Department of Water
Government of Western Australia

The Leschenault Estuarine System, South-Western Australia

Condition Statement and Recommendations for Management

June 2007

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Cover photograph: Leschenault Inlet, Bunbury (by Ashley Ramsay)

Executive Summary

This document describes the current environmental condition of the Leschenault estuarine system, the surface waters feeding into the system and the surrounding estuarine catchment. This system includes the Leschenault Estuary, the lower reaches of the Collie, Brunswick and Preston Rivers, and the Leschenault Inlet.

The report utilises historical records and studies together with recent environmental monitoring to describe the current condition, enabling the Department of Water and the Leschenault Catchment Council to determine natural resource management recommendations and directions for future strategic planning.

The key findings of the document are as follows;

Leschenault Estuary

- Climatic patterns of rainfall and subsequent nutrient loading from catchment runoff in surface water and sediments strongly influences the growth of macrophtyes (seagrass and macroalgae) which in turn determines invertebrate faunal abundance and assemblage diversity.
- The change brought about by the creation of the 'Cut' has resulted in increased salinities, salinity stratification and sedimentation in the estuary. This has imparted gradual changes on fringing and aquatic vegetation towards more salt-tolerant floristic associations, including an increased prevalence of the white mangrove *Avicennia marina*. These changes were precursored by extensive changes in land use in the catchment as land was cleared and subsequently developed for agriculture and more recently for expanding urbanisation.
- Water quality in the estuary is relatively consistent and below accepted Australian standards for nutrients as a consequence of the location and flushing capacity of the 'Cut'.
- Changes in salinity stratification, invertebrate diversity and abundance, and sedimentation all reflect a system that is continuing to evolve from the changes associated with the incision of the 'Cut' and the on-going development and land-use intensification within the catchment.

Lower Collie, Brunswick and Preston rivers

- The hydrodynamics of the lower river systems is governed by tidal influences from the Leschenault Estuary but more strongly from climatic patterns of rainfall and catchment runoff. Tidal movements and saltwater intrusion in summer are replaced by freshwater surface flows in winter.

- Water quality analysis reflects eutrophic conditions in these reaches as these areas act as the 'sinks' for sediment and nutrients transported off the surface and soil profiles of the catchment. The elevated nature of these nutrients and sediments retained in the river systems, in conjunction with seasonal patterns predispose the lower riverine reaches to annual algal blooms in summer and autumn.
- Fish kill events were recorded in the lower Collie River in 2002, 2003 and 2004, and the Brunswick River in 2002 and 2004. These events were associated with, and as a consequence of algal blooms. No reports of fish kills were recorded in these areas prior to 2002.

Leschenault Inlet

- The changes which have brought the Leschenault Inlet to its current form have resulted in the environment changing from an estuarine system to a marine embayment which has altered the biological and physical dynamics, including reduced depth and influence from the ocean, and reduced freshwater inputs which has resulted in more marine associations of fringing and aquatic vegetation and faunal assemblages.
- While a proportion of nutrients are bound in sediment, the water quality indicates nutrients in the water column are readily diluted/ dissipated through high tidal exchange.
- There is a general absence of macrophytes and associated faunal assemblage diversity and abundance due to an absence of sand in the substrate and freshwater nutrient inputs.
- There is an accumulation of heavy metals identified within the sediments as a likely consequence of stormwater discharge from the surrounding urban catchment.

The catchments which source and support the Leschenault estuarine system are subject to increasing pressure; urban and industry expansion in the immediate adjacent areas, increasing water requirements in a drying climate, and intensification and changes in land use all impose pressure on the system. The Leschenault estuarine system exhibits symptoms which reflect the state of the catchment environment. Therefore, the management of these water bodies and waterways requires management that not only needs to reflect the immediate environment, but has outcomes that comply with a broader catchment management approach – integrating regulatory, statutory and community-driven stakeholders working in partnership.

