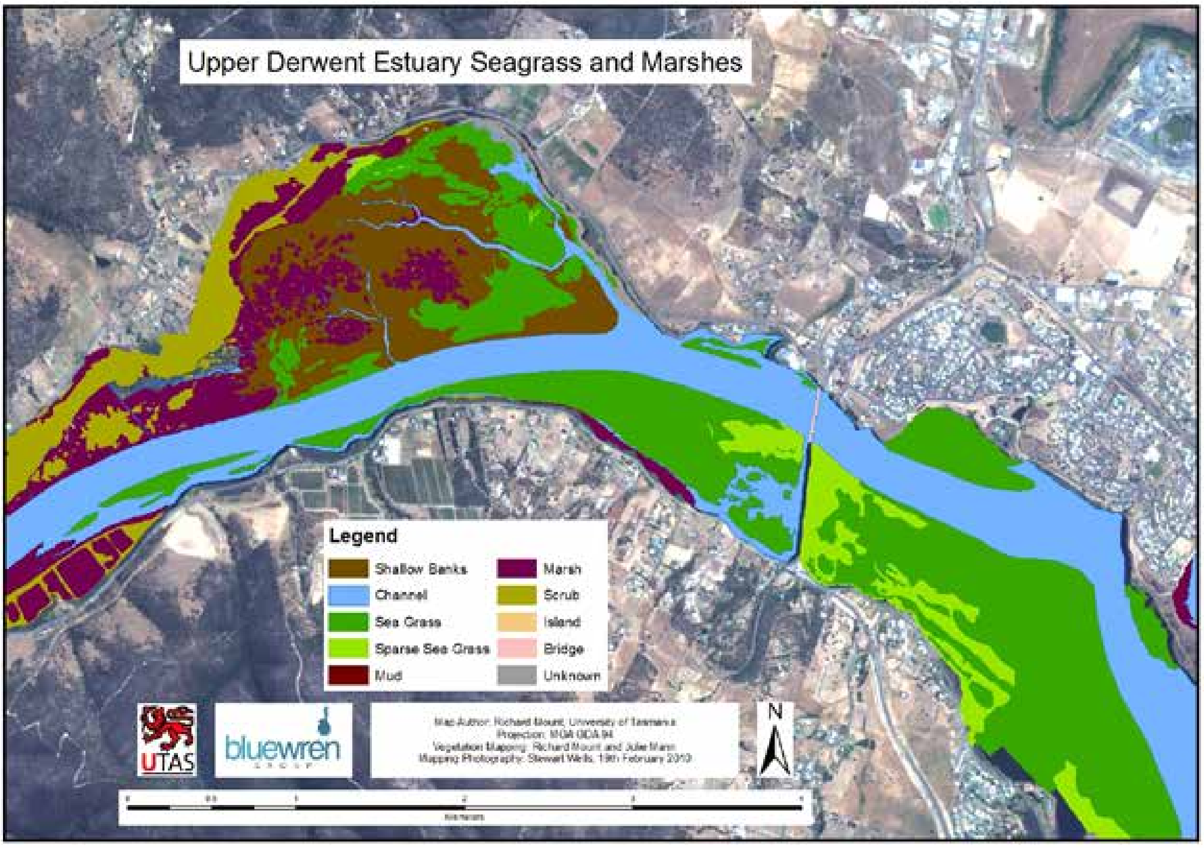
In March 2009, Miles Lawler undertook a boat-based underwater video assessment of known seagrass and macrophyte beds throughout the estuary. Three genera were observed: *Ruppia* (upper estuary), *Heterozostera* (broadly distributed) and *Zostera* (Prince of Wales Bay only). The towed submersible video camera (supplemented with grab samples) provided useful estimates of seagrass cover, species to genera level, epiphyte loads and approximate blade length (see Lawler, 2009 for details). This project was supported by the DEP through an Australian Government Community Coastcare grant.

In Feb–March 2010, Richard Mount investigated macrophyte communities in the upper estuary using a combination of photographic surveys (through-water and infrared), kayak-based field surveys and analysis of recent remote sensing and aerial photographic records. All data records were spatially referenced, and a very high resolution orthophoto mosaic was produced with an accuracy of ~1 m (Figure 9.5). The survey area was subdivided into six seagrass 'banks', and a simple colour-based classification scheme was developed to distinguish between different components of the seagrass and wetland communities. A method for interpreting the imagery using megaquadrants was trialled. It was possible to detect changes in habitat extent and cover, and actively growing seagrass areas, however the imagery could not be used to identify the deep edge of seagrass beds, seagrass density or patchiness. The study recommended that the historic aerial photo archive be analysed to provide context for future monitoring, that new imagery continue to be collected, and geo-located surface water imagery be collected in key locations to provide ground-truthing (see Mount, 2011 for details). This project was supported by the DEP through an Australian Government Community Coastcare grant.

Since 2010, the DEP has collected some additional aerial photographic and field-based observations of seagrass cover and condition in the upper estuary, specifically in 2011, 2013 and 2014 (images plus kayak-based ground-truthing). This information has not yet been fully processed.

During the period from February 2010 to April 2011, Ross et al. (2011) investigated how the Derwent's two main macrophyte/seagrass genera, *Ruppia* and *Heterozostera*, respond to altered environmental conditions, particularly changing light climates. Four key sites were established along a gradient starting above the Bridgewater Causeway (*Ruppia* only) through to Windermere Bay (*Heterozostera* only). The first part of the study measured key environmental parameters (temperature, salinity, light, nutrients), epiphyte cover and light attenuation by epiphytes. The second part of the study assessed seagrass photosynthetic performance using pulse amplitude modulated (PAM) fluorometry. Plant morphology was also assessed to evaluate potential responses to different environmental conditions. The results suggest that seagrass in the mid to upper estuary is light limited, particularly during winter when surface irradiance is lowest. High epiphyte and sediment loads have the

Figure 9.5 Upper Derwent estuary seagrass and wetland communities (source: Mount, 2011)



potential to exacerbate light limitation. Epiphyte loading generally increased with distance downstream, and was highest at most sites between autumn and spring (however the *Ruppia*-dominated site showed the opposite trend, with highest epiphyte loadings during summer months). The study suggested that, at the time of the investigation, the greatest risk to seagrass health was in the middle estuary, where water quality was relatively poor. The strong link between dissolved nutrient concentrations and epiphyte biomass indicates that nutrients rather than light limit epiphyte growth, providing further support for the need to limit nutrient inputs to the estuary (see Ross et al., 2011 for details). This project was supported by the DEP, through an Australian Government Community Coastcare grant.

University of Tasmania Honours student Sam Gray studied morphological and photosynthetic characteristics of intertidal *Zostera muelleri* at five sites along a salinity gradient between Cornelian Bay and Granton during January 2013. Lower estuary sites (Cornelian Bay, Elwick Bay) had the greatest biomass, while upper estuary sites (Claremont, Granton) had significantly lower biomass. Shoot density did not follow the salinity gradient with lowest density at each end of the salinity gradient and highest density in mid-estuary sites. PAM fluorometry results indicate that *Z. muelleri* received, and is acclimated to, more light at downstream sites compared to upstream sites, indicating greater light penetration in the lower estuary. Mesocosm studies to assess photosynthetic response over a range of salinities, suggested that short-term floods are unlikely to have an impact on the photosynthetic performance of *Z. muelleri* (Gray, 2013).

9.1.4 Intertidal sand flats and mud flats

Intertidal sand flats and mud flats (often referred to as tidal flats) are low-lying areas that are inundated during high tides and are aerially exposed during low tides. The Derwent estuary contains large areas of tidal flats (12.4 km^2), with mud flats predominating in the upper estuary and sand flats predominating in Ralphs Bay (particularly the tidal flats at Lauderdale, Mortimer Bay and the eastern side of South Arm). Tidal flats perform a wide range of essential functions. For example, these areas:

- support large populations of 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 mud flats 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 mud flats varies in proportion to the presence or absence of larger plants (notably macrophytes), which shade the underlying tidal flats and reduced the amount of light available for microphytobenthos photosynthesis (NSR, 2001). In the lower estuary at Ralphs Bay the microscopic benthic algae distribution is rather 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, with flow-on benefits to higher trophic levels, such as wading shorebirds (Cook et al., 2007).

The intertidal sand flats 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 9.3.4). In contrast, intertidal mud flats (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

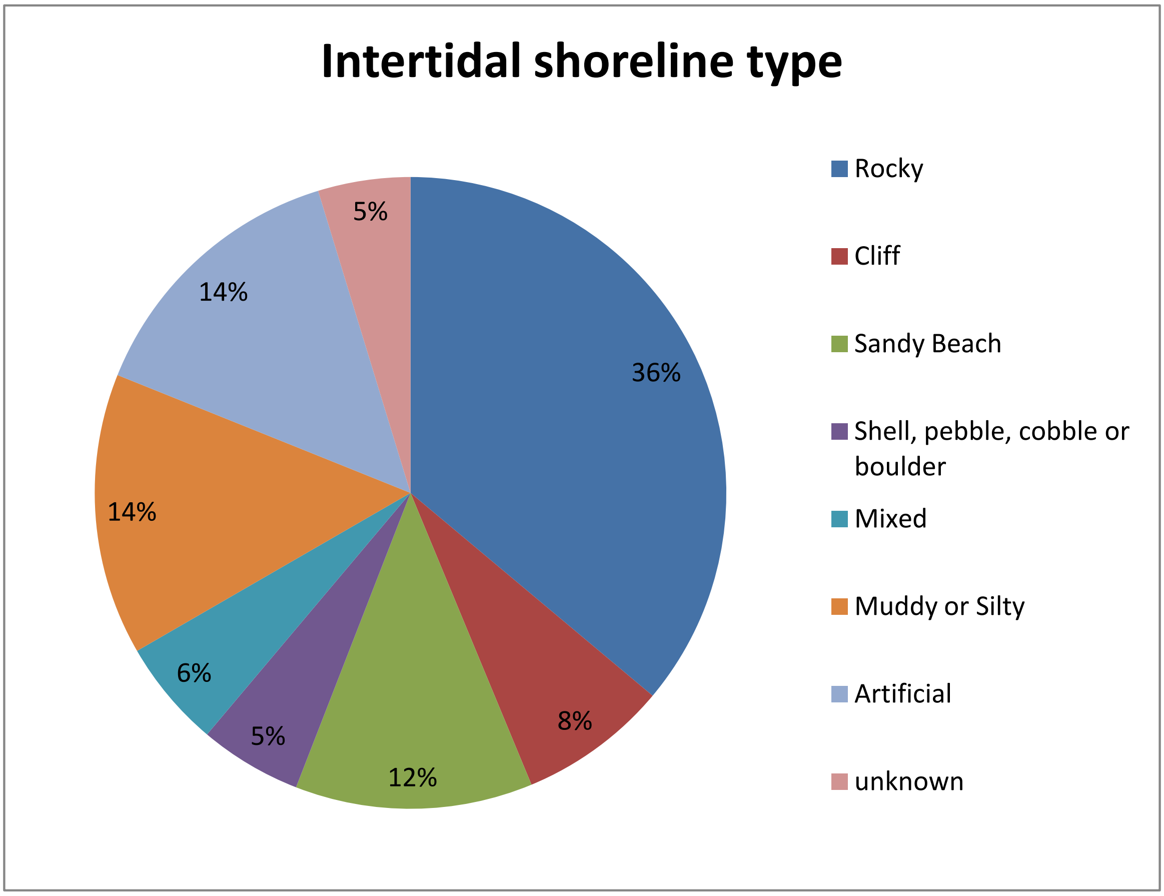
Beaches and rocky shorelines are a conspicuous part of the Derwent estuary, providing habitat for native species as well as public amenity and access to the estuary. The intertidal mean high water mark (MHWM) around the Derwent estuary is approximately 233 km long, and represents the length of the intertidal zone (the coastal strip between high and low tide). Figure 9.6 presents the type and relative proportion of intertidal shoreline around the estuary based on geological and geomorphological data collected by Sharples (2006), based on mapping that extends up-estuary as far as Boyer.

Rocky shorelines comprise 84 km or 36% of the length of the Derwent intertidal zone, notably in the middle and lower estuary, while sandy beaches occupy about 12%. About 14% of the Derwent intertidal zone is artificial, largely as a result of land reclamation and wharf construction in the middle estuary. More detailed assessment and mapping of intertidal zone values, condition and pressures in the Southern NRM region (including the Derwent estuary) were carried out by Aquenal (2008b). Seventeen electronic mapping layers were produced, which have been used to classify the intertidal zone based upon parameters such as biological values and conditions.

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^2 area of the Derwent estuary. Wetlands and saltmarsh can be broadly differentiated on the basis of salinity. 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 (e.g. samphire), grasses, sedges, rushes or herbs. Wetlands typically occur in the upper estuary, where brackish conditions prevail.

Figure 9.6 Types of upper intertidal shoreline in the Derwent estuary (source: Sharples 2006)



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 and biochemical interactions with soils and plants acts as a natural filter, removing 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 is found along a 15 km stretch of the upper estuary, between New Norfolk and Bridgewater. Other important wetlands and saltmarshes occur at Goulds Lagoon, Lauderdale (Racecourse Flats) and southern Ralphs Bay; these are described in more detail below.

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). In August 2013, subtropical and temperate coastal saltmarshes were further protected, being listed as vulnerable under the EPBC Act.

Climate change, particularly sea-level rise, is a significant long-term risk to coastal wetlands and saltmarshes, particularly where retreat pathways may be blocked. In 2009, the DEP undertook a mapping and planning study of Derwent estuary coastal wetlands in collaboration with the University of Tasmania and NRM South. Prahalad et al. (2009) mapped the current extent of wetland and saltmarsh communities and then used inundation modeling to estimate the future extent of these wetlands in 2100, based on a sea level rise scenario of 110 cm, as illustrated in Figure 9.7. Existing tidal wetlands cover an area of 3.4 km^2, primarily in the upper estuary, followed by Ralphs Bay; 80% of these were found to be on public land. The project found that there is definite potential for tidal wetlands, especially saltmarshes, to migrate inland, provided the land use is compatible with saltmarsh colonisation. However, most areas identified as future wetland refugia occur on private land and require management actions to either acquire important areas for reservation, or engage with landowners to promote wetland conservation. Some refuge areas occur on public land, which could be designated for future wetland conservation. The DEP used this information, and associated GIS based maps, to prepare a discussion paper and planning overlay that shows existing wetlands and their potential migration pathways across the region (Whitehead, 2011). This mapping approach was later extended throughout the NRM South region, and some aspects have been included in regional planning overlays.

Tidal wetlands of the upper Derwent estuary

The Derwent River Conservation Area (gazetted in 1941) includes most of the upper Derwent estuary tidal wetlands below high water mark from New Norfolk to Dogshear Point, 22 km downstream. These wetlands consist of a mosaic of freshwater and saline sedgeland/rushland communities, ranging from a few meters to several hundred meters in width. Large stands of tea tree and acacia scrub are present on better drained areas, together with small patches of *Eucalyptus ovata* woodland. Between Granton and Bridgewater, a complex network of marshy islands, mud flats and submerged aquatic macrophytes (dominated by *Ruppia*) are present. These islands are relatively recent landforms that have largely developed since the 1940s and have been listed as having geoheritage significance (MacDonald, 1995). The wetlands and their main vegetation communities have been previously mapped at a system-wide scale, as described in Whitehead et al. (2009), with more detailed mapping and investigations of Murphys Flat in 2006. These 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 water (Aquenal, 2006).

The Dromedary marshes form the largest area of emergent wetland complex in the upper estuary and are relatively intact and highly diverse. In 2011, the DEP commissioned at detailed survey of this marsh, which was undertaken by Prahalad and Mount (2011). High resolution maps were developed based on a combination of aerial imagery and ground-truthing. Thirteen vegetation community types were identified and mapped across the marsh, as illustrated in Figure 9.8, providing a valuable baseline from which future changes can be assessed (see Prahalad and Mount, 2011 for details).

Despite their partial protection within a Conservation Area, the tidal wetlands of the upper Derwent are vulnerable to degradation and incremental loss. 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 and there have been several incidents of illegal fill or drainage. In 2000, the DEP coordinated an initiative to purchase the 66 hectare wetland known as 'Murphys Flat', increasing the total area under protection by approximately 30%. More recently in 2013, another 17.5 ha wetland area on private land was protected through a conservation covenant. In 2010, Parks and Wildlife prepared a management strategy for the Murphys Flat Conservation Area that outlines key management challenges at the site, lists strategies and actions related to weed, fire and biodiversity management, and recommends monitoring action (PWS, 2010).

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 popular site for bird watchers. The major management issues at Goulds Lagoon are related to subdivision development in its catchment, resulting in water quality decline (particularly from nutrient enrichment and sedimentation), weed invasion, domestic and feral animals, and human disturbance

Figure 9.7 Example of current and predicted future wetland extent (source: Prahalad, 2009)

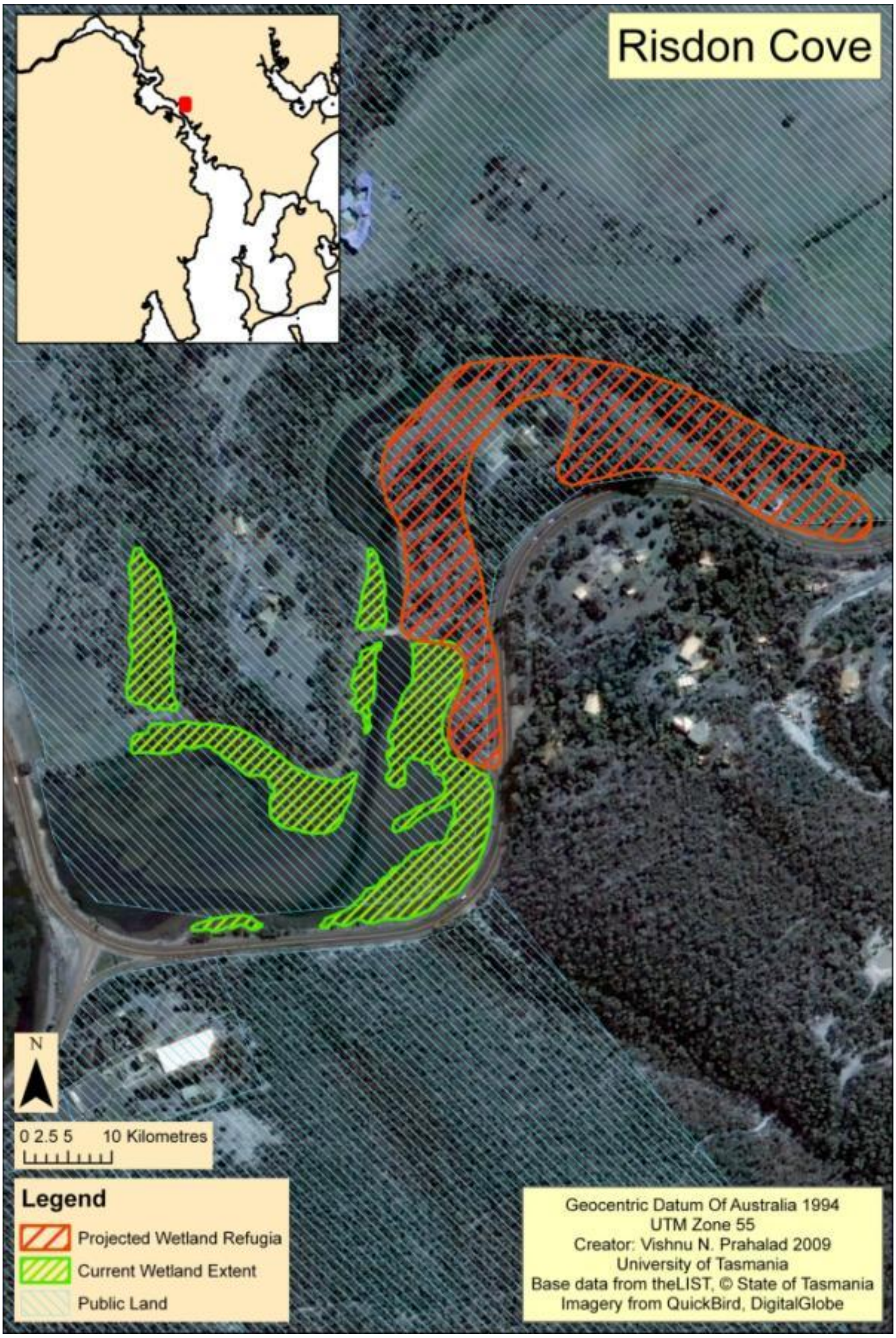
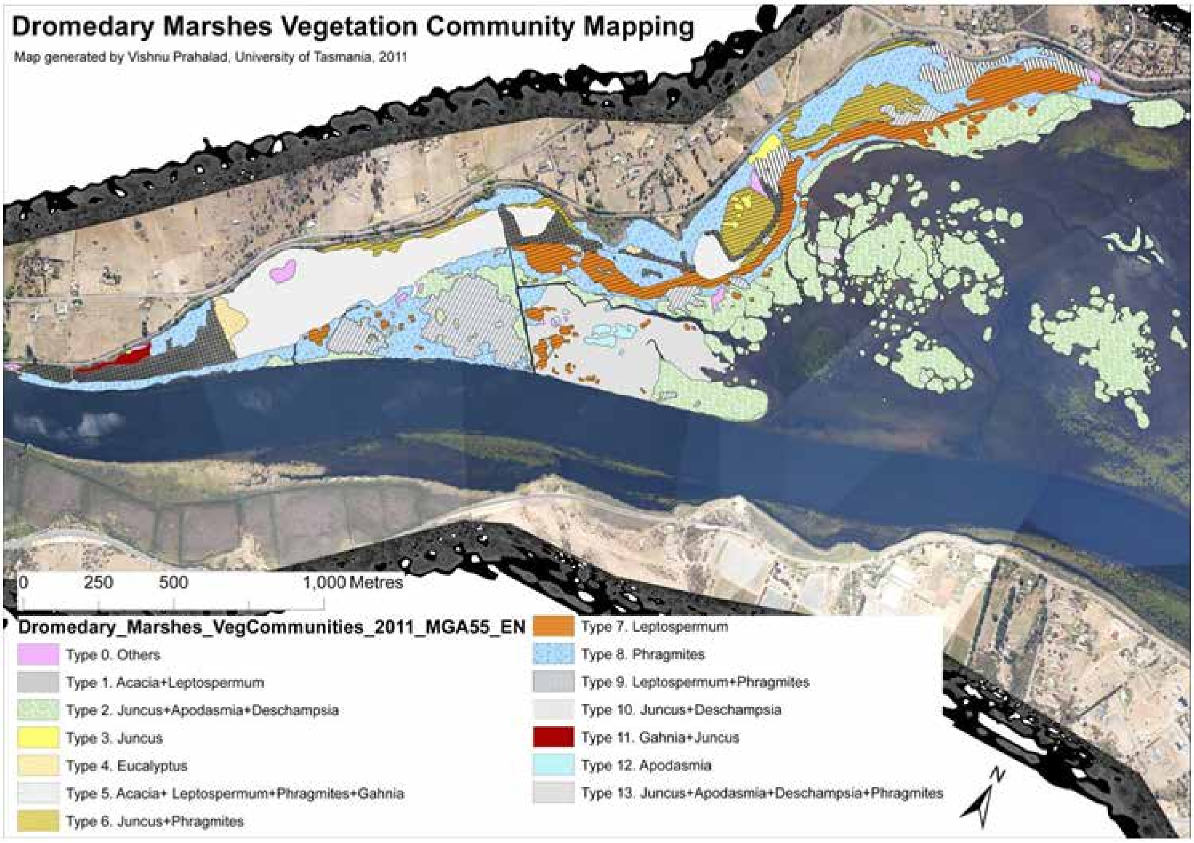