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1 Introduction

This document describes the current environmental condition of the Leschenault estuarine system, the surface waters feeding into the system, and the surrounding estuarine catchment. In describing the current environmental condition of these waterways and the region, a brief summary is provided on the study area, historical and current use of the surrounding catchment, and background to the environmental state of the system. This information, together with recent environmental monitoring of the system, has been used to describe the current environmental condition, from which resource management recommendations and strategic directions have been made.

1.1 Study area

The Leschenault estuarine system is located approximately 180 km south of Perth in south-western Australia (Figure 1). Originally there was only one shallow tidal water body known as the Leschenault Inlet. In 1951, the natural outlet to the ocean of this water body at Point MacLeod was closed to eliminate the accumulation of river silt in the old Bunbury port area. At the same time, a connection to the ocean was excavated through the sand dunes opposite the mouth of the Collie River (“The Cut”). In 1968-69, the Preston River downstream of the Australind Road Bridge was realigned to allow for the construction of the Bunbury Port Authority Inner Harbour. In 1971, work on the Inner Harbour commenced, cutting off the southernmost part of the inlet. On completion of the Inner Harbour, a channel was cut at Point MacLeod (“The Plug”) to allow water circulation to this small body of water, and allow the passage of boats to and from Koombana Bay. These modifications have resulted in the renaming of the water bodies; the smaller water body at Point MacLeod is now known as the Leschenault Inlet and the main water body to the north is known as the Leschenault Estuary. These changes in the Leschenault Estuary are described in Figure 2.