Figure 9.8 Vegetation community map of Dromedary marshes in the Upper Derwent wetlands (source Prahalad and Mount 2011)

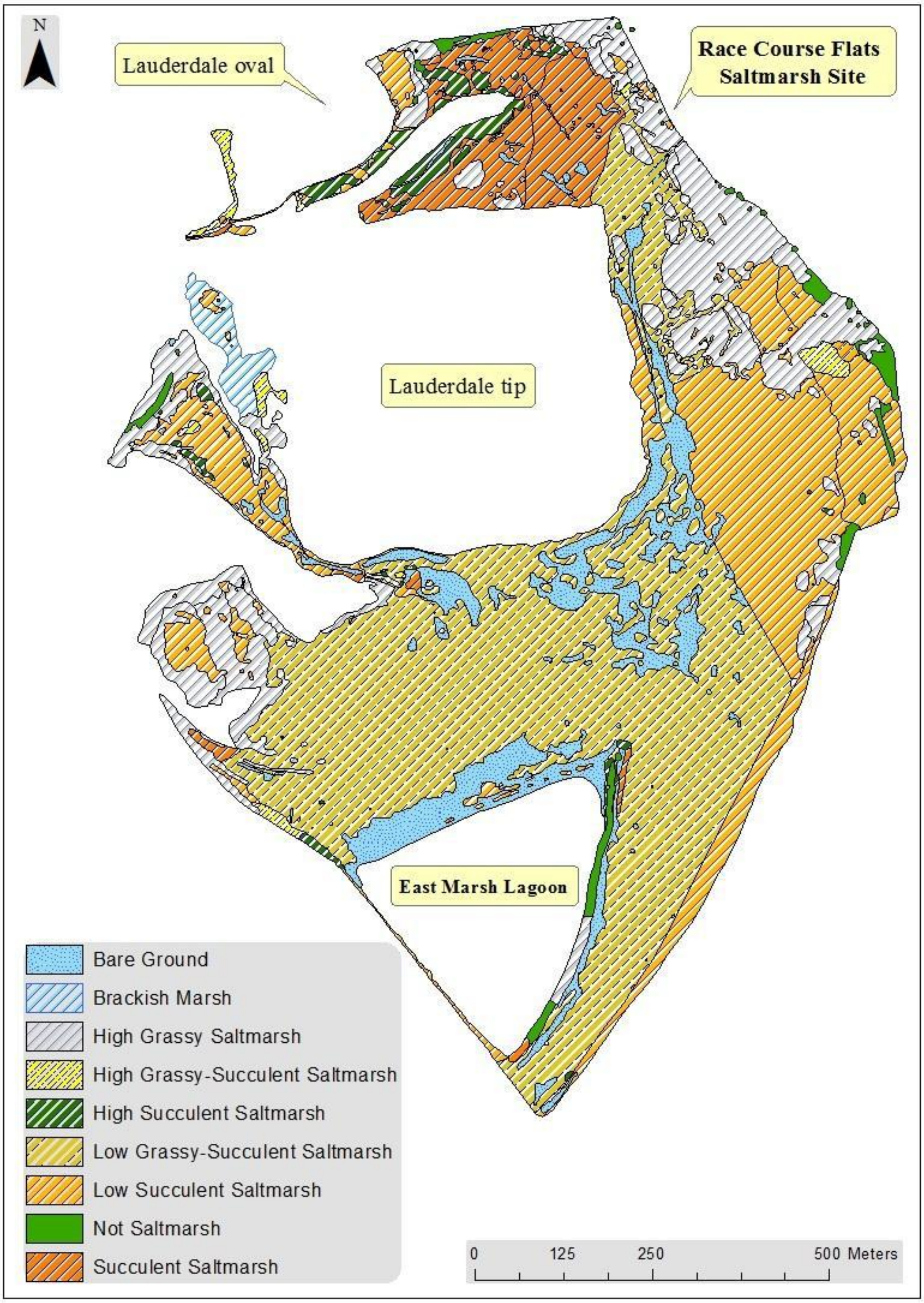


(GCC, 1997). Some revegetation, weeding and treatment of stormwater runoff has been undertaken by the local council in an attempt to maintain and restore suitable habitat for wildlife. Protection of remnant wetlands, such as Goulds Lagoon, is very important as many of the original wetlands of the Derwent 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. A self guided discovery trail was developed by the DEP in 2012 to encourage school groups' exploration of Goulds Lagoon Wildlife Sanctuary, together with an associated information guide that can be can be downloaded at www.derwentestuary.org.au.

Lauderdale saltmarshes

The Lauderdale saltmarshes occupy an area of approximately 1 km^2 and include the larger Racecourse Flats marsh on the landward side of the South Arm Highway and the Dorans Road marsh, on the seaward side of the highway (adjacent to Ralphs Bay). The vegetation communities are dominated by succulent saline herbland, representing 88% of the Derwent estuary coverage of this vegetation type (North Barker, 2008b), and the complex mosaic of vegetation communities reflects variations in salinity, water and disturbance regimes. The Lauderdale saltmarsh is a critical habitat for Tasmanian saltmarsh moths, as described in Section 9.3.6 and 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).

Figure 9.9. Racecourse Flats saltmarsh vegetation communities (source: Prahalad, 2012)



Several recent surveys have been undertaken in this area, including an inventory of environmental assets in the Lauderdale area, prepared by the DEP for the Local Government Association of Tasmania (Whitehead, 2012) and a pilot study of new UAV-based survey methods to generate high-resolution orthophoto and surface models suitable for salt marsh vegetation (Kelcey and Lucieer, 2012). In addition, vegetation community mapping and baseline assessment of the Racecourse Flats saltmarsh has been completed (Prahalad, 2012), as has a preliminary condition assessment/ rehabilitation proposal to improve flushing (Cook, 2012), as described below.

In 2012, Vishnu Prahalad mapped and assessed the condition of existing vegetation communities at Racecourse Flats, providing an excellent baseline from which to document future changes. A two-pass mapping process was followed, whereby an orthophoto mosaic was generated from high resolution aerial imagery, polygons representing different vegetation communities were digitised, and the communities and their boundaries were then validated in the field. Seventy vegetation community types were mapped over the 68.5 ha area, of which 21 accounted for 93% of the area. These were further grouped into eight major ground cover categories, illustrated in Figure 9.9. The low lying succulents *Sarcocornia* spp. and *Disphyma crassifolium* were found to be the two most important plant species, often associated with *Spergularia* spp. These three species, combined with the low grasses *Lachnagrostis* spp. and *Puccinellia stricta,* cover close to half the area mapped. The condition assessment involved establishing three permanent line transects along the northern, middle and southern sections. Condition was also recorded from nearby Doran's Road saltmarsh, which provided a control site as it is not impounded by a road. Drier saltmarsh species and a higher number of weeds occurred at Racecourse Flats signifying a changed ecological character due to the impeded tidal connectivity of the site, compared to Doran's Road (see Prahalad 2012 for details). This project was supported by the DEP, through an Australian Government Caring for Our Country grant.

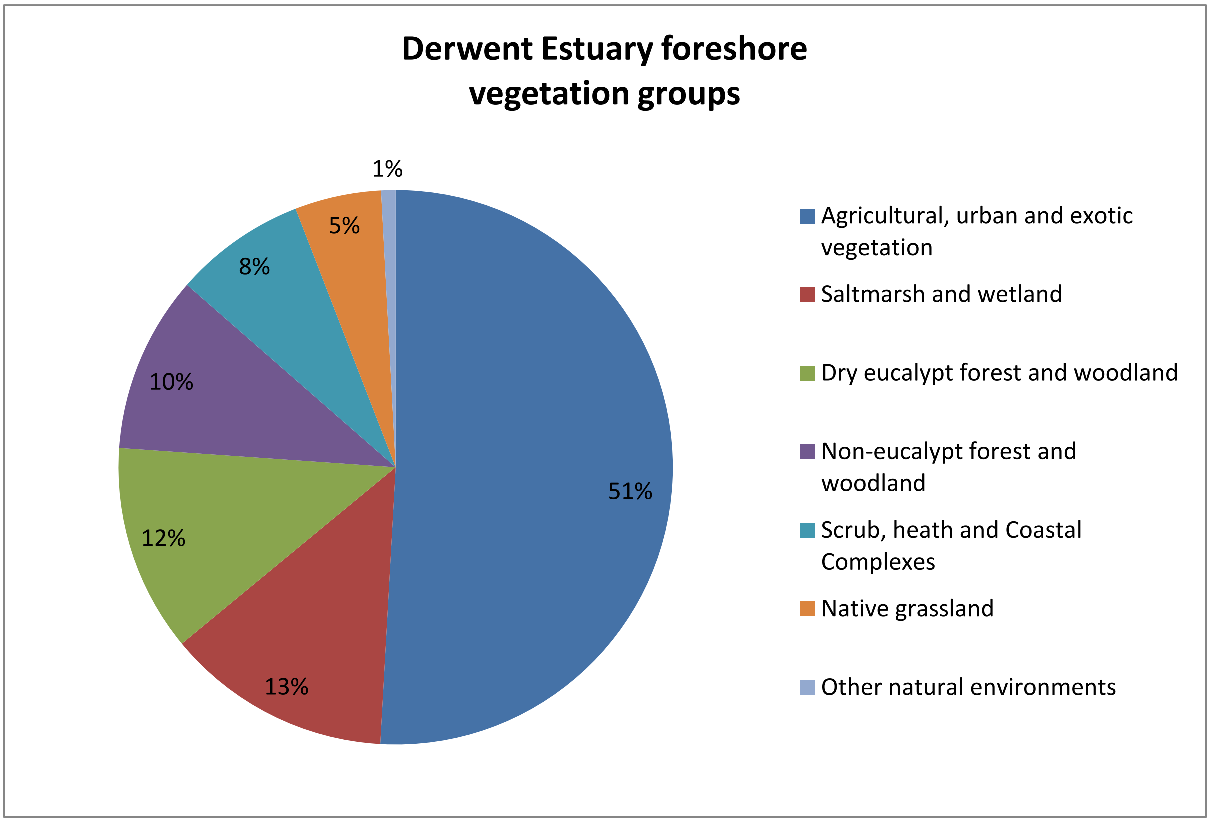
In October 2012, the DEP contracted saltmarsh ecologist Dr Faith Cook to evaluate the condition of the Racecourse Flats wetlands, including the current level of tidal exchange, and to identify possible engineering solutions to improve this. The wetland was found to have a number of characteristics more closely associated with a freshwater system, due to the limited tidal exchange under the highway, and it was recommended that a tidal variation of at least 0.8 m Australian Height Datum (AHD) be reinstated to flood the majority of the *Sarcocornia* marshes and allow East Marsh Lagoon to fully drain. This would allow for recovery and repair of the saltmarsh vegetation and soils, and allow for improved carbon sequestration at the site (Cook, 2012). As a first step, the DEP provided advice to DIER on an upgrade of one of the existing pipes under South Arm Highway, whereby a larger (450 mm) pipe was installed at sea level on 27 February 2013 in order to improve flushing between East Marsh Lagoon and Ralphs Bay.

9.2 Foreshore vegetation

Vegetation along the entire Derwent estuary foreshore (within 100 m of mean high water) has previously been mapped in detail by North Barker through projects supported by the Australian Government, NRM South, State Government and DEP (DTAE, 2007; North Barker, 2008a). The major foreshore vegetation groups can be broadly categorised as:

- saltmarsh and wetland;
- dry eucalypt forest and woodland;
- non-eucalypt forest and woodland (e.g. she-oak forests);
- scrub, heath and coastal complexes;
- native grassland she-oak forest, grassy woodlands/ grasslands and dry eucalypt forest.

Figure 9.10 Type of Derwent foreshore vegetation (%), as mapped with in a 100m swath above the mean high water mark (source: North Barker, 2008)



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 communities (see Table 9.2 for details). As shown in Figure 9.10, 51% of foreshore has been cleared of native vegetation and consists predominantly of urban and rural land or exotic vegetation The remaining 49% retains its native vegetation, of which about two-thirds consists of forest/woodland and coastal scrub and the remainder 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.

Table 9.2 Vegetation communities of the Derwent estuary foreshore* (see Harris and Kitchener (2005) for descriptions of the vegetation mapping units

Vegetation Groups		Area sq km	Area sq km
TASVEG code	Vegatation type		
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 Poa 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 100m 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*

9.2.1 Threatened flora

Twelve state-listed threatened vegetation communities are found along the Derwent foreshore (as listed in Table 9.2), together with the following two nationally EPBC listed communities:

- Subtropical and temperate coastal saltmarsh: listed as vulnerable. (10 Aug 2013);
- Lowland native grasslands of Tasmania: listed as critically endangered (2009).

In 2010, the DEP undertook a more detailed assessment of threatened flora based on records in the DPIPWE Natural Values Atlas database (Whitehead, 2010). This desktop study assessed the number of threatened species both within the adjacent estuary catchment (~800 km^2) as well as the immediate foreshore (~27km^2), with a particular focus on 'hot spots' (where multiple threatened species co-occur and/or areas that contain a significant proportion of state records). Key findings include the following:

- 147 threatened Tasmanian plant species have been recorded within the adjacent estuary catchment, of which 11 species are found only in this region (endemic), and 24 species have ≥50% of their Tasmania records in this region;
- 42 threatened species have been recorded along the Derwent foreshore, of which eight species have ≥10% of their Tasmania records in this region.

Threatened flora hot spots along the foreshore include Gagebrook–Old Beach, Cornelian Bay and Bedlam Walls (East Risdon State Reserve). Other foreshore areas containing a large proportion of one or two threatened species include the Upper Derwent estuary edge, Green Point, Clarence Rivulet, Lauderdale saltmarsh and South Arm (see Whitehead (2010) for details).

9.2.2 Foreshore and intertidal 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 along the foreshore include Weeds of National Significance (WoNS) as well as many state-listed declared weed species, including the invasive intertidal rice grass *Spartina anglica*, which poses a serious risk to tidal flat communities and protected wading birds. There are 15 declared weed 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, specifically blackberry, boneseed, gorse, serrated tussock, willow, Chilean needle grass and bridal creeper.

A number of statewide 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 Weeds Strategy 2011–2016* (NRM South, 2011) provides a framework for coordinated weed management in the NRM South region. Numerous community groups are also involved in weed management activities along the foreshore, often in collaboration with councils and Parks and Wildlife.

In 2010, the DEP developed a Derwent-specific foreshore weed management strategy with support from an Australian Government Community Coastcare grant. Weed information was compiled from multiple sources and management priorities were selected based on a number of criteria including presence of threatened vegetation communities, presence of threatened flora and fauna records, ease of access and community group involvement. A total of 71 weed species were documented within the project area, with the highest number of records attributed to boneseed and African boxthorn (Table 9.1). Sixteen priority sites were identified for further work (Figure 9.11) and two project proposals were developed as a basis for on-ground works, specifically:

- Karamu control in the Upper Derwent estuary wetlands (see following section for details)
- Bedlam Walls/East Risdon (a joint DEP, SCAT and CCC project that is underway)

Figure 9.11 Priority sites for weed management (source: North Barker 2010)

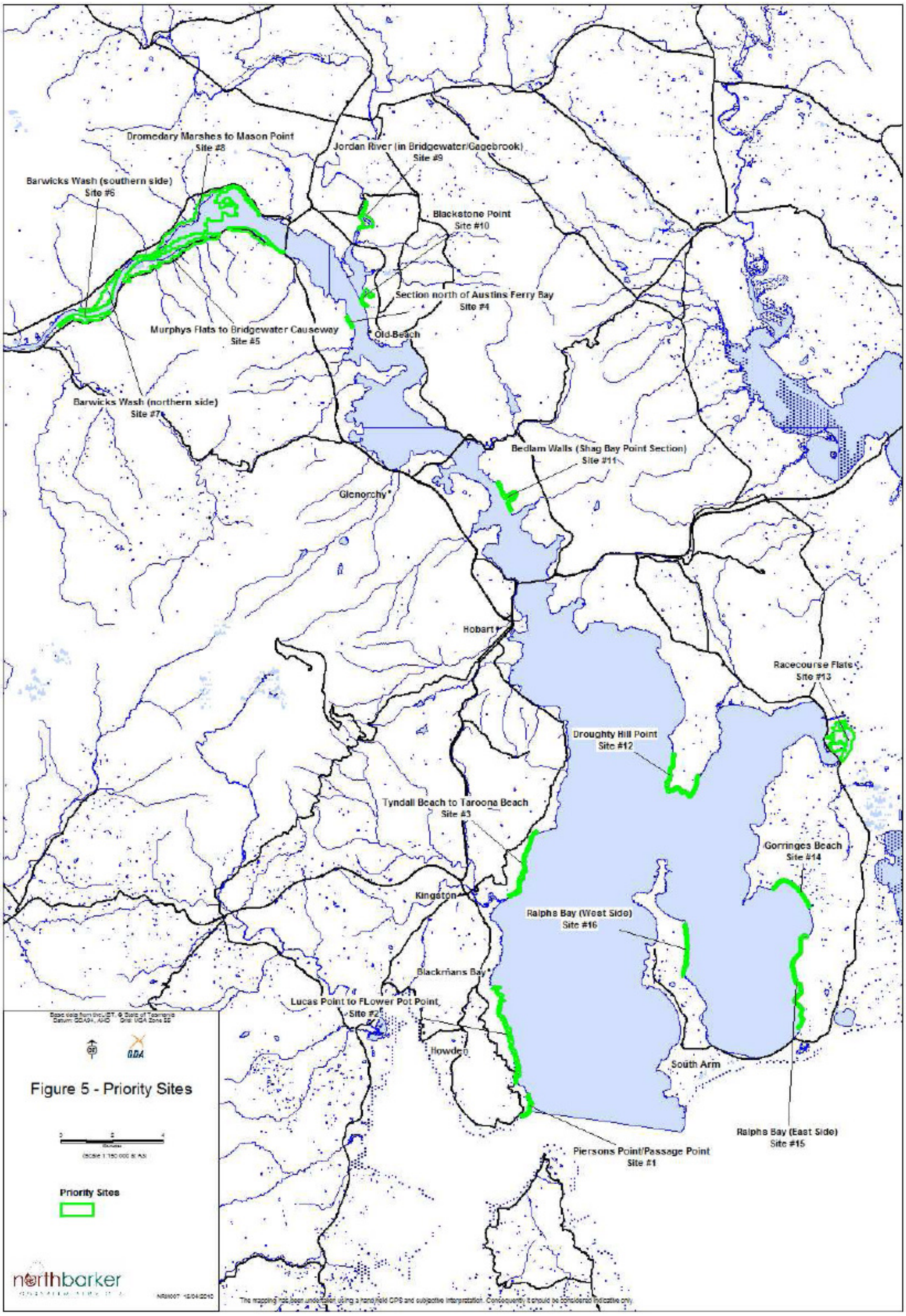


Table 9.3 Highest number of weed records in data set for Derwent estuary foreshore zone (100 m inland from mean high tide mark (source: North Barker 2010)

Number	Common Name	Scientific Name	Record Count	Priority for DEP area
1	Boneseed	*Chrysanthemoides monilifera*	860	High
2	African boxthorn	*Lycium ferocissimum*	825	High
3	Blackberry	*Rubus fruticosus*	427	High
4	Fennel	*Foeniculum vulgare*	414	High
5	Radiata pine	*Pinus radiata*	205	High
6	Sweet briar	*Rosa rubiginosa*	168	High
7	Marram grass	*Ammophila arenaria*	148	High
8	Willow	*Salix* sp.	147	Very high
9	Mirror bush	*Coprosma repens*	108	High
10	Cotoneaster	*Cotoneaster* sp.	73	Medium

Karamu

Karamu *Coprosma robusta* is native to New Zealand and a declared weed in Tasmania. It has been found in several localised areas across Tasmania, but the infestation in the upper Derwent estuary is the largest by far, as a result of its occurrence along the river's edge where berries fall into the water and disperse downstream. Karamu control is a particularly high priority in this area as it has the potential to spread into high conservation value tidal wetlands. In 2010, the DEP commenced a karamu control program for the upper Derwent estuary, with support from an Australian Government grant. North Barker was engaged to survey the extent of the infestation and produced detailed maps to provide a basis for strategic management. The maps showed that the karamu infestation was much more extensive than anticipated, extending from Bryn Estyn approximately 11 km downstream to the start of the Dromedary Marshes (Figure 9.12), with highest densities between New Norfolk and the Norske Skog paper mill.

A Karamu Working Group was established to develop a strategic plan, and guide the implementation of on-ground works. An experienced contractor was engaged to

Figure 9.12 Karamu control and monitoring activities undertaken from 2010–12 (as of Dec 2012)

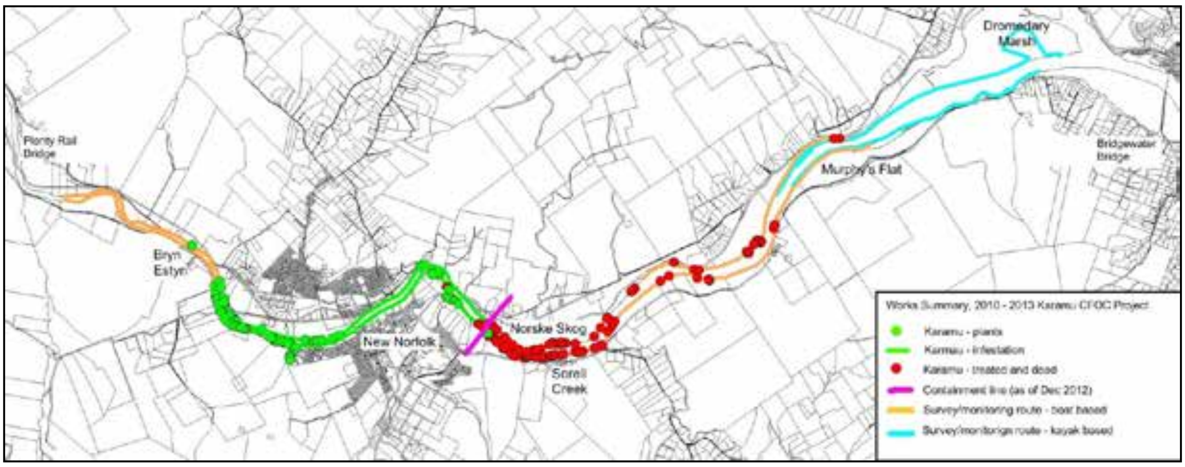
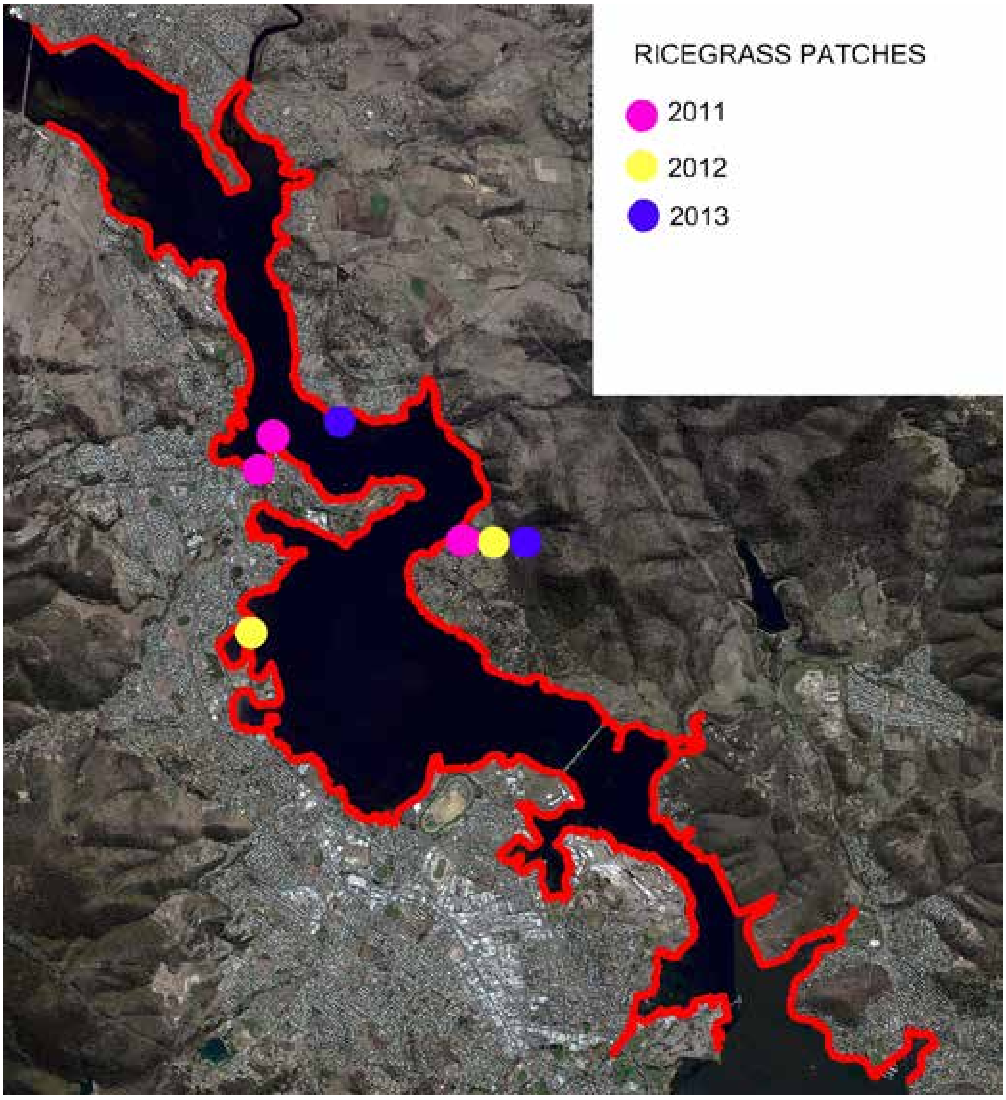


Figure 9.13 Annual rice grass survey area (red) in November 2009–14 showing the locations where rice grass patches were found and subsequently treated in the mid-estuary



treat karamu from a boat along the river's edge, and has removed thousands of plants from over 10 km of shoreline and wetland fringe. The project has also worked with private landholders, businesses and community groups to remove karamu on both public and private lands. To date all outliers have been successfully treated and the core infestation has been reduced to a four kilometer section in central New Norfolk. A draft Karamu Management Plan has been prepared to guide the project over the long-term (see Einoder et al., 2013 for details). The project has been supported by a number of organisations including NRM South, SCAT, Norske Skog, Parks and Wildlife, and others.

Rice grass

Rice grass *Spartina anglica* is a native of Europe and was deliberately introduced to Tasmania in a number of areas, including the Derwent, with the intention of stabilising shorelines, assisting with land reclamation and to provide fodder for livestock (Shepherd, 2011). Rice grass seed is water dispersed (thus influenced by tides, currents and winds) and remains viable for several years. Infestations progressively invade intertidal zones altering estuarine sediment dynamics, invertebrate and microphytobenthic communities, as well as access by fish and shorebirds (Shepherd, 2011). In the mid-1990s, the Tasmanian Government recognised rice grass as a weed and prepared a management strategy to control it (DPIWE, 2002). In the Derwent, where rice grass had spread to a maximum area of ~1 hectare, DPIPWE and PWS conducted annual treatment and monitoring from 1998 until 2002, at which point the infestation had been nearly eradicated.

In 2006, the DEP commenced annual monitoring and treatment of rice grass, with support from a number of state and local government agencies and volunteers. Each survey takes place in November–December (before seeds have set) and focuses on about 70 km of foreshore in the middle estuary (Figure 9.13). On the first day, any previously treated patches are re-visited; then over a period of several days, teams of two people walk most of the foreshore between the Bowen Bridge and Bridgewater Causeway. A final day of boat based surveys is conducted in areas that are not accessible on foot. In December 2008 a single 4 m2 of rice grass was found in the middle estuary, which was subsequently treated. In 2009 and 2010 no rice grass was found, but in 2011, 2012 and 2013 several small patches (<1 m^2) were located among native Juncus krausii at sites in the mid estuary, including at Old Beach, Bilton Bay, Dragon Point, McCarthy's Point, and Woodville Bay (Figure 9.13). All patches have been treated with Fusilade Forte®, in accordance with recommended management methods.

9.3 Derwent estuarine fauna

The Derwent estuary supports an enormous diversity of animals, ranging from the microscopic zooplankton and benthic invertebrates that form the base of the food chain to higher order fish, birds and marine mammals. These include a number of rare and endangered species, as described in Section 9.3.6 as well as over 70 introduced species, some of which occur in pest proportions (see Section 9.3.7).

9.3.1 Zooplankton

There has been little Derwent-specific zooplankton research during the reporting period, however Swadling et al. (2013) recently published a *Guide to Zooplankton of Southeastern Australia* that includes species found in the Derwent. An on-line taxonomic guide and atlas for Australian marine zooplankton is also available at www.imas.utas.edu.au/zooplankton.

9.3.2 Benthic macroinvertebrates

Benthic macroinvertebrates include crustaceans (e.g. crabs and amphipods), molluscs (e.g. gastropods and bivalves) and polychaetes (e.g. worms) that are visible to the naked eye and which live in sediments or on rocky substrates. Benthic macroinvertebrates are a critical component of a healthy ecosystem and occur in all Derwent estuary habitats. Some macroinvertebrate species or communities make good environmental indicators because they are relatively immobile and as such are unable to evade impacts such as nutrient enrichment and toxicant loading, thus reflecting the cumulative impacts of their environment.

Macroinvertebrate studies carried out in the Derwent estuary prior to 2009 include those by Edgar and Samson (2004), Macleod and Helidoniotis (2005) and Aquenal (2008), and were reviewed in the previous State of the Derwent Report (Whitehead et al., 2009). Of these, the comparative survey of benthic invertebrates between the Derwent and Huon estuaries by Macleod and Helidoniotis (2005) provides an excellent, whole of estuary perspective and a baseline for future surveys.

There have been few macroinvertebrate investigations since

2009, with the exception of Barrett et al. (2011), which surveyed both sessile and mobile macroinvertebrates associated with rocky reef communities as part of a broader study (see Section 9.1.2 for details). In additional, there have been several localised surveys conducted in the vicinity of sewage or industrial outfalls, sometimes as a permit requirement by the EPA (e.g. TasWater, Norske Skog).

9.3.3 Fish

Approximately 150 finfish species have been documented in the middle and lower parts of the Derwent estuary (see Whitehead et al., 2010 for full list). These fish communities can be broadly classified as pelagic (living in the mid water column), demersal (bottom dwelling on soft sediments) or reef. Some species, such as flathead (typically associated with soft sediments) and cod (reef dwellers) are permanent residents of the estuary, while others are transitory or seasonal migrants.

Common species of pelagic fish include: 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).

Common demersal 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).

A recent investigation of Derwent reef communities (Barrett et al., 2010) documented 74 fish species during surveys of rocky reef and adjacent soft-sediment habitats. The most abundant species were hulafish *Trachinops caudimaculatus*, bastard trumpeter *Latridopsis forsteri*, long-fin pike *Dinolestes lewini*, blue-throat wrasse *Notolabrus tetricus*, toothbrush leatherjacket *Acanthaluteres vittiger* and little rock whiting *Neoodax balteatus*. Abundance generally increased in the lower estuary, except for hulafish which were more abundant in the upper estuary.

Since 2009, there have been relatively few studies of Derwent estuary fish, with the exception of the following:

- *2012–13 Survey of Recreational Fishing In Tasmania*: a periodic statewide survey based on telephone surveys and individual fishing records. The vast majority (93%) of the fishing activity in the Derwent estuary was attributed to locally based fishers and primarily involved line fishing. While flathead dominated catches, barracouta, black bream and Australian salmon were also regularly caught in the Derwent (Lyle et al., 2014).
- An investigation of the movement and diet of the broadnose seven gill shark *Notorynchus cepedianus* in the Derwent estuary and Norfolk Bay. This study showed relatively low dietary and spatial overlap, suggesting resource partitioning and site fidelity over relatively fine spatial scales (~30 km) (Abrantes and Barnett, 2011; Barnett et al., 2011).
- *Understanding movement patterns of key recreational fish species in southeast Tasmania*: this study tracked the movement of three recreational fish species (flathead, trout and bream) in the Derwent estuary and Norfolk/Frederick Henry Bay. In the Derwent, 50 individual fish were tagged and tracked using an acoustic telemetry array of passive receivers. All but two of these fish remained within the estuary for the period of the study and, while the home ranges of the three species differed in size, the individual fish remained resident around the middle estuary, displaying strong site fidelity (see Tracey et al., 2011).
- Several studies of heavy metal levels in recreationally targeted species, as discussed in Section 8.3.2.

Migratory fish

Derwent estuary migratory fish include trout, whitebait, short-finned eel, lamprey and other species that undertake seasonal migratory 'runs' between marine, estuarine and freshwater environments, as listed in Table 9.6. Other fish with some migratory-like movement within the Derwent include black bream *Acanthopagrus butcheri*, and yellow-eyed mullet *Aldrichetta forsteri*. Migratory fish cannot pass

Table 9.4 Migratory finfish of the upper Derwent estuary (source: Davies et al., 1988)

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 cleaveri*)	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 habitat (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 Imia	Spawning in fresh water Access to sea	Upstream Downstream	September to November September to December
10) Short-headed lamprey (*Mordacia mordax*)	Velasia Macropthalmia Imia	Spawning in fresh water Access to sea	Upstream Downstream	November to January September to December

upstream of Meadowbank Dam on the River Derwent, but do enter the Plenty River, Tyenna River, Styx River and a number of rivulets in the Hobart metropolitan area. Physical barriers to fish migration such as dams, culverts and weirs are a significant management issue.

An important migratory group consists of small 'whitebait' – a collective name for small transparent native fish that migrate from the sea into the estuary during spring and summer. These include the Tasmanian endemic whitebait *Lovettia sealii*, jollytail *Galaxias maculatus*, climbing galaxias *Galaxias brevipinnis*, spotted galaxias *Galaxias truttaceus*, Tasmanian mudfish *Neochanna cleaveri* and Tasmanian smelt *Retropinna tasmanica*.

Species composition varies with tide, time and location. Most whitebait are juveniles, with the exception of *Lovettia sealii* which are adults migrating to spawn. This species 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 impacts on reproduction or survival in any one year may have serious implications.

Whitebait are an important food source for larger migratory fish, which perform a simultaneous seasonal migration.

The Tasmanian whitebait (*L. 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 in a few rivers, including the Derwent. A management plan has been developed for the fishery to protect populations of whitebait species while enabling a small legal catch of whitebait for personal consumption during a six-week season: 1 October to 11 November (see Whitebait Fishery Management Plan 2011–16 for details (IFS, 2011).

The Derwent is an important catchment for eel and lamprey, however these species are not able to migrate beyond Meadowbank Dam. In 2007 a specialised fish trap was installed at the base of the dam, which is designed to catch juvenile short-finned eel (elvers), and lamprey as they attempt to migrate upriver. Up to 300 kg of elvers (about 120,000 individuals) are released above the dam each season, while any surplus is translocated by Inland Fisheries Service (IFS) to other waterbodies in Tasmania, or sold interstate (Shepherd, 2010). All trapped lamprey and any climbing galaxias are released above the dam wall. The peak season for elver migration is November–March, but the timing and number of migrating elvers varies considerably from year to year.

Introduced fish species

Introduced trout *Salmo trutta* is a common species in the Derwent estuary that is targeted by recreational fishers. 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 introduced into the River Derwent in the early 1900s (Telfler, 2002).

Shark nurseries

The Derwent is a nursery area for a number of commercially important shark species such as gummy and school shark, and commercial netting of sharks is prohibited within the estuary. 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, TAFI, pers. comm., 2009). Nevertheless, Ralphs Bay is still an important region for juvenile school shark, typically one to two years of age (Stevens and West, 1997).

9.3.4 Birds

Over 120 species of birds have been recorded within the Derwent estuary region, as listed in Table 9.5. These include both resident species and migratory visitors, many of which depend upon the Derwent's diverse environments. Birds can be broadly categorised as waders, waterfowl, seabirds, woodland/forest birds and raptors. Derwent estuary habitats of particular importance to birds include the wetlands and macrophyte beds of the upper estuary, the sheltered bays of the middle estuary (including Goulds Lagoon) and the Ralphs Bay tidal flats and saltmarshes. The dunes and beaches of the South Arm peninsula are also of great importance to seabirds and shorebirds, as are the bluffs at Fort Direction which support a short-tailed shearwater or mutton bird colony. Little penguins also breed at a number of sites along the Derwent foreshore. 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*.

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) region provides vital habitat for at least eight migratory and six resident shorebird species. 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

Table 9.5. Birds of the Derwent estuary region (source: Abbott and Park, BirdLife Tasmania, May 2009)

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*

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 (BirdLife Tasmania records, E Woehler pers. comm., April 2009).

There has been a long-term decline in the abundance of many of the migratory shorebirds observed in the DEPA as demonstrated by monitoring records (see Figure 9.14). For example, over 1,000 curlew sandpiper were observed in southeast Tasmania in the late 1980s but are now found in very low numbers. The larger bodied eastern curlew *Numenius madagascariensis* have also undergone extensive declines, with low numbers sighted in the Derwent estuary in recent years. The region still supports sharp-tailed sandpiper *Calidris acuminata* and red-necked stint *Calidris ruficollis*, with the Pacific golden plover *Pluvialis fulva*, common greenshank *Tringa nebularia*, and bar-tailed godwit *Limosa lapponica* also occurring on the tidal flats of Ralphs Bay in low numbers. 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, BirdLife Tasmania pers. comm., 2009); however, local habitat loss and increasing levels of human disturbance are also contributing to this decline.