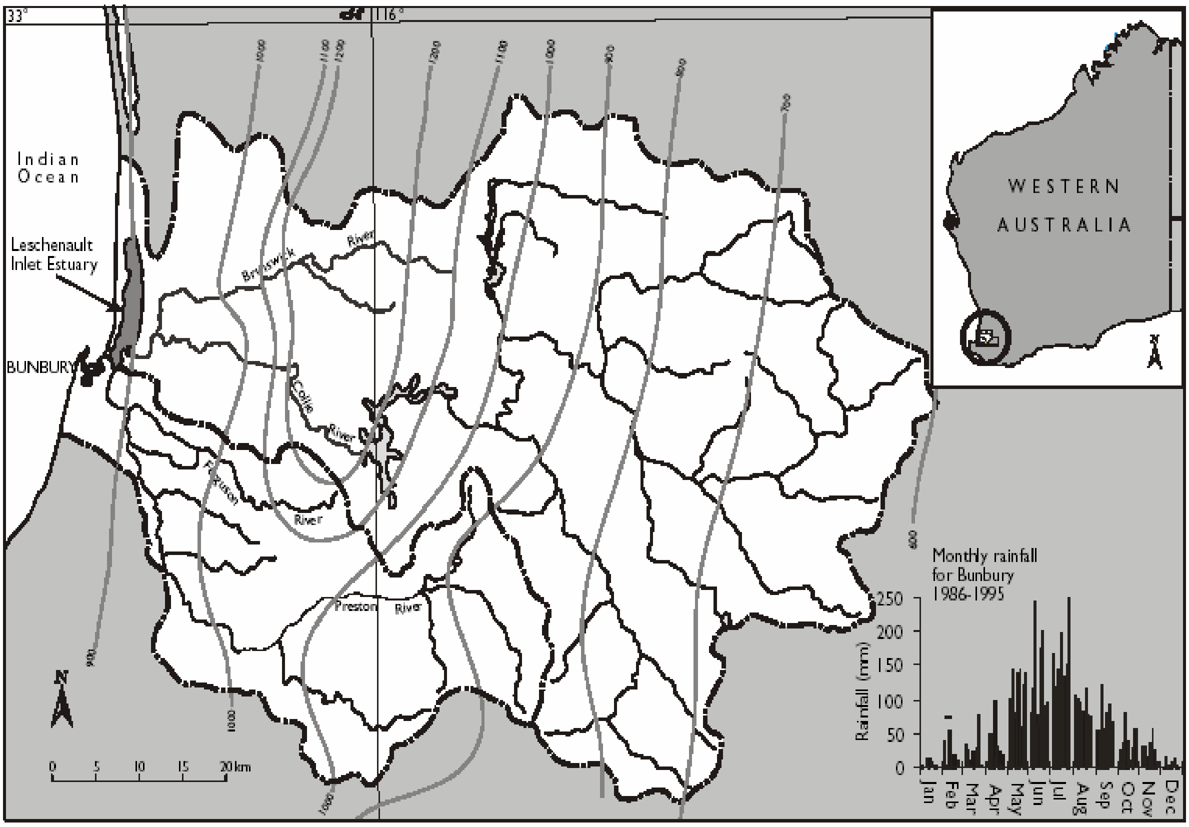


Figure 1. Location of the Leschenault Estuary showing setting within the extensive drainage basin of the Collie, Brunswick (including Wellesley), Ferguson and Preston Rivers, and rainfall isohyets in millimetres. Rainfall graph demonstrates typical annual rainfall pattern for the catchment (demonstrated through the period 1986-1995) (Semeniuk *et al*., 2000).

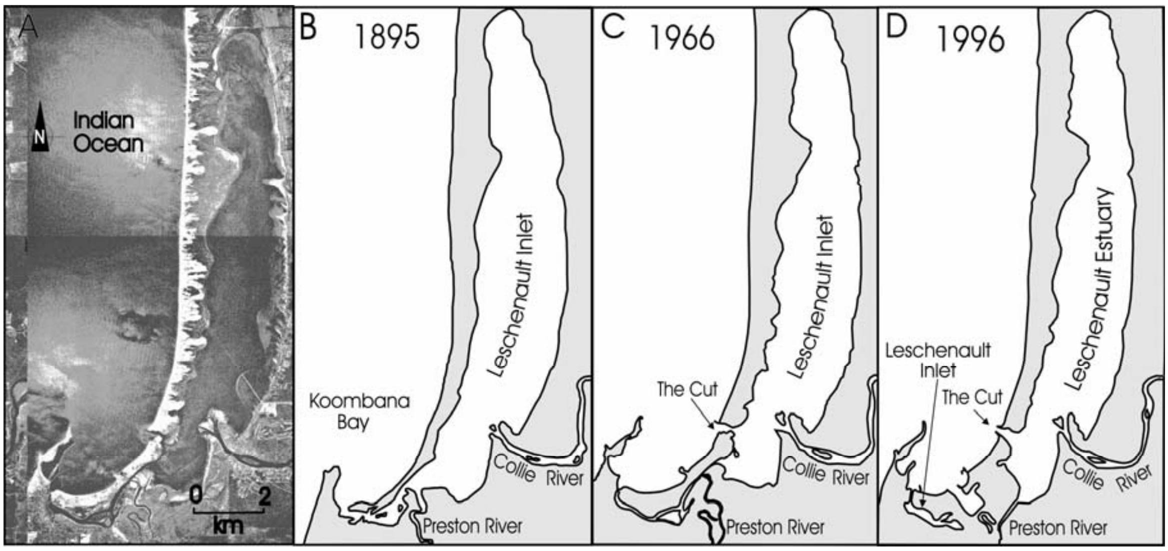


Figure 2. Changes to the Leschenault Inlet/ Estuary over time. (Semeniuk *et al*., 2000).

The Leschenault Inlet, about 1,900 metres long and up to 200 metres wide, has an urban catchment area of around 500 hectares and with its unique stand of the white mangrove, *Avicennia marina*, is a major feature of the City of Bunbury.

The Leschenault Estuary is a shallow, elongated water body, lying roughly north-south and separated from the Indian Ocean by a sand dune peninsula. The estuary is about 13.5 kilometres long, up to 2.5 kilometres wide and has a surface area of approximately 25 square kilometres. The Leschenault water catchment has an area of 1,981 square kilometres, encompassing the Wellesley, Brunswick, (lower) Collie, Ferguson and Preston River sub-catchments. The Collie and Preston Rivers discharge directly into the estuary at its southern end with runoff from the catchment discharging into the ocean via “the Cut” through the peninsula.