Some Northern Hemisphere migrant shorebirds do not occur on tidal flats, preferring other habitats within the Derwent estuary. For example, the ruddy turnstone *Arenaria interpres* occurs on exposed rocky coastline and beaches, and is occasionally seen in the lower estuary, but more commonly on the exposed coastline of Bruny Island, and further afield. Latham's snipe *Gallinago hardwickii* have been recorded from Goulds Lagoon, however, numbers and areas used across the Derwent estuary are probably higher than observations suggest as these are highly cryptic and occur in dense wetland vegetation where they are rarely observed.

Habitat in the DEPA also supports at least six resident shorebird species, including the red-capped plover *Charadrius ruficapillus*, masked lapwing *Vanellus miles* and pied oyster catcher. 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 DEPA pied oystercatcher population is the second-largest in mainland Tasmania and one of the largest in Australia (Lane 1987). This population has increased over the last 40 years, but shows considerable interannual variability and recent decreases (Figure 9.15).

Wetland and saltmarsh birds

The tidal wetlands and submerged macrophyte beds of the upper Derwent estuary are used by an abundant and diverse community of waterbirds. The expansive meadows of submerged aquatic vegetation are grazed by plant eating waterbirds such as black swan *Cygnus atratus* and Eurasian coot *Fulica atra*. Macrophyte habitats also provide abundant invertebrates and small fish for predatory waterbirds such as musk duck *Biziura lobata* and little pied cormorant *Microcarbo melanoleucos.* The convoluted water/reed edge of the tidal wetlands provides mixed foraging habitats for waterbirds and the dense vegetation provides ample shelter and concealment. Purple swamp hen *Porphyrio porphyrio*, and Tasmanian native hen *Tribonyx mortierii* are commonly sighted, while other species are highly cryptic and thus rarely seen, such as the Australian spotted crake *Porzana fluminea* and the endangered Australasian bittern *Botaurus poiciloptilus* (see Section 9.3.6 for further information on the Australasian bittern, including recent surveys).

For over two decades DPIPWE has conducted a mid-summer survey of four species of waterbird along the Bridgewater Causeway and Dromedary marshes. This survey is a part of a state-wide waterbird census at 80 sites to inform management of the duck shooting season. As shown in Figure 9.16, black swans are the most common waterbirds with 1,000 to 2,500 counted in most years, followed by chestnut teal *Anas castanea*. There is a high degree of inter-annual variability, and it has been suggested that this area provides a drought refuge during dry summers. Until recently, the numbers of chestnut teal and black swan numbers have been correlated, however teal numbers have been quite low since 2009, as have blue winged shoveler

Figure 9.14 Trends in numbers of migratory shorebirds in southeastern Tasmania, 1973 - 2014 (source: Birdlife Tasmania unpublished data, 2014)

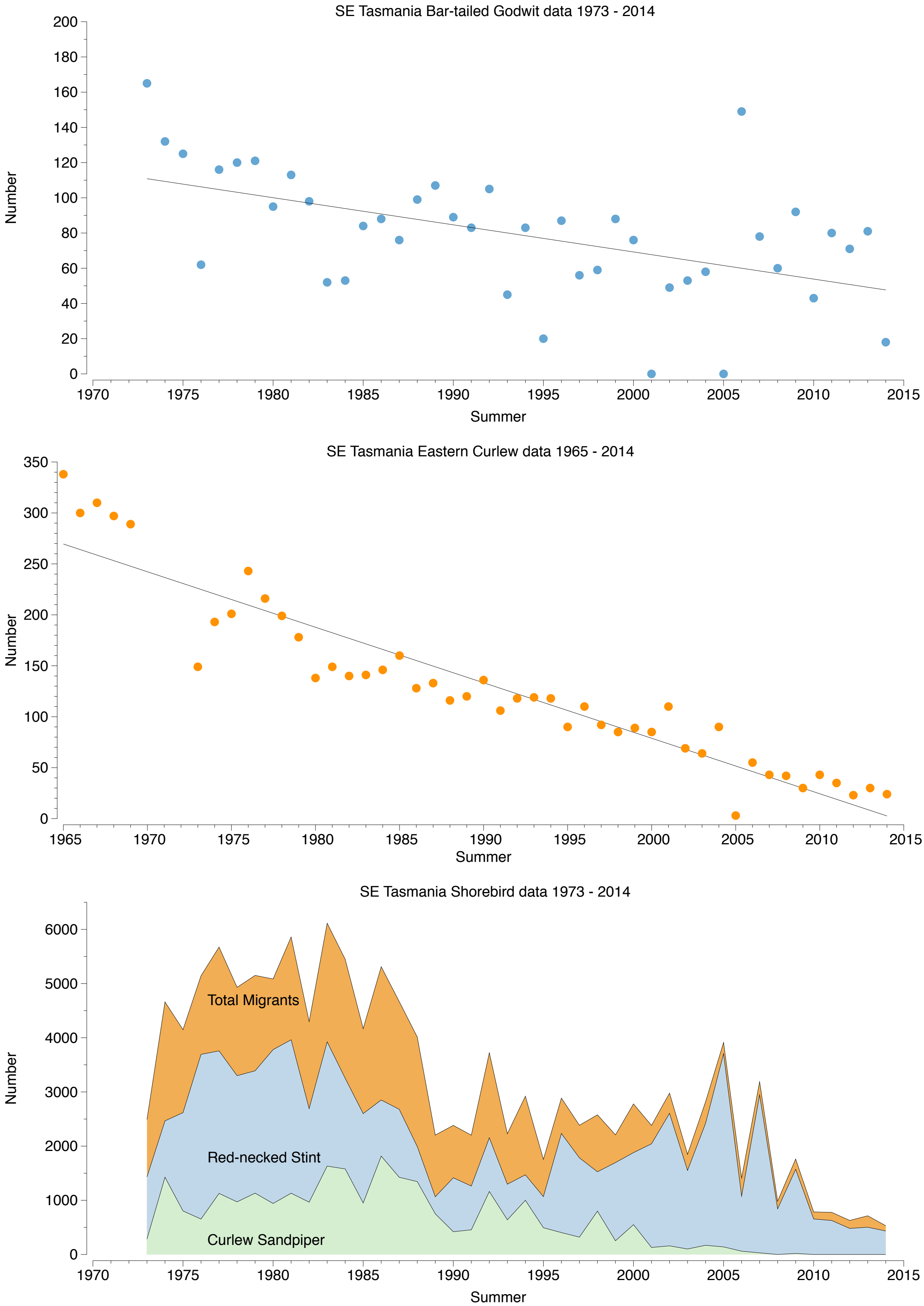
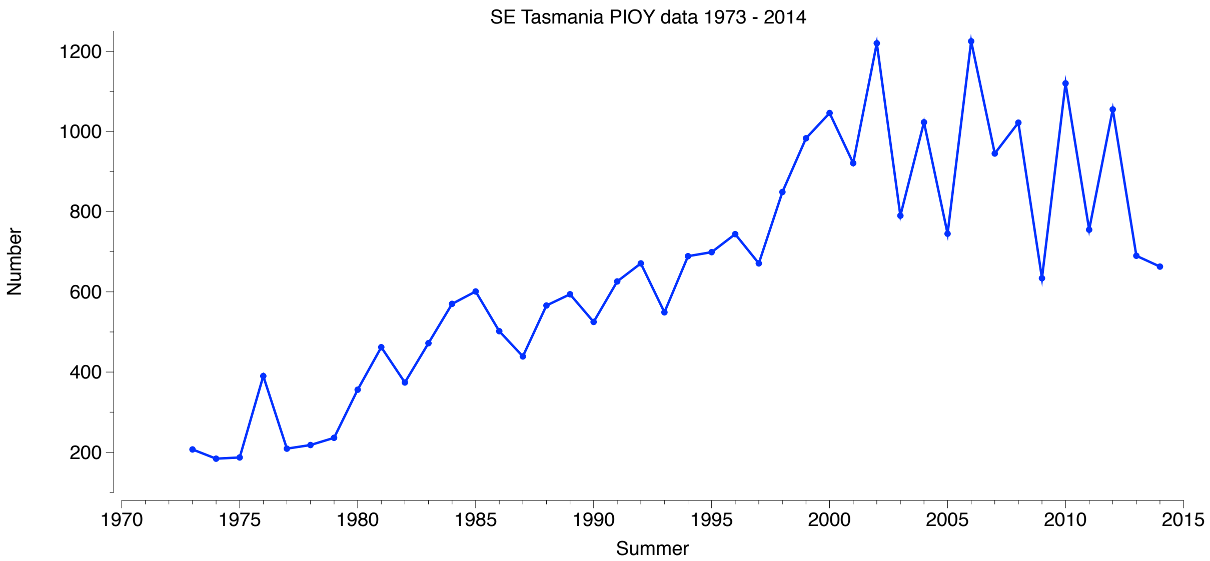


Figure 9.15 Trends in numbers of pied oystercatchers in southeastern Tasmania, 1973 - 2014 (source: Birdlife Tasmania unpublished data, 2014)



Anas rhynchotis. The upper Derwent estuary wetlands also provide a refuge from duck shooting as this is a gazetted Conservation Area where no shooting is allowed (chestnut teal, blue winged shoveler, and Pacific black duck are harvested during the duck-shooting season). Other waterfowl commonly sighted include grey teal *Anus gracilis* and hoary headed grebe *Poliocephalus poliocephalus*.

Other waterbirds commonly observed in the tidal wetlands of the upper and mid Derwent estuary include pelican *Pelecanus conspicillatus*, great cormorant *Phalacrocorax carbo*, egrets *Ardea* sp. and white-faced heron *Egretta novaehollandiae*, all of whom often roost in mixed flocks on dead trees and limbs grounded on the mud flats. A number of raptors are also found in this area, including white-bellied sea eagle *Haliaeetus leucogaster*, marsh harrier *Circus approximans* and brown falcon *Falco berigora.*

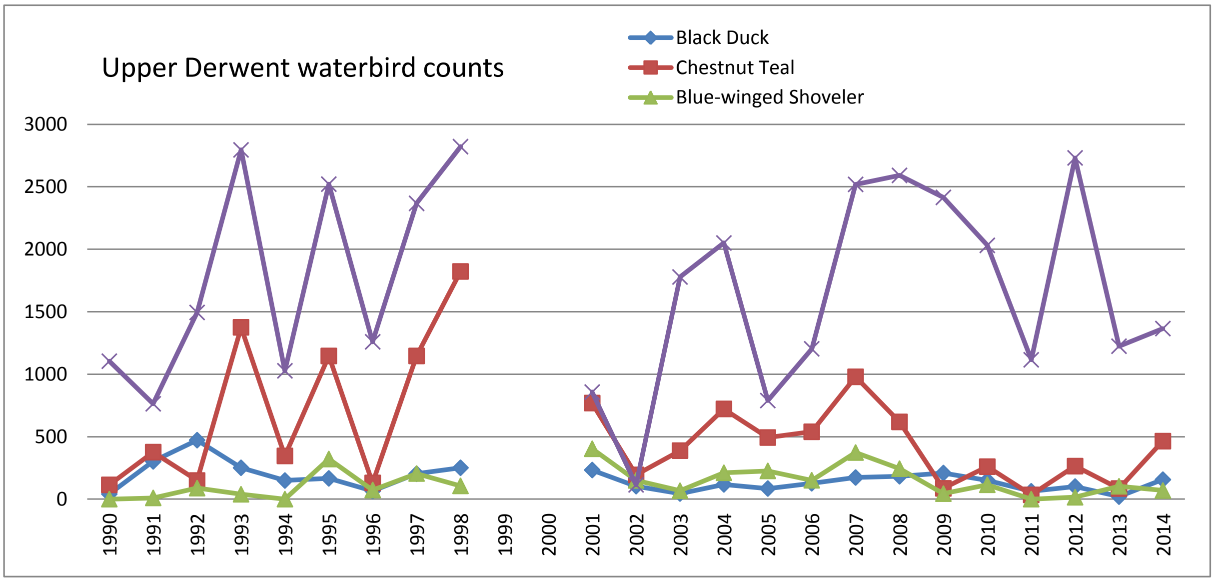
The saltmarshes of the middle and lower estuary provide habitat for a range of birds that roost, feed or breed among the salt resistant vegetation. The white-fronted chat *Epthianura albifrons* is an endemic Australian saltmarsh-dwelling bird that is in decline Australia-wide. Chats are small insect-eating birds with a short slender bill. Males are distinctively black and white, and females a greyish colour. During 2011–13 numerous small flocks of five to eight white-fronted chats were recorded on saltmarshes at Old Beach, and at Racecourse Flats and Doran's Road saltmarshes at Lauderdale. Striated field wren *Calamanthus fuliginosis*, blue-winged parrot *Neophema chrysostoma*, masked lapwing and red-capped plover are also commonly sighted on Derwent saltmarshes.

Seabirds

Derwent estuary seabirds include both resident species (e.g. gulls, cormorants and some species of terns) and several important migratory species such as short-tailed shearwaters *Ardenna tenuirostris* and Caspian terns *Sterna caspia* that breed locally. Other seabirds breed outside the estuary along the Tasmanian coastline and islands, but are regular visitors to the Derwent, such as the Australasian gannet *Morus serrator*. Derwent estuary little penguins *Eudyptula minor* are discussed in the following section.

Winter gull counts have been undertaken by BOAT, Birds Tasmania and BirdLife Tasmania since the 1980s and include the three species of gull that are resident in southeastern

Figure 9.16. Trends in four waterfowl species observed in the upper Derwent estuary wetlands (source: R. Gaffney, DPIPWE)



Tasmania (kelp, Pacific and silver). 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. The 2014 Winter Gull Count involved more than 70 people and included coastal and estuarine areas between Southport and the Tasman Peninsula, including tips and fish farms. A record number of silver gulls (<16,000) and kelp gulls (>7,000) were recorded, and the number of Pacific gulls (<600) was the second highest on record after 2013. It appears that kelp gull numbers continue to increase, while silver and pacific gull populations show greater interannual variability (Woehler et al, 2014). It also appears that there has been a change in feeding and roosting areas associated with the closure/better management of tips and increased availability of food near fish farms (Woehler, 2014).

Silver gulls have been a particular concern for a number of land managers along the Derwent foreshore, as they tend to form large breeding colonies of several thousand birds in areas that are also used for commercial and industrial activities (e.g. Domain, Macquarie Wharf, Selfs Point, Nyrstar). A Silver Gull Working Group was convened by the DEP from 2011 to 2014 to share information about gull biology, monitoring and management options.

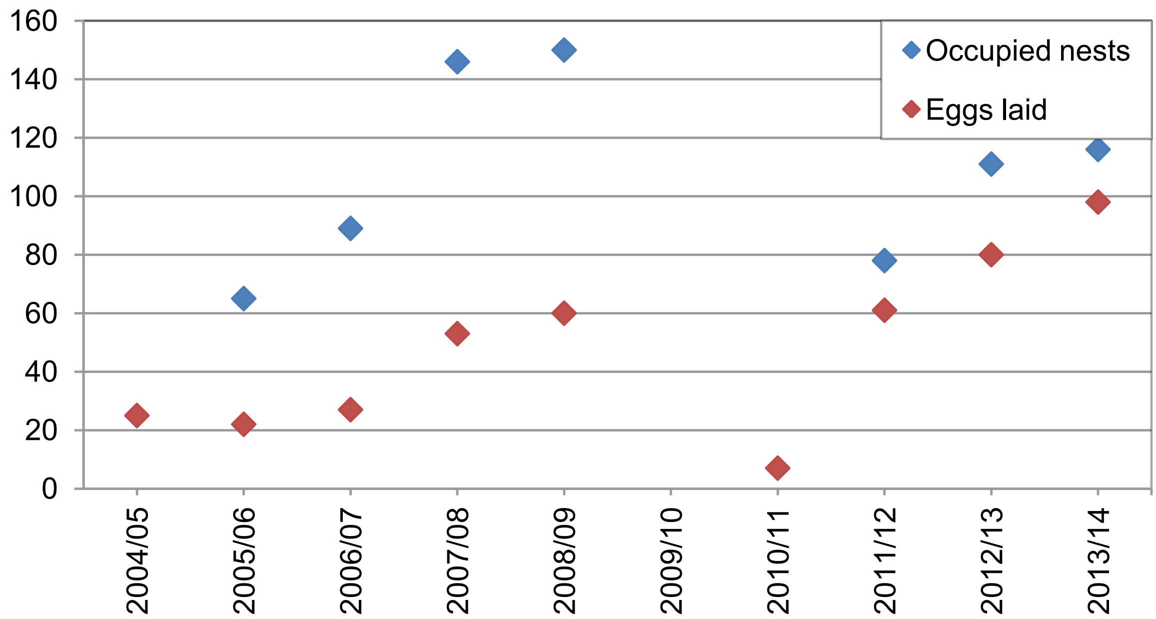
Little penguins

The lower Derwent estuary supports about a dozen colonies of breeding little penguins (formerly known as fairy penguins) along its shoreline, primarily in the Kingborough Council area. These colonies range in size from just a few to over 50 breeding pairs. Little penguins were historically more abundant in the estuary, but their population has been much reduced (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 offshore islands.

Derwent estuary little penguins face a variety of threats, including habitat loss and degradation, seawalls and other physical barriers that prevent access, human disturbance (including lights and noise), predation and gill netting. Domestic and feral cats are an ongoing threat, while uncontrolled dogs can decimate breeding colonies in a matter of hours. For example, in July 2012 two dogs killed 25 penguins at a single colony overnight.

Since 2004, the DEP has coordinated a multi-staged collaborative project between local and state governments, conservation groups, businesses and schools to address

Figure 9.17 Interannual variation in number of occupied nests and, eggs laid from the 5 to 7 little penguin colonies most frequently monitored in the Derwent estuary (source: BirdLife Tasmania, DPIPWE and DEP)



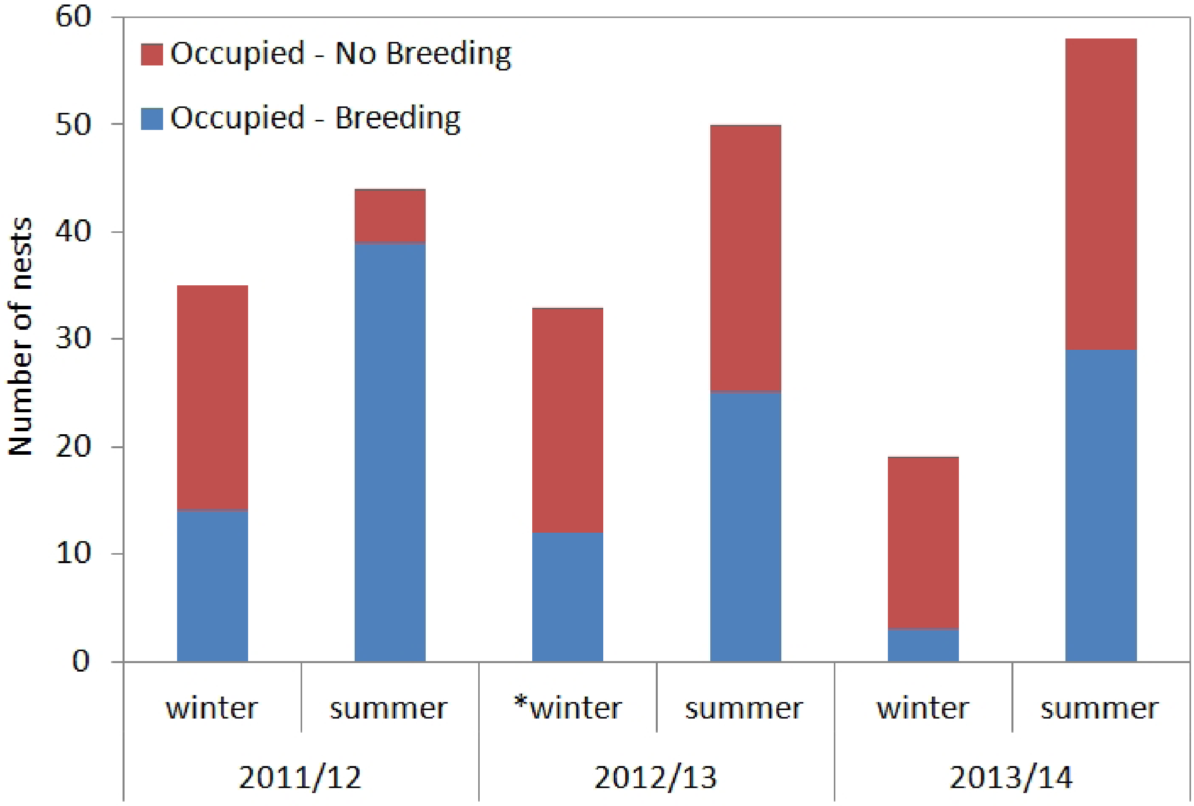
these threats, with some financial support from the Australian Government. Previous stages of the Derwent Estuary Penguin Project (DEPP) have included an inventory of existing and former nesting areas, regular population monitoring, on-ground works to improve habitat and breeding success, and education and awareness-raising activities (see Whitehead et al., 2009 for details).