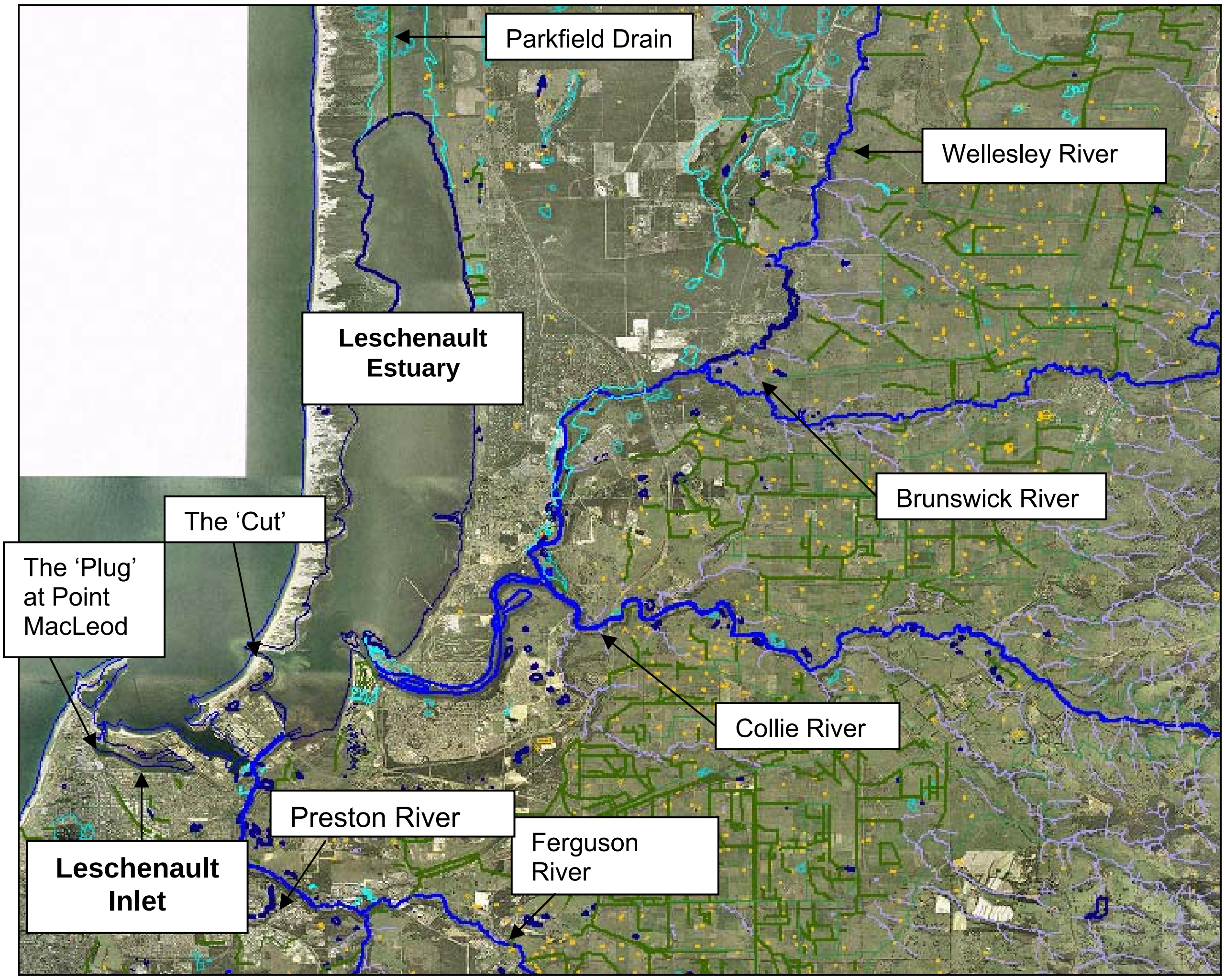


Figure 3. Waterways of the Leschenault Catchment (Aerial Photography 2003).

The upper Collie River catchment contains a further 2,830 square kilometres of land but is hydrologically separated from the lower catchment by the Wellington Dam which was constructed in 1933, and subsequently raised by 1960. The contribution of the upper catchment to lower river flows is limited to overflow events and limited scour releases used to manage salinity within the dam, and from irrigation overflows associated with licensed allocations; both resulting in increased summer flows in the Wellesley, Brunswick, Collie and Ferguson Rivers.

For the purposes of this condition statement, the focus of discussion has been limited to the estuarine reaches of the Leschenault Estuary and associated rivers, and the Leschenault Inlet, as the areas most subject to population and recreational pressures.

1.2 Leschenault waterways management planning

The Leschenault Waterways Management Program was prepared for the Leschenault Inlet Management Authority (LIMA) by the Waterways Commission in 1992. LIMA was required under Section 35 of the *Waterways Conservation Act 1976*, the statute by which the management authority was created, to prepare a management program for the management area under its control, such that its decisions and advice are consistent with the program. The aim of the program was:

> *"To fulfil the demands for use and development in so far as they are consistent with the conservation and enhancement of a functional healthy estuarine environment for the enjoyment of present and future generations."*

Under the Machinery of Government Reforms, the statutory responsibilities of the management authority was removed, reverting much of the powers conferred on LIMA under the *Waterways Conservation Act 1976* to the then Water and Rivers Commission (WRC). As a consequence, the scope of management influence provided under the Leschenault Waterways Management Program similarly became the responsibility of the WRC, commensurate with the administrative responsibilities of the Act. The membership of LIMA continued to function under the name of the Leschenault Catchment Council (LCC) and undertook a draft Strategic Planning Process in 2002 to coincide with the preparation of the South West Regional Strategy for Natural Resource Management (2002). In 2004, the LCC amalgamated with the membership of the Leschenault Catchment Coordinating Group (LCCG) and resolved to continue under the banner of the Leschenault Catchment Council, as the peak community consultative body for the Leschenault catchment.

Table 1. Historical listing of Leschenault Waterways and catchment planning documents.

Year	Document Title	Responsible Body
1992	Leschenault Waterways Management Program	Leschenault Inlet Management Authority
1995	Management Strategy for the Leschenault Catchment	Leschenault Catchment Coordinating Group
1998	Leschenault Catchment Sub-Regional Strategy	Leschenault Catchment Coordinating Group
2002	Leschenault Catchment Strategy (Draft)	Leschenault Catchment Council
2002	South West Regional Strategy for Natural Resource Management (including Leschenault Subregion Framework)	South West Catchments Council
2005	South West Regional Strategy for Natural Resource Management (including Leschenault Subregion Framework)	South West Catchments Council

1.3 Future strategic management

In 2005, the South West Catchments Council (SWCC) released the revised South West Regional Strategy for Natural Resource Management (NRM). The strategy, the outcome of a partnership between the Commonwealth and State governments and the SWCC, will provide an avenue for Natural Heritage Trust (NHT) and National Action Plan for Salinity and Water Quality (NAP) funding to be delivered through the SWCC to sub-regional NRM groups to achieve NRM outcomes. The Leschenault Catchment Council (LCC) is one of six sub-regional NRM groups under the SWCC. The LCC completed its own period of revised strategic planning over the 2005-06 period after funding was secured under the SWCC strategic planning and investment process. The Leschenault Natural Resource Management (NRM) Catchment Management Strategy is due for release in mid-2007.

Concurrently, the Department of Environment, after completing a report in March 2005 on community perceptions of causes and solutions to perceived problems within the lower catchment and Leschenault Estuary, undertook a number of physical and biological surveys pertaining to the Leschenault Estuary and Inlet in May 2005 to provide an indication of the current condition of these water bodies. Findings of these studies, coupled with technical reviews of existing data have been included within this document.

The recommendations presented within this condition statement, combined with those presented as part of the community perceptions report, will be utilised to identify strategic planning objectives and avenues for project expenditure by the Department of Water and the Leschenault Catchment Council into the future.

2 Historical land use in the catchment

2.1 Pre-European settlement

Before European settlement in Western Australia in 1829, Aboriginal people lived in extended family groups that did not have permanent or fixed places of habitation, but rather moved according to a set pattern within a designated tract or territory. As hunter-gatherers, these groups generally moved along major river systems or along chains of other freshwater resources. Within the Leschenault catchment evidence suggests that communities of Nyungars, the collective name of Aboriginal people from the south west, moved predominantly along the Brunswick/Collie River system and movement along the Preston River is also likely (O'Connor *et al*., 1989).