The DEPP has continued since 2009, with support from the DEP, Kingborough and Hobart councils, BirdLife Tasmania, Understory Network and others. Major activities completed during this time have included:

- Development of site-specific management plans for seven colonies;
- Growing and planting 'penguin friendly' native vegetation, and controlling weeds to improve habitat;
- Installation of secure nesting boxes and concrete igloos at key sites;
- Installation of fencing and signage to protect penguins from dogs and other predators;
- Presentations to schools, dog-walkers and the wider community to raise awareness;
- A specialist workshop for wildlife carers on caring for injured little penguins, held in October 2010;
- Development of educational materials, including a little penguin kit for primary school children;
- Updated management guidelines (DEP, 2009) and standard advice for councils when assessing development applications in areas used by penguins.

Monitoring of Derwent estuary penguin colonies has been undertaken in most years since 2004 through the combined efforts of Birdlife Tasmania, the DEP, DPIPWE and the University of Tasmania. The number of breeding pairs, eggs laid and chicks successfully reared has varied considerably from year to year depending on both local factors and wider regional factors. For example, the total number of breeding pairs at all Derwent estuary monitoring sites has ranged from nearly 200 in 2007/08 to fewer than 30 in 2009/10; these low numbers were attributed to poor food availability associated

Figure 9.18 Little penguin nest use and numbers breeding at the largest Derwent estuary colony, demonstrating lower breeding during winter (Jun – Aug) and increased breeding in summer (Sept – Mar) (source: DEP)



with a strong La Nina year (E Woehler, pers comm., 2011). The number of sites monitored and the frequency of monitoring have also varied over time. Figure 9.17 presents monitoring results for the core penguin colonies that have been most consistently monitored, and provides an indication of the interannual variability. While little penguins in southeastern Tasmania tend to breed predominantly in summer, some also breed in winter, as shown in Figure 9.18.

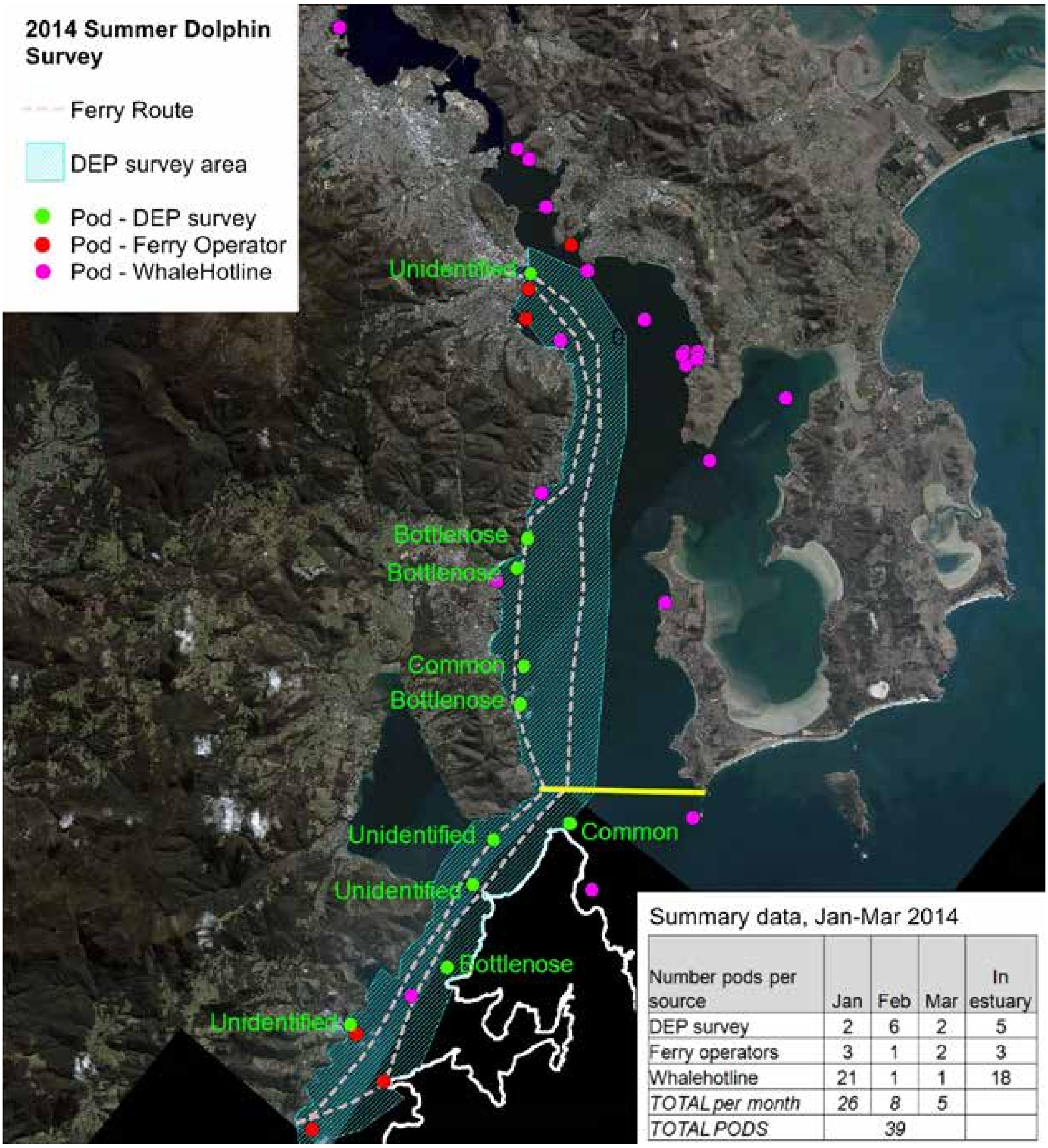
9.3.5 Marine mammals

Three species of whales, two species of dolphins and five species of seals have been recorded in the Derwent estuary based on records kept by DPIPWE (Tasmanian Cetacean Marine Occurrence Database). Records are sourced from staff surveys, agency reports (including the Tasmanian Parks and Wildlife Service) and information received via an all-hours Whale Hotline for the reporting of strandings, and other marine mammal incidents.

Bottlenose dolphin *Tursiops truncates* and common dolphin *Delphinius delphis* are regular visitors to the estuary, and while pods are most commonly observed in the lower and middle estuary, recent sightings have occurred as far upstream as Bridgewater and even New Norfolk. Surprisingly little is known about Derwent dolphins, and in 2014 the DEP conducted a three-month Dolphin Watch trial to collect more information on the numbers and types of dolphins in the lower Derwent estuary and upper D'Enrecasteaux Channel area. The trial included boat-based observations by trained volunteers along the Peppermint Bay ferry track as well as public reports via DPIPWE's Whale Hotline. A total of ten pods of bottlenose and common dolphins (40 individuals in total) were reported during 22 cruises, with another 27 reports made to the whale hotline. The approximate location of these sightings is shown in Figure 9.19.

Three whale species are known to visit the Derwent estuary: the southern right whale *Eubalaena australis*, humpback whale *Megaptera novaeangliae*, and rarely, the orca *Orcinus orca*. 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

Figure 9.19 Dolphin sightings in the Derwent and D'Entrecasteaux Channel, 2014



Number pods per source	Jan	Feb	Mar	In estuary
DEP survey	2	6	2	5
Ferry operators	3	1	2	3
Whalehotline	21	1	1	18
TOTAL per month	*26*	*8*	*5*	
TOTAL PODS		*39*		

these species were hunted close to extinction in the 19th century. Southern right whales are becoming more regular visitors to the Derwent estuary, with between one and 14 sightings recorded every year since 2003, including a whale and young calf (possibly born in or near the Derwent) in August 2010. Records of mother and calf sightings and even births in southeastern Tasmania have increased in recent years, suggesting that populations may be slowly starting to recover. Humpback whales have also been sighted in the Derwent estuary in most years over the past decade, though in smaller numbers. There have been only a few sightings of orcas in the past ten years, including in December 2010, when a pod of six spent a few days in the estuary. Table 9.6 provides information on whale sightings between 2009–13.

Table 9.6. Reported whale observations in the Derwent estuary from 2003–13 (source: K. Carlyon, Biodiversity Monitoring Section, DPIPWE, 2013) Note: these figures should be considered as indicative, as some may represent the same individual reported over a period of several days

Year	Southern Right Whale	Humpback Whale	Orca	Total
2003	5	3	2	10
2004	3	1		4
2005	14	1		15
2006	4	1		5
2007	5			5
2008	3	3	1	7
2009	1	1		3
2010	9		6	15
2011	3	1		4
2012	7			
2013	9		2	11
Total	63	11	11	87

Seals are often seen in the Derwent estuary and occasionally haul out on the foreshore; however, no regular haul-out or breeding sites occur in the estuary. Five species of seals have been recorded in the Derwent, particularly the Australian fur seal *Arctocephalus pusillus* and New Zealand fur seal *Arctocephalus fosteri*, plus rare visits from leopard seals *Hydrurga leptonyx*, southern elephant seals *Mirounga leonina* and Australian sea-lions *Neophoca cinerea*.

See Whitehead et al. (2009) and Aquenal (2008) for further information on Derwent estuary cetacean observations, cetacean strandings and pinnipeds observations.

9.3.6 Threatened fauna

As listed in Table 9.7, 16 threatened fauna species inhabit or visit the Derwent estuary, with an additional 16 species recorded along the foreshore and adjacent terrestrial habitats. Threatened species include the humpback and southern right whales (both endangered), fairy tern (rare), the New Zealand fur seal (rare) and the spotted handfish (endangered).

Spotted handfish

The spotted handfish *Brachionichthys hirsutus* is a small benthic fish endemic to southeastern Tasmania, and is currently found at a limited number of sites in the lower Derwent estuary (three sites on the western shore and seven sites on the eastern shore). The total area occupied by spotted handfish is estimated at 4 km^2, with most fish located within a 2 km^2 area. This species has been listed as a threatened species under both Tasmanian and Australian legislation, and is listed as critically endangered by the IUCN. It is considered to be vulnerable to extinction due to its highly restricted and patchy distribution, low population density, limited dispersal capabilities and a reproductive strategy of producing low numbers of demersal eggs that are highly susceptible to disturbance.

Spotted handfish occur primarily on unconsolidated substrate ranging from well sorted coarse sand and shell grit, to areas of fine sand and silt. They have been recorded from depths between 2–30 m but appear to be most common in 5–10 m. Spotted handfish spawn during September and October,

Table 9.7 Threatened fauna in the Derwent estuary

Common Name	Scientific Name	Listing status	
		Tasmania (Thr Sp Prot Act)	Australia (EPBC)
ESTUARINE AND MARINE SPECIES			
Derwent seastar*	*Marginaster littoralis*	e	CR
Live-bearing seastar	*Pateriella vivipara*	pv	
Australian grayling	*Prototroctes maraena*	v	VU
Spotted handfish*	*Brachionichthys hirsutus*	e	CR
Great white shark	*Carcharodon carcharias*	v	VU
Great crested grebe	*Podiceps cristatus*	v	
Australasian bittern	*Botaurus poiciloptilus*		EN
Fairy tern	*Sterna nereis* subsp. *nereis fairy*	v	
White-bellied sea-eagle	*Haliaeetus leucogaster*	v	
Shy albatross	*Diomedea cauta subsp. cauta*	pv	PVU
Eastern curlew	*Numenius madagascariensis*	e	
New Zealand fur seal	*Arctocephalus forsteri*	r	
Sub-Antarctic fur seal	*Arctocephalus tropicalis*	e	VU
Southern elephant seal	*Mirounga leonina*	e	VU
Humpback whale	*Megaptera novaeangliae*	e	VU
Southern right whale	*Eubalaena australis*	e	EN
TERRESTIAL AND FRESHWATER SPECIES			
Chevron looper moth	*Amelora acontistica*	v	
Chaostola skipper	*Antipodia chaostola*	e	
Saltmarsh looper moth	*Dasybela achroa*	v	
Mt. Mangana stag beetle	*Lissotes menalcas*	v	
Land snail	*Lathamus discolor*	e	EN
Silky snail	*Roblinella agnewi*	r	
Green and gold frog	*Litoria raniformis*	v	VU
Tussock skink	*Pseudemoia pagenstecheri*	v	
Swift parrot	*Discocharopa vigens*	v	
Forty-spotted pardalote	*Pardalotus quadragintus*	e	EN
Masked owl	*Tyto novaehollandiae castenops*	e	
Grey goshawk	*Accipiter novaehollandiae*	e	
Wedge-tailed eagle	*Aquila audax fleayi*	e	EN
Eastern barred bandicoot	*Perameles gunnii*		VU
Spotted-tailed quoll	*Dasyurus maculatus*	r	VU
Tasmanian devil	*Sarcophilus harrisii*	e	VU

*Endemic

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

- National: *Environment Protection and Biodiversity Conservation Act 1999*
  CR=Critically Endangered; EN=Endangered; VU= Vulnerable and PVU = presumed vulnerable
- Tasmania: *Threatened Species Protection Act 1995*
  e=endangered; v=vulnerable; r=rare and pv=presumed vulnerable

females laying eggs on small, vertical, semi-rigid structures. The stalked ascidian, Sycozoa sp., provides the primary spawning substrate within the Derwent estuary, although spawning around seagrasses, sponges, small seaweeds and polychaete worm tubes has also been recorded.

Throughout the 1960s, 70s and early 80s, handfish were frequently seen by divers along the eastern and western shores of the Derwent, and adjoining bays. However, major declines occurred in the mid 1980s and extensive surveys of the estuary floor in 1994 and 1996 found only a handful of specimens at several locations throughout their former range. Conservation actions have been carried out since 1999, guided by the Australian Government, *Spotted Handfish Recovery Plan 1999–2001* (Bruce and Green, 1998), a Tasmanian government Recovery Plan for 2002–06 and more recently by the 2005 Australian Government, *Recovery plan for four species of handfish*, which is currently being revised (DOE, 2015). Monitoring and recovery actions carried out prior to 2009 are described in Whitehead et al. (2009).

Key threats include the loss or degradation of foraging and spawning habitat through a combination of:

- poor sediment and/or water quality associated with urban and industrial development resulting in siltation, contamination of sediments or prey species, and blooms of filamentous algae;
- loss of preferred spawning substrate (the ascidian Sycozoa sp.) and egg masses due to predation by the introduced northern Pacific seastar Asterias amurensis;
- physical disturbance and/or displacement of handfish by new developments such as marinas, walkways and other infrastructure, as well as by anchors or dragging mooring chains.

A number of actions have been undertaken to monitor and manage spotted handfish in the Derwent estuary since 2009, as part of a DEP coordinated project, funded by the Australian Government. The following actions were undertaken in collaboration with organisations and individuals including Reef Life Survey, CSIRO, IMAS, Aquenal, TasUni Dive Club and Mark Stalker.

- Population surveys were carried out by community divers at the two western shoreline sites (Sandy Bay and Battery Point) in 2011, 2012, and 2013;
- Population surveys were carried out by contractors at Ralphs Bay in 2011 and 2012, at Opossum Bay in 2011 and at Bellerive in 2012;
- Over 2500 artificial spawning substrates were installed at the Sandy Bay, Battery Point and Ralphs Bay sites in 2011 and 2013, and mid-breeding season surveys were carried out to assess the degree to which these were being used;
- A handbook outlining survey methods, construction and installation of spawning substrate, and other useful information was prepared for use by scientific and community divers (Cooper et al., 2014);
- A University of Tasmania Honour's project was completed using photo-identification and spot matching software to study spotted handfish (Moriarty, 2012).

The population surveys described above were undertaken along 100 m transects (30–40 per site), with densities of spotted handfish, the invasive northern Pacific seastar and stalked ascidians recorded in 1.5 m wide blocks on either side of the transect line. Size (mm), depth (m) and precise location (as recorded by diver-towed GPS) were recorded for all handfish observed, and lateral images of each fish taken using digital photography. Population surveys suggested stable densities of spotted handfish at Battery Point and Opossum Bay, but found fewer fish at Sandy Bay and Ralphs Bay than in previous years (as reported by CSIRO using the same methods). Very low numbers of juvenile spotted handfish were found over all the surveys and imply poor recruitment over the last two years. Densities of stalked ascidians were low across all sites, but no decrease was apparent from previous surveys by CSIRO. Northern Pacific seastar densities were markedly lower at all sites during 2011 and 2012 compared with previous surveys, but increased strongly at western shoreline sites in 2013, illustrating the boom and bust cycle of this introduced species. A number of other factors were observed that may influence handfish populations from site to site and year to year, including dense drift algae and spider crab aggregations (Green et al., 2012).

The second component of the project was to install artificial spawning substrates as a means to enhance spotted handfish spawning success and recruitment over a larger scale than previously trialled. Over 2,500 artificial spawning substrates were constructed by the DEP and planted out at Sandy Bay, Battery Point and Ralphs Bay by IMAS, CSIRO and Aquenal divers. The rate of usage of these by handfish and observations on fouling and persistence were recorded by Aquenal divers in targeted surveys. Although only a small percentage of substrates planted were found to have egg masses attached (<1%), the majority of egg masses found during the spawning season at these sites were found on these artificial spawning substrates. Preliminary results were encouraging, but data on the densities of handfish recruits in surveys in the next two years, combined with further targeted research on this method are required to provide a better assessment of the success of artificial substrates (Green et al., 2012).

In addition to the work described above, a number of spotted handfish surveys have been carried out in association with major development proposals, such as the expansion of the Derwent Sailing Squadron marina and the Battery Point Foreshore Walk.

Moriarty's 2012 University of Tasmania Honours project assessed the use of photo-identification and spot matching software to study spotted handfish. A number of surveys were undertaken off Sandy Bay and Battery Point to locate and re-identify a set of individual handfish over a period of several months. The study confirmed the validity of using natural marks as a means of individual identification for spotted handfish, verified that distinct markings remain stable over time and was able to track the movement of individual handfish over a two month period. The Sandy Bay study site saw significant fluctuations in the number of individuals present, with a moderate population size estimated to be approximately 72 individuals on average. The nearby Battery Point site displayed more stable population densities and an overall population estimate of 130 handfish. Results indicate that the collection of quality photos and use of I^{3}S Manta software can provide a cheap, efficient and successful method to monitor populations of this critically endangered fish (Moriarty, 2012).

Derwent estuary endemic seastar (Marginaster littoralis)

The Derwent estuary endemic seastar *Marginaster littoralis* has previously been identified within intertidal habitats in the middle estuary but has not been observed in many years (Dartnall, 1970). The species is currently state-listed as endangered and EPBC-listed as critically endangered. Extensive and targeted surveys were undertaken by Barrett et al. (2010) to locate this species, including repeated intertidal and subtidal searches within the core habitat of this species, however none were found. The co-occurrence and super-abundance of the seastars *P. elongatus* and *P. regularis* in these habitats suggests that if any individuals of *M. littoralis* are left they would be subject to severe competition and predation by these species. Barrett et al. (2010) also suggest that the low winter salinities in this area coupled with summer desiccation during spring tides and high temperatures would make an obligate mid-estuarine intertidal niche impossible. If the species is valid and continues to persist it must also occupy subtidal habitats below salinity lows during winter as well as the intertidal zone it is described from, or occupy additional intertidal habitats away from the influence of physical extremes.

The searches included many of these habitats but failed to detect any specimens. As *P. regularis* displayed great morphological variability within the central area of occupancy of *M. littoralis*, some specimens of which displayed similar features (such as an off-white marginal fringe), it is suggested that a revision of the taxonomy of this species be undertaken with regard to the variability of *M. calcar* characters, and a molecular genetic comparison to be made between these species once molecular techniques evolve to cope with the formalin preserved type specimens (see Barrett et al., 2012 for details).

Threatened saltmarsh moths and butterflies

The saltmarshes and adjacent coastal habitats of the Derwent estuary and Pittwater – Orielton Lagoon are home to a diversity of moths and butterflies. The first broad scale survey of saltmarsh moths in southeastern Tasmania identified over one hundred species (McQuillan, 2009). Some of these species were largely confined to coastal habitats, and the chevron looper *Amelora acontistica* and saltmarsh looper

Dasybela achora were only found on saltmarshes of the Derwent estuary and neighbouring Pittwater – Orielton Lagoon (McQuillan 2009). These two geometrid moths are listed as vulnerable on the Tasmanian *Threatened Species Protection Act 1995* in recognition of their limited extent and rarity. Two threatened butterflies are also known to be largely dependent on saltmarsh in southeastern Tasmania: the chequered blue butterfly *Theclinesthes serpentata* lavara and the golden-haired sedge-skipper *Hesperilla chrysotricha plebeia.*

From 2012–14 targeted surveys of Derwent estuary saltmarshes were conducted by Peter McQuillan (University of Tasmania), with support from the DEP and NRM South. Moth surveys were conducted from February – March in 2012 and 2014 and involved setting multiple light traps on warm, calm nights. Traps were positioned at the fringe of sedgeland and succulent saline herbland where the highest diversity of moths were expected to occur, with some arranged in transects along the vegetation gradient from saltmarsh into fringing woodland. Moth surveys of Racecourse Flats and nearby Dorans Road saltmarsh in Lauderdale collected a diverse range of moths. Chevron looper moths were present in high numbers at numerous trapping sites across Racecourse Flats saltmarsh, confirming earlier records of the species being locally common on saltmarshes in the southeast of Tasmania (McQuillan 2007). In late February 2012 a localised hot-spot of chevron looper moths was located with over 30 individuals sighted in 30 minutes, including numerous mating pairs. Although saltmarsh looper moths were not recorded in these surveys, they may still occur at Racecourse Flats saltmarsh, as there was a relatively low sampling effort at this site.

Saltmarsh surveys targeting threatened butterflies were also carried out in February 2013 at Racecourse Flat saltmarsh, Dorans Road saltmarsh, and the spit adjacent to the Lauderdale canal. During these surveys 25–40 chequered blue butterflies were observed flying and roosting on the coastal saltbush *Rhagodia candolleana*. The eastern subspecies of the golden-haired sedge-skipper was also observed, feeding on flowers of boxthorn that had invaded the saltmarsh. Several larval shelters (cylindrical silk bound leaves) were also recorded on *Gahnia filum* (McQuillan pers. comm.). This species may be confined to stands of *G. filum* in saline coastal habitats like other sedge-skippers (e.g. *Hesperilla flavescens flavia* McQuillan pers.comm), placing great importance on the management of saltmarsh vegetation to retain this species.

Australasian bittern

The Australasian bittern *Botaurus poiciloptilus* is a large (66–76 cm), stocky, thick-necked heron with mottled buff-and-brown streaky plumage. They mostly occur singly or in pairs, usually within beds of reeds, rushes or sedges in freshwater wetlands. With its cryptic plumage, it is heard more often than it is seen. During the breeding season (October–January), males utter a distinctive, resonant booming call, repeated several times in succession, calling most frequently at dusk and dawn. The eerie call of the Australasian bittern is said to have been the origin of the Aboriginal and colonialist myth of the Bunyip – a mythical creature said to live in creeks, swamps, billabongs, riverbeds and waterholes, Australasian bitterns occur in southeastern Australia, including Tasmania. They require large, relatively undisturbed wetlands, where they breed in densely vegetated areas, building nests in deep cover over shallow water. Australasian bitterns feed on a wide range of small animals, including eels, frogs, fish and yabbies. There has been a rapid loss of suitable natural habitat for the Australasian bittern over the past 20 years due to drainage and degradation of wetlands combined with prolonged drought, and populations have declined significantly. It is now listed as Endangered under the EPBC Act (1999) in Australia, and globally in the IUCN Red List (see Birdlife Australia factsheet).

In spring and summer of 2013–14, the DEP carried out targeted surveys for the Australasian bittern in the wetlands of the upper estuary area, between Boyer and the Dromedary marshes. Both visual and listening surveys were undertaken, resulting in six documented observations (three visual, three listening) over the six-month period (Einoder, pers. comm., 2014).

9.3.7 Introduced marine species

Introduced marine and intertidal species are a particularly insidious form of ecological pollution in that, once established, they can be extremely difficult or impossible to eradicate, and can result in severe consequences to the marine environment, commercial and recreational fishing, aquaculture and public health. Some introduced marine and intertidal species have the propensity to out-compete native flora and fauna. It is believed that introduced marine species pose a serious threat to a number of native species found in the estuary, particularly the endangered spotted handfish, and may also affect human health (e.g. introduced toxic algae) and public amenity (e.g. feral Pacific oysters on foreshore areas).

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, all vessels and equipment used in the marine environment (including commercial and recreational fishing gear, and diving equipment) are at risk of further translocating them. Temperate southern hemisphere estuaries such as the Derwent are susceptible to marine pest invasions from other temperate regions, including the northern Pacific, Mediterranean 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.

Many introduced species have flourished in the Derwent, taking advantage of the disturbed or altered environment. A number of physical attributes in the Derwent estuary make it susceptible to exotic marine species introductions; these include low current velocities and an abundance of sheltered habitats, which may entrap marine pest larvae and increases the likelihood of larval retention in the estuary. The estuary also contains a diversity of habitats suitable for survival and settlement of larvae, which also increases the likelihood of successful colonisation (Aquenal, 2002).

At least 79 introduced and cryptogenic (possibly introduced) marine species have been identified in the Derwent estuary, and there are probably many more unrecorded species (Aquenal, 2002, 2008a). These include eight 'target' pests (listed by the Australian Ballast Water Management Advisory Committee), and over 70 non-target species, as listed in Table 9.8. Of these, the northern Pacific seastar *Asterias amurensis*, European green crab *Carcinus maenas*, toxic dinoflagellate *Gymnodinium catenatum*, feral Pacific oyster *Crassostrea gigas*, Japanese 'wakame' seaweed *Undaria pinnatifida*, New Zealand seastar *Patiriella regularis*, New Zealand screw shell *Maoricolpus roseus*, New Zealand half crab *Petrolisthes elongatus* and European clam *Varicorbula gibba* are likely to be impacting on the ecology of the environment (Aquenal, 2002; MacLeod and Helidoniotis, 2005).

Further information on a number of these species, including potential management options, was provided in the DEP's *Introduced Marine and Intertidal Species Discussion Paper* (Whitehead, 2008). However, there has been relatively little additional research, monitoring or management of Derwent marine pests since then, with the exception of the following:

- Information on northern Pacific seastar densities were collected as part of spotted handfish surveys in 2011, 2012 and 2013 (see Section 9.3.6);
- Information on introduced species was collected by Barrett et al. (2010) and by ReefLife Survey as part of Derwent rocky reef surveys (see Section 9.1.2);
- University of Tasmania Honours student H T Ko investigated the New Zealand half crab at 12 intertidal sites in the lower Derwent in 2010, and evaluated the use of this species as an indicator of heavy metal contamination (Ko, 2011);
- Several community groups have removed oysters (oyster 'donging') at a number of intertidal areas in southeastern Tasmania, including Blackmans Bay in 2011, with support from SCAT. While this practice may reduce local densities, it is not recommended during oyster spawning season, as it may promote the mass release of gametes, potentially improving breeding success (pers. comm., C McLeod).

Table 9.8 Introduced and cryptogenic (possibly introduced) marine species 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

Source: Aquenal, 2002

* species identified in Aquenal (2008a)

** Alastair Morton (DPIPWE) pers. comm. 21 Aug 2009 – Blackmans Bay

9.4 Biodiversity planning and recommendations

9.4.1 Conservation Action Planning

Estuaries are inherently complex systems, where a myriad of anthropogenic impacts often disrupt physical and ecological processes, and contribute to reduced ecological integrity of species, and habitats. One of the most challenging processes in the management of coastal and marine ecosystems is identifying where to direct limited resources for maximum conservation gain. Various planning tools can assist this decision making process. The DEP applied the Conservation Action Planning (CAP) framework developed by the US-based conservation group The Nature Conservancy to develop a Conservation Action Plan. This framework is widely used in the development of international conservation projects and is becoming more widely adopted in Australia for planning large scale conservation projects with multiple stakeholders. The basic concepts of this conservation approach follow an adaptive management framework of setting goals and priorities, developing strategies, taking action and measuring results. For the Derwent estuary, this process involved a fresh look at the current state of natural values and sources of major threat in the system to identify high conservation priorities. One of the underpinning goals of CAP planning is to move conservation projects from the site scale (10s or 100s of hectares) to the conservation and preservation of functional landscapes (1000s to 100,000s hectares) which are able to sustain and support biodiversity at an eco-regional scale (Low, 2003).

The CAP process typically involves a series of conservation planning workshops with 5–10 participants from multiple organisations. The process is facilitated by a trained CAP coach and uses an established step-by-step methodology (refer Low, 2003) and an Excel-based software program to guide participants through the development of a landscape conservation plan. The components of the process include clearly defining the 'conservation targets' or most critical values; identifying and rating threats to these targets; using monitoring data and other information to assign current conservation status (poor, medium, good or very good) to each target; and applying the findings to adaptive management.

The Derwent estuary CAP process commenced in February 2010 and the planning team met six times over several months to develop a first iteration CAP for the region, released in July 2010. Eight key habitats, one community (migratory fish) and two species (spotted handfish and little penguin) were selected as core conservations assets. Tables summarising the key ecological attributes of these assets, their viability and major threats are presented in Figures 9.20 to 9.22. This first iteration CAP was adopted by the DEP and has influenced works programs since. The CAP reinforced the value of DEP's core business in areas of water quality and pollution management, and the support of single species conservation programs (e.g. spotted handfish and little penguins). The CAP also raised the profile of some natural values, ecological attributes, and threatening processes that have been largely overlooked in the Derwent estuary. In response, some of these areas were targeted in 2010 and 2011 (e.g., saltmarsh condition and futures).

The Derwent CAP was revisited in 2012 in a second iteration with a focus on further strategy development, prioritisation, and action planning. The CAP was restructured around five major conservation strategies and refined to better identify the key action steps required to meet objectives. The result is a collection of high priority major projects and a proposed road map for their implementation designed to help conserve key targets within the Derwent estuary. See the full CAP for details (DEP, 2013).

Figure 9.20 Key ecological attributes of the conservation assets (status = Poor, Fair, Good)

Conservation Asset	Landscape Context Key Ecological Attributes	Condition Key Ecological Attributes	Size Key Ecological Attributes
1. Upper Derwent wetlands & macrophyte beds	adjacent buffer / retreat areas • freshwater regime marine tidal influence	fauna species diversity primary productivity flora species diversity water quality	total area remaining and patch size
2. Saltmarshes	adjacent buffer / retreat areas freshwater regime marine tidal influence connectivity to adjacent vegetation communities	fauna species diversity flora species diversity sediment quality water quality	total area remaining and patch size
3. Ralphs Bay tidal flats	marine tidal influence adjacent buffer / retreat areas nutrient cycling integrity of shorebird network	fauna species diversity flora species diversity sediment quality water quality	total area remaining (size)
4. Inter-tidal zone	buffered by terrestrial vegetation adjacent retreat areas marine tidal influence mosaic / proportion of different habitat types (sand, rock, mud)	fauna species diversity flora species diversity functionality of food chain water quality sediment quality	total area remaining (size)
5. Terrestrial foreshore vegetation	fire regime connectivity to adjacent vegetation communities	fauna species diversity flora species diversity	total area remaining and patch size
6. Rocky reefs & kelp forests	connectivity (degree of fragmentation) of reef systems	fauna species diversity flora species diversity water quality & circulation	total area remaining and patch size
7. Subtidal soft sediments & seagrasses	mosaic / proportion of different habitat types (sand to silt)	fauna species diversity flora species diversity seagrass condition / cover water quality & circulation sediment quality sediment processes	total area remaining (size)
8. Pelagic system (water column)	hydrological regime	fauna species diversity functioning plankton system water quality	total area remaining (size)
9. Migratory fish & associated tributaries	fish passage / connectivity between freshwater and marine habitat	migratory species diversity habitat condition recruitment success	total number of migratory fish
10. Spotted handfish	dispersal ability between populations & suitable habitats	habitat condition population structure (age class) & recruitment success	total number / populations of spotted handfish
11. Little penguin	dispersal ability between suitable habitats	habitat condition population structure (age class) & recruitment success	total number / populations of little penguins

Figure 9.21 Viability ratings of the conservation assets

Conservation Asset	Landscape context	Condition	Size	Overall viability
1 Upper Derwent wetlands & macrophyte beds	Poor	Fair	Good	Fair
2 Saltmarshes	Poor	Fair	Poor	Poor
3 Ralphs Bay tidal flats	Fair	Good	Good	Good
4 Inter-tidal zone	Poor	Poor	Good	Fair
5 Terrestrial foreshore vegetation	Fair	Fair	Fair	Fair
6 Rocky reefs & kelp forests	Good	Fair	Good	Good
7 Subtidal soft sediments & seagrasses	Fair	Poor	Good	Fair
8 Pelagic system (water column)	Fair	Fair	Good	Fair
9 Migratory fish	Poor	Fair	Fair	Fair
10 Spotted handfish	Poor	Poor	Poor	Poor
11 Little penguins	Fair	Fair	Fair	Fair
Overall landscape viability				Fair

9.4.2 Recommendations

The following actions are recommended to maintain and enhance biodiversity monitoring and investigations around the Derwent estuary.

- Regularly monitor the extent and condition of key habitats within the estuary, particularly those that are vulnerable to reclamation and drainage (e.g. wetlands, saltmarsh and forshore vegetation) and those that are sensitive to water quality decline (e.g. macrophytes and seagrasses), for example using annual aerial surveys.
- Review and update the Derwent estuary habitat atlas every 5 to 10 years.
- Investigate phytoplankton and zooplankton populations in more detail.
- Re-survey benthic macroinvertebrates on a regular basis.
- Re-survey marine pests and foreshore weeds on a regular basis.
- Continue population surveys of little penguins and spotted handfish.
- Encourage and facilitate conservation planning to allow for the landward migration of wetlands, saltmarshes and sandy beaches in response to sea-level rise.

Figure 9.22 High ranked threats to the conservation assets

Threats across targets	Upper Derwent wetlands & macrophytes	Salt-marshes	Ralphs Bay tidal flats	Inter- tidal zone	Terrestrial foreshore vegetation	Rocky reefs & kelp forests	Subtidal soft sediments & seagrass	Pelagic system	Migratory fish	Spotted hand- fish	Little penguins	Overall threat rank
Absence of adequate retreat / buffer areas (with sea level rise)	High	Very High	High	High							High	Very High
Urban stormwater & upper catchment runoff	Low	Medium		High		High	Medium	Medium	Low	High	Low	High
Introduced estuarine fauna			High	High		Medium	Medium	Low		High		High
Reclamation	High	High	High	Low								High
Sewage treatment plants & industry discharges	Medium			High		Medium	Medium	High	Low	Medium	Low	High
Extraction from Derwent river, tributaries, hydro power generation	Medium					Medium	Medium	High	High			High
Construction and upgrade of roads, railways, pipelines & infrastructure	High	High			Medium	-			Medium			High
External nutrients (e.g. aquaculture, ocean currents)				High		Medium	Medium	High				High
Bio-availability of heavy metals	Medium	Medium	Medium	Medium		Medium	High	Medium				High
Aquatic / wetland weeds	High	Low				Medium		Low	Low			Medium
Drought					Medium				High			Medium
Subdivisions, infill housing and other developments (land clearing)					High						Low	Medium
Asset protection, view enhancement (land clearing)					High							Medium
In-stream dams, weirs, fords, pipes									High			Medium
Terrestrial weeds					High							Medium
Land-based recreational activities		Low		Medium	Medium						Medium	Medium
Recreational fishing, boating & diving	Low		Low			Medium	Low	Low	Low	Medium	Low	Medium
Threat status for targets and project	High	High	High	High	High	High	High	High	High	High	Medium	Very High

10.0 INTEGRATED STUDIES

Several major integrated studies of the Derwent estuary have been carried out in recent years to better understand links between water quality, sediment processes and biological response, and how the system may respond to changing inputs and river flows. In addition, a suite of high resolution estuarine models have been developed that provide improved system understanding as well as predictive capacity. These integrated studies are described below and include:

- The Derwent estuary water quality improvement plan (heavy metals and nutrients);
- Derwent estuary biogeochemical model upgrades and associated sensor trials;
- ARC-Linkage study: 'Nutrients: sources, transformation and fate of carbon and nitrogen in the upper estuary'.

10.1 Derwent estuary water quality improvement plan – Stages 1 and 2

The first two stages of the *Derwent estuary water quality improvement plan* (WQIP) were supported through grants from the Australian Government's Coastal Catchments Initiative program. Stage 1 focused primarily on heavy metal contamination, while Stage 2 included a major focus on nutrient enrichment. Over 20 scientists contributed to the WQIP, primarily through partnerships with CSIRO and IMAS (previously the Tasmanian Aquaculture and Fisheries Institute). Key elements of the WQIP included:

- an assessment of heavy metal and nutrient sources, sinks and cycling within the estuary;
- monitoring of water, sediments and biota;
- review of environmental flows from the River Derwent catchment;
- investigations of sediment processes, toxicity and bioaccumulation;
- implementation of a suite of high-resolution system models (hydrodynamics, sediment transport, toxicants and nutrient-response);
- use of these models to test a range of management scenarios;
- development of proposed targets for heavy metals and nutrients;
- management recommendations.

Further details on the various investigations are provided in greater detail in the WQIP reports and synthesis document (DEP, 2007; DEP, 2010).

10.1.1 Key findings – heavy metals

Zinc was selected as the primary indicator of heavy metal contamination 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 estuarine models. Furthermore, levels of most other heavy metals (e.g. cadmium, copper and lead) show a strong correlation with zinc levels, and it was anticipated that management actions proposed to address zinc contamination would address most other metals as well. It was identified, however, that mercury behaves differently and could require other approaches.

An assessment of heavy metal loads discharged to the estuary from a variety of sources was carried out, including major industries, sewage treatment plants, urban stormwater, tips and landfills, and the River Derwent catchment. The single largest source (>80%) was found to be the zinc smelter, in particular the groundwater contamination at the site which contributes the majority of the current load. The second largest source was identified as urban stormwater runoff.

The large area of contaminated sediments in the Derwent estuary raised a number of important questions for future management. Analysis of short cores indicates that the most contaminated middle reaches of the estuary are undergoing some degree of natural recovery, with highest heavy metal levels now occurring at a depth of more than 20 cm below the surface. While surface sediments are still highly contaminated, the majority of these metals are relatively inert and/or tightly bound to sediments and do not appear to leach readily to the overlying waters under current conditions. However, should the current situation change (e.g. oxygen depletion, physical disturbance), it was suggested that sediments could become a significant source of heavy metals. Sediment incubation experiments demonstrated a clear link between dissolved oxygen levels and heavy metal mobility, with a very rapid response to reduced oxygen levels (i.e. within 24 hours) (Banks and Ross, 2009).

Investigations into heavy metal toxicity yielded varying results, depending on the specific sites and test organisms used. An earlier comparative survey of benthic invertebrate communities in the Derwent and Huon estuaries documented an unexpectedly abundant and diverse benthic community in most areas of the Derwent. This indicated that heavy metal contamination was not the overriding factor controlling benthic infaunal community composition for the estuary as a whole (McLeod and Helidoniotis, 2005). A series of experiments using the native brittlestar

Amphiura elandiformis suggested that this could be a useful native indicator of sediment quality/toxicity in the Derwent, particularly as it can be readily observed using video survey methods (Eriksen et al., 2008). Surveys of Derwent estuary biota confirmed high levels of heavy metal bioaccumulation, with the highest levels recorded in fish and shellfish from the middle estuary and from Ralphs Bay. A pilot survey of a broader range of functional groups also documented generally higher levels of metals in biota collected from the middle estuary but did not find a consistent pattern between trophic levels (Swadling and Mcleod, 2008). Based on the investigations carried out to date, it appears that the issue of bioaccumulation rather than toxicity may be a more significant concern in the Derwent estuary and warrant further investigation, particularly with respect to mercury.

As part of the target-setting process, an interim water column target of 15 µg/L total zinc was selected, corresponding to the ANZECC trigger level to protect 95% of species (i.e. slightly-to-moderately disturbed system). A series of modelling runs suggested that this would correspond to a reduction in the annual load by approximately 30–95 tonnes of zinc/year (Margvelashvili et al., 2005), and that this could potentially be achieved through a combination of remediation works at the zinc smelter site and improved stormwater management.

10.1.2 Key findings – nutrients

An assessment of nutrient loads discharged to the estuary was carried out, with particular focus on nitrogen as it is the limiting factor for algal growth in most marine systems. The majority of nitrogen was found to be derived from marine sources (44%), followed by inputs from the River Derwent catchment (29%) and sewage treatment plants (18%). While the majority of marine inputs are seasonal – associated with Southern Ocean water masses during winter months – aquaculture wastes associated with fish farms in the D'Entrecasteaux Channel and Huon are likely to be a component of marine inputs during summer months.

A detailed biogeochemical model for the Derwent estuary was successfully implemented and validated against 2003 observations (an average rainfall and river flow year), providing a good understanding of the interplay between estuarine morphology, hydrodynamics and nutrient processing. The model indicated that the majority of nutrients within the estuary are retained within the system, with elevated levels of dissolved nitrogen, phosphorous and chlorophyll-a predicted (and observed) in the middle reaches of the estuary and at depth.

The model was used to evaluate three alternative management scenarios:

1. A near pristine scenario which removed all anthropogenic inputs but retained the existing (modified) flow regime of the River Derwent.
2. An 'Active Management' scenario for 2015 that assumed reduced anthropogenic inputs as compared to 2003.
3. A 'Business-as-Usual' scenario for 2015 that assumed increased anthropogenic inputs as compared to 2003, as well as low river flows.

These model runs highlighted the critical role played by sediment denitrification in maintaining the overall health of the estuary, in that an estimated 40–60% of the nitrogen load to the estuary is removed through this process. Without this denitrification capacity, nutrients could accumulate to high levels in the Derwent, resulting in poor water quality. This highlights the need to identify and protect areas with high nutrient removal capacity.

The model runs also indicated that freshwater flows from the River Derwent play a major role in nutrient and chlorophyll dynamics throughout the estuary. Low river flows affect the estuary in several important ways, particularly through increased penetration of seasonally nutrient-rich water from the Channel and Storm Bay into the lower estuary, and through reduced discharge of highly coloured river water, resulting in greater water clarity in the upper estuary.

Further work is needed to develop robust nutrient indicators and targets for the Derwent estuary, particularly in light of the critical role played by river flows. It was recommended that additional model scenarios be tested to evaluate future management scenarios under a range of different river flows to determine under what conditions and in which areas the estuary is most vulnerable. Using this information, targets could be set to protect against a 'worst case scenario'. In the interim, the 2015 'active management' scenario was clearly a preferred management direction, in comparison to either the 2003 or 2015 'business-as-usual scenario'. This would suggest a maximum annual nitrogen load of about 2,600 tonnes, and certainly no more than 2,900 tonnes (which was the 2003 load) if the current trophic status and oxygen levels of the Derwent are to be maintained or improved. It will be particularly important to set dissolved oxygen targets that both protect benthic communities and maintain sediment processes, particularly with respect to the remobilisation of heavy metals.

10.1.3 Management recommendations and implementation

The following management actions were recommended to further reduce heavy metal loads to the Derwent, manage nutrient inputs, limit risks associated with contaminated sediments and manage seafood safety risks. A number of these actions have been completed or are currently underway to implement these recommendations, as described below.

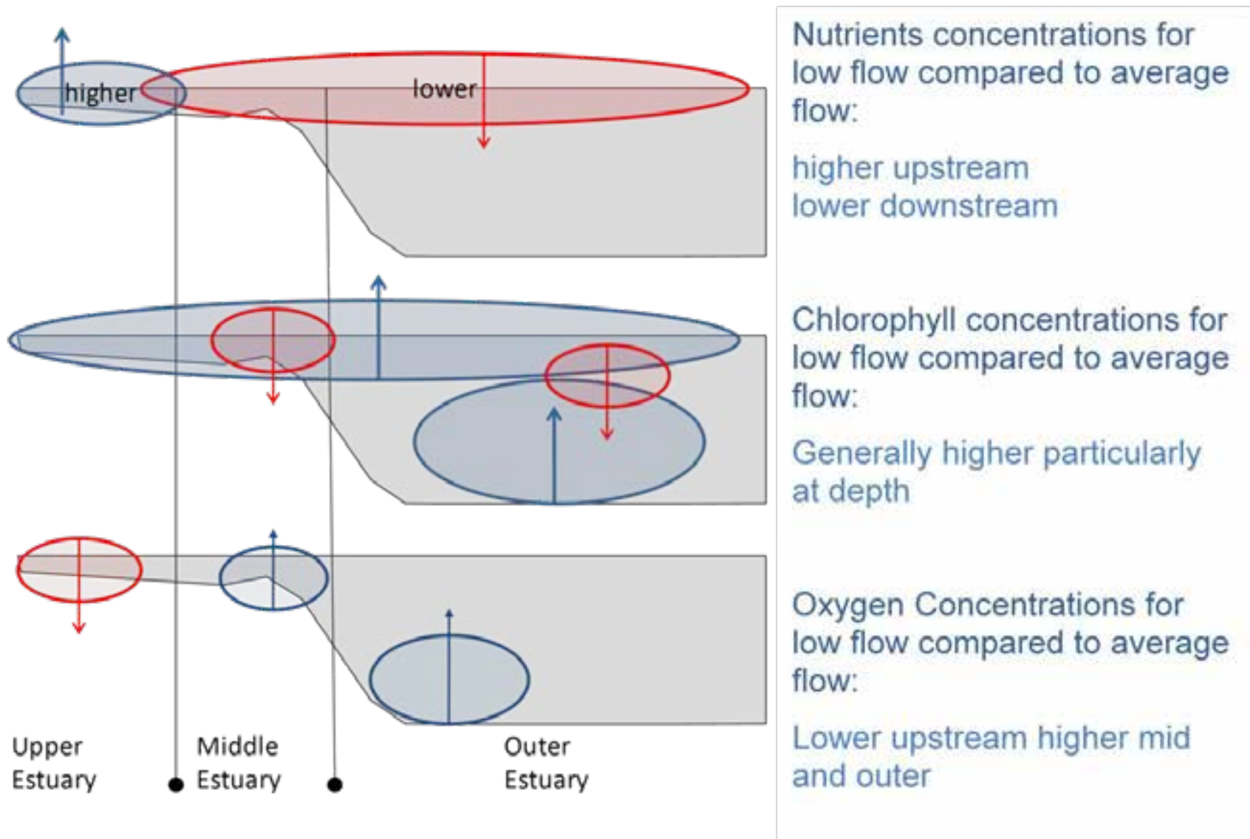
1. ***Continue to reduce heavy metal inputs*** from external sources, particularly through remediation of contaminated groundwater and stormwater at the zinc smelter site and improved management of urban stormwater. Actions to implement this recommendation include:
    - major groundwater and stormwater remediation projects at the Nyrstar Hobart Smelter, covering and/or reprocessing of stockpiles, and sealing of the Electrolysis section basement (see Section 4.2.1);
    - stormwater management projects, including a number of Water Sensitive Urban Design initiatives by regional councils (see Section 4.4).
2. ***Minimise disturbance of heavy-metal contaminated sediments*** by limiting and carefully managing dredging and reclamation activities. Recent actions to implement this recommendation include:
    - development of Derwent-specific dredging and reclamation guidelines (DEP, 2010).
3. ***Improve seafood safety monitoring and public reporting*** to minimise potential risks associated with recreational fishing in the Derwent estuary. Actions to implement this recommendation have included:
    - extended surveys of mercury levels in recreationally-targeted fish and other biota in the Derwent estuary (see Section 8.3);
    - updated seafood safety brochures, signage and community service announcement providing precautionary health advice.
4. ***Manage nutrient and organic inputs*** from marine, catchment, sewage treatment and industrial sources to prevent further eutrophication. Actions to implement this recommendation have included:
    - implementation of major sewage effluent reuse schemes in Clarence and Brighton (see Section 4.1.2);
    - tertiary treatment at Selfs Point and Rokeby sewage treatment plants (see Section 4.1);
    - construction of new secondary treatment system at Norske Skog paper mill (removal of organic matter) (see Section 4.3).
5. ***Manage freshwater flows*** to enhance water quality, wetlands and macrophytes.
6. ***Conserve areas with high nutrient-removal capacity*** including wetlands, tidal flats and seagrass/macrophyte beds. Recent actions to implement this recommendation have included:
    - expansion of the Ralphs Bay Conservation Area.
7. ***Enhance and integrate monitoring and reporting.*** Recent actions that will support this recommendation include:
    - continued ambient water quality monitoring in the Derwent estuary (monthly) and preparation of annual Report Cards (see Section 5.1);
    - ambient water quality monitoring programs in Storm Bay and the D'Entrecasteaux Channel (see Section 3.3);

8. ***Improve understanding through targeted investigations.*** Actions to support this recommendation include:
   - investigations into Derwent estuary sediment processes, including denitrification rates (see Section 10.3);
   - mapping and investigation of upper estuary wetland and macrophyte communities (see Section 9.1.3) ;
9. ***Extend and integrate system models to refine targets and guide management***, as described in the following section.

10.2 Extension and further development of integrated models and sensor technologies

Following on from stages one and two of the WQIP, several additional projects have been undertaken to evaluate additional scenarios, to extend the Derwent-specific biogeochemical model to cover a larger area (Storm Bay and D'Entrecasteaux Channel) and to better quantify nutrient inputs at the landward and seaward ends of the system using several different sensor technologies.

Figure 10.1 Schematic diagram showing a generalised representation of the model scenarios in the estuary with respect to flow scenarios (source: Wild-Allen and Skerratt, 2011)



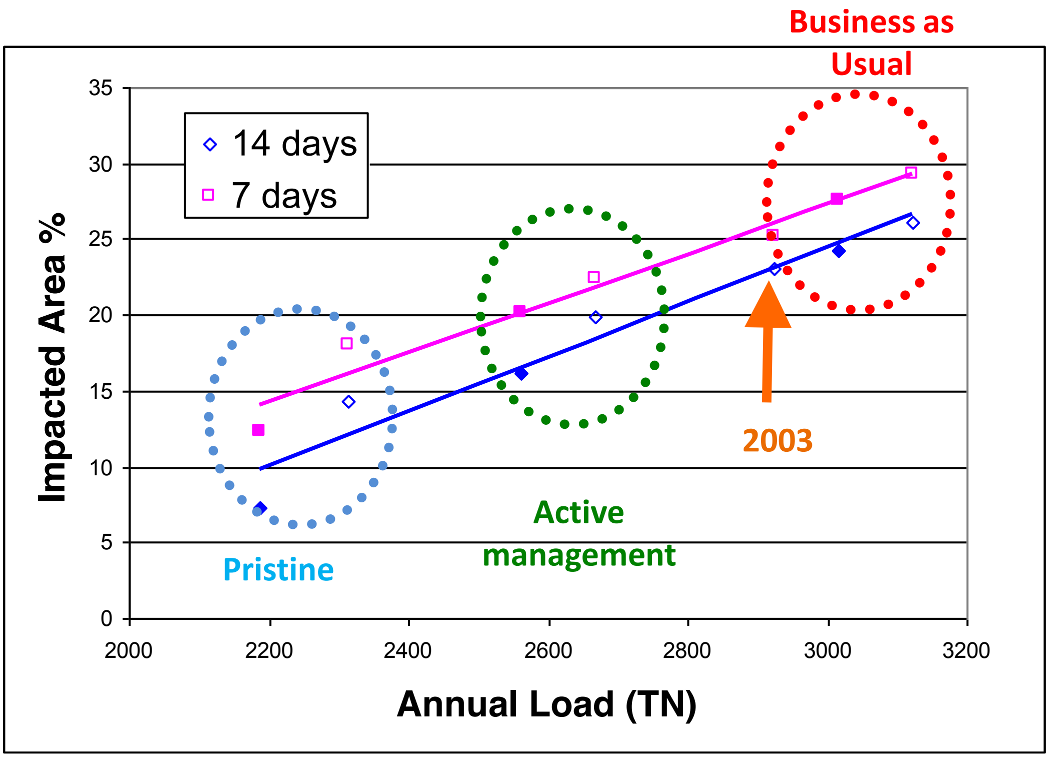
10.2.1 *Derwent estuary biogeochemical model: scenario extensions*

In 2011, Wild-Allen and Skerratt modelled several additional scenarios to complement their previous work in order to better understand the influence of differing river low conditions on estuarine biogeochemistry. Each of the three scenarios (near pristine, 2015 active management and 2015 business-as-usual) was thus modelled using an average flow year (2003) and a low-flow year (2007). Results from these simulations illustrate the strong relationship between river flow, nutrient loads and water quality.

In all simulations the reduction in Derwent river flow corresponded to an increase in phytoplankton biomass in the estuary and the area classified as eutrophic increased by 3–5%. DIN and DIP (dissolved inorganic nitrogen, dissolved inorganic phosphorus) concentrations in the low flow scenarios were on average lower in the middle and outer estuary surface layers and higher in the upper estuary. Bottom water dissolved oxygen was generally lower in the upper estuary under low flow conditions coincident with greater upstream excursion of the salt wedge, but higher in the outer estuary due to a stronger intrusion of oxygenated marine water into the lower estuary.

The budget summaries for each scenario show a consistent reduction in riverine nutrient input under low flow conditions but a greater influx of nitrogen across the marine boundary. There was little variation in denitrification between scenarios under contrasting flow conditions, however under low flow export across the marine boundary was reduced. Under low flow conditions the model simulated a small but consistently

Figure 10.2 Annual total nitrogen input to the estuary and area of estuary with sediment oxygen saturation less than 40% for 7 and 14 days from the near-pristine, 2003, active management and business-as-usual model simulations [shaded markers are low flow; open markers are moderate flow] (source: Wild-Allen and Skerratt, 2011)



greater (by 46–65 tN/y) accumulation of nutrients in the estuary than under moderate flow. Greatest accumulation of nutrients in the estuary occurred in the business as usual scenario under low flow.

A positive linear relationship was established between the total annual nutrient load to the estuary and the area of sediments experiencing less than 40% oxygen saturation for 7 or 14 days in a year. The near pristine scenario had the smallest impacted area (~ 10%), whilst the largest impacted area was simulated by the business as usual scenario (>25%). Under low flow the area of sediment impacted by low oxygen concentrations was reduced in all scenarios (1–7%); greatest reduction occurred in the near pristine scenario. Under reduced flow there was a greater influx of oxygenated marine water into the outer estuary alleviating low bottom water concentrations in the lower estuary. However under high nutrient loading the increase in biomass resulted in greater oxygen drawdown throughout the estuary, which offset the increase in concentration due to ventilation. This project was funded in part through an Australian Government grant, with co-investment by CSIRO (see Wild-Allen and Skerratt 2011 and Skerratt et al 2013 for details).

10.2.2 Development of integrated regional models, including near real time models

HDD hindcast model

In 2013, Wild-Allen et al. developed an integrated regional model for the Huon, Derwent and D'Entrecasteaux Channel (HDD model). This biogeochemical model was implemented on a very fine resolution (<100 m) 3D model grid based on a hindcast simulation of 2009. The model simulates the cycling of carbon, nitrogen, phosphorous and dissolved oxygen through dissolved and particulate organic and inorganic forms. The model is organised into pelagic, epibenthic and sediment zones and includes multiple plankton, macrophyte, detritus and nutrient compartments.

The hindcast simulation of 2009 was integrated using a novel off-line Lagrangian hydrodynamic transport model which facilitated the rapid integration of the very large number of grid cells. This allows for a much more rapid run time than the previous, fully coupled model. Results were compared with observations from the DEP's monthly monitoring database to evaluate model skill. Model skill was good in the upper estuary and exceeded the skill of the previous Derwent biogeochemical model for nutrients, chlorophyll and benthic plants. However, at the start of 2009 the observed drawdown in bottom water dissolved oxygen and the associated nutrient dynamics were not captured by the model, likely due to an excess in air-sea gas exchange in the model. The simulated biogeochemistry of the mid and lower estuary was less skilful as the model underestimated the concentration of nutrients and failed to reproduce the observed seasonal phase of chlorophyll. The low simulated nutrient concentrations partly resulted from an under-representation of the transport of nutrients across the marine boundary and, compared to the 2003 Derwent model, the omission of stormwater point source loads, many of which drain into the mid estuary.

The HDD model demonstrated the capacity to simulate biogeochemical cycling in the estuary with very high spatial and temporal resolution, particularly in the upper estuary where the grid resolution has been much improved. However further work is underway to improve the overall accuracy of the model with respect to observations. Given the limited skill of the 2009 hindcast simulation, the analysis and presentation of results was restricted to a subset of biogeochemical state variables which could be assessed in the context of observations. The 80th percentile nutrient concentrations were greatest in the upper estuary and decreased downstream. Surface nitrate and dissolved inorganic phosphate exceeded bottom water concentrations, except in the proximity of STP and industrial outfalls, indicating their main source was from river and surface inputs. The 80th percentile chlorophyll concentration was maximal in the mid estuary modulated by access to nutrients, light for photosynthesis, and removal by zooplankton grazing. In several places localised nutrient and chlorophyll plumes were clearly visible in close proximity to STP and industry outfalls.

HDD near real time model

A pilot near real time HDD model was also developed (and has been updated with the marginally coarser DHD grid) to run in fully coupled mode simultaneously with the hydrodynamic and sediment models, with a run time ratio of 4:1 (4 simulated days per day of runtime). This pilot model has been ongoing since May 2013 and model results are routinely archived and displayed on the CSIRO Coastal Environmental Modelling Groups web page: www.emg.cmar.csiro.au/www/en/emg/projects/S-E--Tasmania/Near-Real-Time-Results.html. The skill of this model has not yet been rigorously assessed and the pilot results are presented with a disclaimer, noting that it is under development and for demonstration purposes only.

The model demonstrates the technical ability to automatically co-ordinate forcing data and schedule the hydrodynamic broad-scale (SETAS) and nested fine-scale (STORM) and DHD models. In the absence of live monitoring data, river and point source loads of biogeochemical substances into the estuary are based on annual mean observations, which cannot resolve temporal fluctuations. The biogeochemical model parameter values are equivalent to the 2009 hindcast simulation however, due to fundamental differences in the hydrodynamic fully coupled DHD and Lagrangian HDD transport schemes, the resulting biogeochemical tracer fields may diverge. Recent results have shown that the transport of biogeochemical tracers including nutrients across the marine boundary is more accurate, using a fully coupled or conservative fluxform transport model scheme.

The current pilot near real time biogeochemical model results available on the web are unlikely to be accurate but may provide some interesting insight into system dynamics. More value could be placed on the results given a simultaneous skill assessment against live sensor data and/or an archived climatology of historical observations. This is a priority for future work. Given improvements to the model, better resolution of biogeochemical loads to the estuary and automated skill assessment across a range of spatial and temporal scales, it is envisaged that routine operation of the near real time biogeochemical model will replace sporadic hindcast simulations of historic conditions. Using the BOM short term forecasting system, similar biogeochemical model forecasts could be supplied for example to alert management of falling bottom water oxygen concentrations and prompt management action such as temporary diversion of point source organic loads or regulation of river flow.

These models were funded in part through an Australian Government grant, with co-investment by CSIRO (see Wild-Allen et al., 2013 for full discussion).

10.2.3 Continuous nutrient observations using sensors

Three different continuous nutrient observing systems have been deployed in the Derwent estuary, as described by Wild-Allen and Rayner (2014). These included stationary systems to better characterise riverine and marine boundary conditions, as well as a fine-scale spatial survey using a boat-based system, which is described below.

A Systea Wet Chemistry analyser was deployed at the Bryn Estyn water treatment plant to characterise river water entering the estuary (nitrate, ammonia, phosphate and silicate). Samples were collected 4-hourly from July 2012 to January 2013, and compared and calibrated against grab samples analysed in the lab. At the head of the estuary the observed variability in river nutrient concentrations was not propagated into the biogeochemical model by an upstream boundary condition based on interpolated monthly observations. In the absence of correlations between river nutrient concentrations and other water quality observations, further investment in automated nutrient analysis of river conditions is recommended to better inform the model. The River Derwent nutrient observations showed an increase in nitrate and phosphate concentration in the past 15 years and a possible change in Redfield ratio from least supply of phosphate throughout the year, to least supply of nitrogen in early winter. Ongoing observations and the implementation of a catchment model would better resolve the evolving nutrient conditions in the river and allow improved parameterisation of the biogeochemical model in the upper estuary.

An in situ ultraviolet optical nitrate analyser was deployed on a benthic lander at the mouth of the estuary to monitor the marine nitrate concentrations entering the estuary (Nov 2009 – March 2010, and August–September 2012). This system provided four months of good quality data, following calibration against grab samples. Temporal variability in this nitrate data identified the nutrient concentration of characteristic water masses in Storm Bay and their seasonal evolution, however the observed variance in nitrate concentration was somewhat greater than simulated.

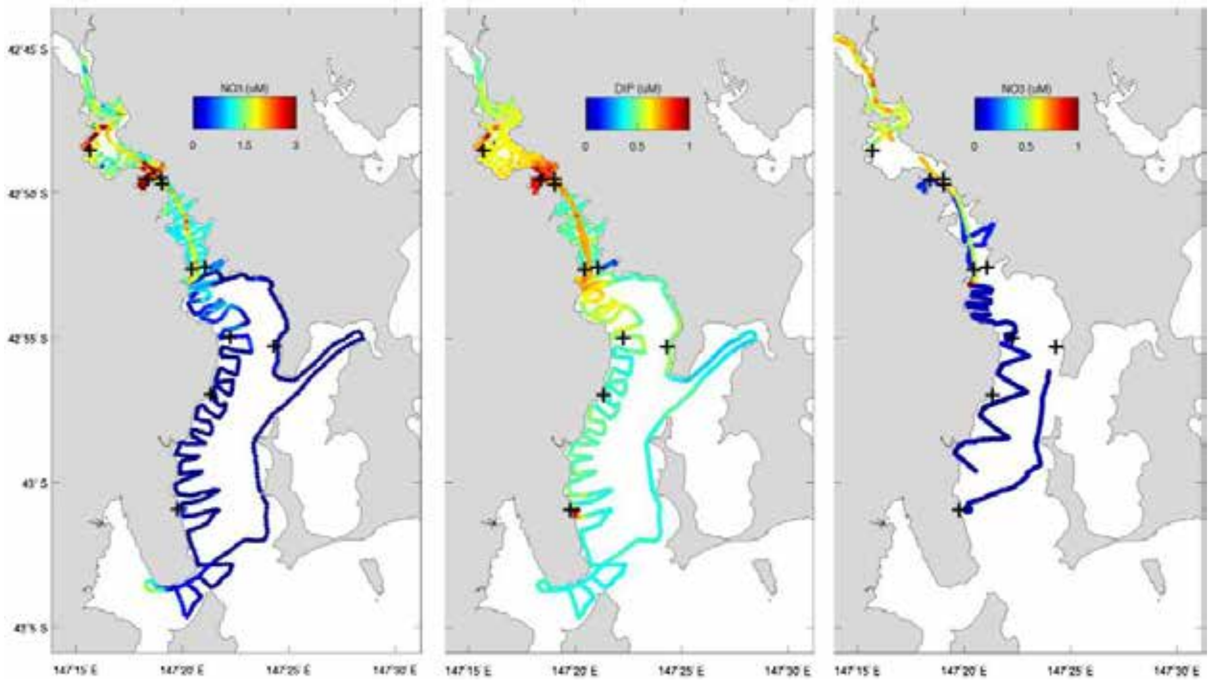
Finally, a rapid reverse flow injection analysis system was used to undertake a high resolution spatial survey of conditions throughout the estuary (nitrate and phosphate). Two multi-day surveys were conducted in the mid and lower Derwent in May 2010 and March 2012, with over 1,000 samples processed during each survey. Observed snapshots of fine-scale spatial variability in surface nitrate and phosphate throughout the estuary matched model results in contrasting years, with surprising accuracy. Plumes of elevated nutrient concentration associated with point source discharge locations were clearly identified against a background gradient in nutrient concentration from fresh to marine, as illustrated in Figure 10.3 (see Wild-Allen and Raynor, 2014 for further details).

10.3 Nutrients: sources, transformation and fate of carbon and nitrogen in the upper estuary

In 2007–08, scientists at the University of Tasmania, together with scientists and students from the University of Melbourne, Southern Cross University and CSIRO, were awarded a four-year ARC-Linkage grant to investigate how nutrients are processed in the Derwent estuary, with a particular focus on sediments. This project was also supported by the DEP and Norske Skog Boyer, as industry partners. The three broad objectives of the study were to:

1. Examine spatial and temporal variability in nutrient cycling processes in Derwent sediments, including relationships with organic enrichment and other environmental properties.
2. Assess changes in sediment nutrient processes following large-scale reduction in organic carbon inputs from Norske Skog Boyer paper mill.

Figure 10.3 Observed nitrate (left) and phosphate (mid) concentrations in May 2010 and nitrate (right) in March 2012; crosses mark sewerage and industry outfalls, arrow points to a fish farm (FF) (source: Wild-Allen and Rayner, 2014)



3. Conduct manipulative experiments to quantify the influence of other natural and anthropogenic influences on nutrient cycling.

The key studies and results are reported in the subsections below.

10.3.1 Spatial and temporal variability in nutrient cycling processes and relationships with biological and environmental properties

The large-scale survey work identified in Objective 1 set out to provide a measure of nutrient fluxes in benthic sediments throughout the estuary for the first time. Sixteen sites were surveyed in the area between New Norfolk and lower Sandy Bay at the locations shown in Figure 10.4. To gain an understanding of the temporal dynamics of nutrient cycling in the estuary, surveys were repeated seasonally for two years at a subset of these sites. At each site, Banks (2011) conducted sediment core incubations to assess how water quality, sediment chemistry and benthic macrofauna influenced the flux of nutrients. Overall, sediment fluxes (oxygen, carbon dioxide, ammonia, nitrate, silicate and phosphate) were within the range reported in other Australian coastal bays and estuaries. Measures of respiration (as a proxy of organic carbon loading to sediment) and denitrification efficiency (DE) were typically in the range considered indicative of oligotrophic to mesotrophic conditions (CO2 fluxes ranging from 60–100 mmol m-2d-1 and DE > 40 % (Eyre and Ferguson, 2009)). The drivers of spatial differences in nutrient cycling were dissolved oxygen concentration of the water column (accounted for 21% of the difference between sites), the degree of sediment enrichment with organic carbon (accounted for 13% of the difference), the concentration of algae at the sediment: water interface (microphytobenthos, accounted for 14%), the distribution of suspension feeding macrofauna (16%) and bioturbating macrofauna (11%). This survey provided a baseline of nutrient flux information that will assist calibration and validation of biogeochemical models.

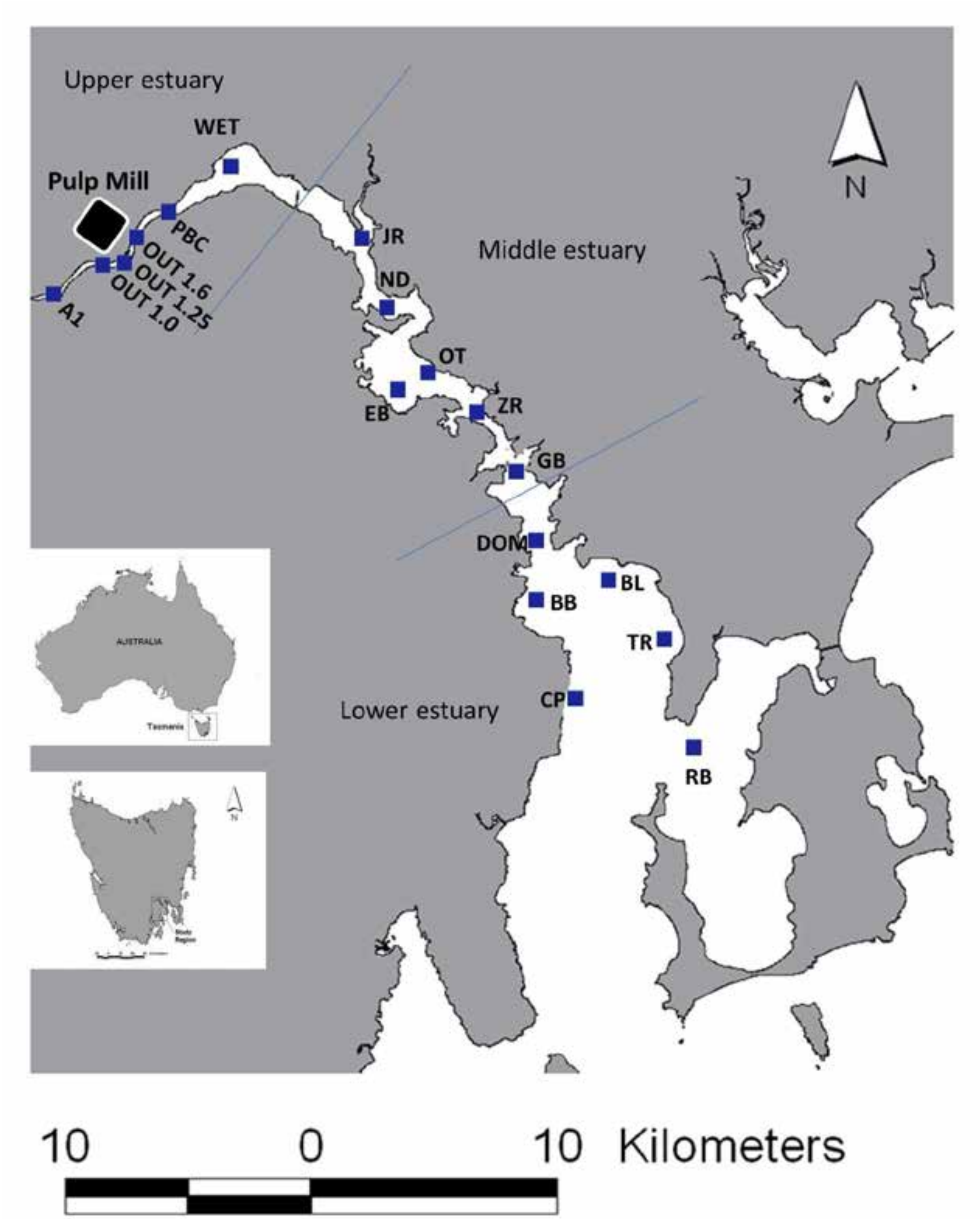
More specifically, the study highlighted the importance of bottom water dissolved oxygen concentrations and total carbon content of sediments in explaining variation in nutrient fluxes. Decreasing dissolved oxygen concentration increased the flux of ammonium and dissolved inorganic phosphorus from sediment to the water column and reduced the flux of nitrite and nitrate, due to decoupling of the nitrification-denitrification link explained by Abell et al. (2014). These results are evident in water quality data reported in Section 5.4. The flux of dissolved organic nitrogen from sediments was reduced by higher concentrations of total carbon and macrofauna, possibly due to nitrogen limitation in sites with high carbon concentration. Low DO conditions are most prevalent in the mid–upper estuary, where organic enrichment of the sediments is high and there is reduced mixing and enhanced stratification during periods of low river flow. There was also evidence of seasonal dynamics in nutrient fluxes, with process rates generally higher in summer than winter. In the upper estuary, however, river flow dynamics, such as the timing of large floods and extended dry periods, appear to be more significant drivers of nutrient fluxes.

It is important to note that this study was restricted to subtidal soft sediments. While these represent the majority of the Derwent benthos, there are extensive areas of shallow subtidal/intertidal sediments, both vegetated (e.g. the extensive seagrass beds in Bridgewater wetlands) and un-vegetated (e.g. Ralphs Bay mud flats) that are likely to play a critical role in nutrient processing in the Derwent. This was highlighted in a pilot study that compared nutrient fluxes in seagrass and unvegetated habitats at Berridale and Bridgewater: at both sites denitrification efficiency was higher in the seagrass habitat. A greater understanding of the role of these habitats is a critical next step in predicting how the estuary will respond to natural and anthropogenic environmental change.

10.3.2 Changes following the large scale reduction in organic carbon inputs from the Norske Skog paper mill

In October 2007, Norske Skog Boyer commenced operation of a secondary treatment plant. This major upgrade provided a unique opportunity to document the ecosystem response to the resultant large-scale reduction in organic inputs to the estuary. Investigations were two-fold. Firstly, water quality and sediment function were compared before and after the

Figure 10.4 Map of 18 study sites within Derwent estuary



upgrade, at control and impact (within 800 m of the outfall) sites (Ross et al., 2010). Secondly, a stable isotope tracer experiment was conducted, whereby the transformation and fate of organic matter associated with PE (residual wood fibre) and SE (activated sludge biomass and phytoplankton) was compared (see Oakes et al., 2011).

To examine potential changes in benthic macrofaunal assemblages and nutrient cycling processes, following the secondary treatment upgrade, a series of sediment experiments were conducted by the University of Tasmania at impact sites (0 m, 250 m and 750 m downstream of the outfall) and control sites located outside the impact zone (1200 m upstream, 3400 m and 8400 m downstream of the outfall) in summer and winter, before the upgrade and again in summer and winter 2008, after the upgrade. Ambient water quality data was also collected at 5 sites in the upper estuary before (January to September 2007) and after (January to September 2008) the upgrade, and compared to changes in effluent water quality for the same periods, to identify whether the secondary treatment upgrade has led to broader water quality changes in the upper estuary.

The before-versus-after comparison demonstrated that the secondary treatment upgrade achieved its primary objective with a significant reduction in the organic carbon loads discharged to the Derwent estuary. TOC and DOC loads declined by 64% and 66%, respectively, while nitrogen and phosphorus loads increased by 62% and 66%, respectively, as part of the secondary treatment process. These changes were reflected in ambient surface water concentrations. However, the results also demonstrated a significant impact in the immediate vicinity of the outfall, in terms of benthic nutrient cycling processes and macrofaunal assemblages living in the sediments. There was a major increase in the rates of respiration and ammonia production, phosphate production and nitrate uptake at the sites in the vicinity of the outfall following the upgrade. These results are consistent with a reduction in coupled nitrification–denitrification in these sediments. In terms of macrofauna, most notable was the appearance of large numbers of capitellid worms at the impact sites following the upgrade, a genus known to be indicative of organically enriched sediments. Ross et al. (2010) suggest that this is largely due to a change in the nature of the particulate matter entering the estuary and settling on the sediments at the impact sites following the upgrade. Rather than the refractory wood fibre particulates contained in the combined effluent stream prior to the upgrade, the particulate matter is now dominated by the spill over of the labile bugs that are essential in the secondary treatment process. Importantly, Norske Skog has taken steps to reduce the total suspended solid loads as a direct result of these findings; since the completion of this study total suspended solid loads have been reduced from 5–6 tonnes/day to less than 0.5 tonnes/day in 2013. This has most likely lead to significant improvements in sediment function in the vicinity of the outfall (see Ross et al. 2010 for details).

The results of the stable isotope tracer experiment, carried out at an intertidal mid-estuary site (Berridale Bay), indicate secondary treatment of paper mill effluent has a greater potential for permanent N removal, via denitrification, than primary treatment of paper mill effluent (see Oakes et al. 2011 for details).

10.3.3 Manipulative experiments

As bottom water DO conditions and organic loading were observed to influence sediment function in both the large-scale survey and the paper mill assessment, a number of manipulative experiments were carried out to further examine the nature of these interactions. See Banks (2012) and Banks et al. (2012) for details. In the first experiment, the effects of short term (24-hour) reduction of bottom water DO saturation were assessed. The DO reduction was sufficient to increase NH4 and decrease NOx fluxes from experimental sediments, indicating a reduction in sediment nitrification efficiency. This is consistent with a greater proportion of nitrogen being released back into the water column in bioavailable forms, rather than been permanently removed from the system via denitrification. Because of the contaminated nature of the sediments, the effect of the short-term reduction in bottom-water dissolved oxygen saturation on metal partitioning (Cd, Cu, Fe, Mn, Pb and Zn) was also assessed. The results showed that even very brief periods of hypoxia may significantly increase the dissolved fraction of these heavy metals (2- and 5-fold increases for Cd and Cu respectively) within contaminated sediments, increasing their potential for ecological harm.

Research was conducted to understand the effects of extended hypoxia on nutrient and metal fluxes and to identify the importance of the underlying ecological properties of a site in influencing the response to hypoxia. Sediment from three sites, characterised by different levels of organic matter enrichment, metal contamination and different macrofaunal assemblages, was incubated without oxygen replenishment for 40 days. In terms of the key nitrogen cycling processes, nitrification and denitrification, there were no discernible differences between sites. When the sediments became hypoxic at all three sites, the production of nitrate within the sediments via nitrification became limited and the denitrification had to rely on nitrate drawn from the water column. The most discernible effect on nitrogen processing was apparent after approximately one week, when there was major drop in denitrification efficiency and a corresponding increase in the release of ammonia into the water column. Macrofaunal properties appeared to influence the initial timing of, and response to, hypoxia. The site with the lowest abundance of macrofauna also contained a large amount of refractory organic material; decomposition at this site was slow until conditions became anoxic. Metals manganese (Mn) and iron (Fe) which are known to significantly regulate the release of other divalent cations from suboxic sediments, were fluxed from sediments at all sites as hypoxia developed. However, the release of arsenic (As), cadmium (Cd), copper (Cu) and zinc (Zn) was comparatively low and unrelated to the degree of sediment contamination, although release of the metalloid As increased significantly under anoxic conditions. This is consistent with the notion that the metals in the sediments are largely refractory. Importantly, the most significant release of Cu and Zn occurred within the first few days of hypoxia, suggesting that brief and recurring episodes of oxygen depletion may present a greater risk for metal release than periods of extended hypoxia.

Finally, the importance of a bioturbating polychaete worm, Cirriformia filigera – the dominant (90%) component of macrofaunal assemblages in severely metal-contaminated sediments – in regulating nitrogen processing was assessed. The presence of C. filigera resulted in a doubling of sediment metabolism. Although the activities of C. filigera did not change the combined nitrate and nitrite fluxes there was an increase in ammonia flux to the water column and critically, a three-fold increase in denitrification. These results highlight the important ecosystem service provided by a single species due its metal tolerance and burrowing activities.

10.3.4 Key findings and recommendations

Overall, the key findings of this study were as follows (Ross et al., 2012):

- There are clear spatial and temporal patterns in sediment nutrient cycling processes in the Derwent;
- DO conditions and organic matter loading are key drivers of these patterns;
- Sediment nitrification is the key process that is limited when DO concentrations are reduced;
- Two key causes of reduced bottom water DO observed in this study were reduced environmental flows and elevated organic matter deposition in the vicinity of the paper mill outfall;
- The secondary treatment upgrade led to an increase in supply of labile organic matter and reduced nutrient cycling capacity in the immediate vicinity of the outfall. Importantly, as a direct result of these findings Norske Skog has taken steps to reduce the total suspended solid loads; since the completion of this study total suspended solid loads have been reduced from 5–6 tonnes/day to around 1 tonne/day. This has most likely lead to significant improvements in sediment function in the vicinity of the outfall;
- At a broader scale, the secondary treatment has led to a significant reduction in overall inputs of carbon to the estuary and there is a greater potential for permanent nitrogen removal via denitrification from secondary treated paper mill compared with primary treated paper mill effluent;
- Metal tolerance and the functional characteristics of macrofauna can play a major role in maintaining key nutrient cycling processes in metal-contaminated sediments;

- Heavy metals in the sediments are largely refractory, however there still remains a significant fraction that can become bioavailable following short term oxygen depletion events.

Recommendations for managers and for future research include the following (Ross et al., 2012):

- Greater integration of estuarine responses in environmental flow management in the Derwent catchment;
- Increased focus on monitoring bottom water dissolved oxygen concentration directed at sensitive times and locations (e.g. mid–upper estuary in summer) using high frequency in situ loggers;
- Further investigation of nutrient cycling processes in the large shallow subtidal/intertidal areas (e.g. extensive seagrass beds around Bridgewater and Ralphs Bay tidal flats), including their response to environmental change.

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ACRONYMS

ACE CRC	Antarctic Climate Ecosystem Cooperative Research Centre
ANOVA	Analysis of Variance
ANZECC	Australian New Zealand Environmental 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	Biological Oxygen Demand
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
DEP	Derwent Estuary Program
DEPA	Derwent Estuary – Pittwater Area
DGT	Diffusive Gradient Thin-Film
DHHS	Department of Human Health 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
IMAS	Institute of Marine and Antarctic Studies
IPCC	International 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 (theLIST website: www.thelist.tas.gov.au)
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	Sewerage 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 & 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	Under-Ground 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