Nyungar communities within the region utilised fire-stick farming, as both a tool for rejuvenation of vegetation within the area, and to flush out game. In addition, the communities had established fish traps along stretches of the Leschenault Estuary and lower Collie and Preston rivers whereby fish could be caught by hand. The Nyungar activities within the catchment were subsistence practices and required large open areas to work effectively.

2.2 Early European settlement

Like much of the west coast, the area around the Leschenault was explored by the Dutch in the 17th century and the French in the 19th century, and settled by the British in the mid-1800s. Within months of settlement at the Swan River in 1829, Dr Collie and Lieutenant Preston, ships' officers on *HMS Sulphur*, explored the area around Leschenault and discovered the rivers flowing into the estuary. A subsequent exploration by the same officers the following year to map these two rivers resulted in their now given names (Brearley, 2005). The first British land settlers arrived in the Leschenault catchment in 1830, when a military detachment and party, including military staff, medical officers and seven prospective settlers, intended to establish a military post and settlement at Port Leschenault (now known as Bunbury). However, the group's residence in Leschenault was short-lived as the expedition moved on and settled in Augusta. The catchment was finally first settled in 1839, after 400 acres was leased to John Scott of Guildford adjacent to the Preston River at Eelup, with the intent of using catchment land for agricultural practices (O'Connor, 1996).

Over the next decade, many more settlers arrived in the region. Stock was introduced and allowed to roam free across large areas under amendments to the State's land regulations. A large range was necessary due to the poor carrying capacity of the region. For the first few years, the settlers experienced many hardships. This was mostly the result of the nature of the soils and climate of the region, combined with the agricultural practices applied by the European settlers that had been developed in a country with very different environmental conditions.

As such, the quest for the best pieces of land acceptable for agricultural practices within the catchment commenced, and many of the first settlers chose land on the river flats, where soils were relatively organic-rich and were readily accessible by boat.

2.3 Evolution of agricultural activities within the catchment

By 1850, the settlers had reached some understanding of the Western Australian environment – the crops that could be grown and the stock that could be reared (Government of Western Australia, 1979). At this time, small areas of intensive mixed farming including dairying and the growing of potatoes, wheat and barley predominated. Clearing of land began with the commencement of pastoral activities, although it was not until 1887 that an Agricultural Commission was appointed to plan agricultural development across the State (Cunningham, 2005). By 1890, grain and fodder crops predominated and cattle were grazed on the coast, plain and scarplands, with sheep farther inland. As early as 1898, the impacts of salinity were beginning to be observed across the State as clearing of native vegetation from the fertile coastal plain was recognised as removing the necessary protection of fresh water resources and in 1924 a Special Committee on ‘Salinity in Soils’ was set up as farmers confirmed a wide distribution of the phenomenon (Cunningham, 2005).

The transition to intensive mixed farming was evident by 1918 along the coastal plain and in the valley of the Preston River. On the plain, the production of hay, sheep, dairy cattle, potatoes and fruit predominated. Irrigation was also practised on a small scale after being selected for government-sponsored irrigation. The Harvey Weir was completed in 1916 with a view to supplying good volumes of water to 40,000 ha of irrigable land consisting largely of established citrus orchards. This first attempt at large scale irrigation in Western Australia was unsuccessful after flooding and waterlogging were found to be a problem in the early years and a main drain had been constructed in the early 1900s relieving flooding by taking water to the lower Harvey River (Harvey Water, website).

Dairying had been consolidated on the coastal plain of the Leschenault by 1939. Irrigation facilities continued to be expanded by damming the Collie River, and mixed farming had been widely abandoned to concentrate on whole milk production for the Perth market. Milk, cheese and condensed milk were produced, with some cattle, pigs, vealers and sheep also being bred. In addition, surplus hay was sold and potatoes were grown in sumplands (Government of Western Australia, 1979). With increased development of the catchment came increased clearing of land, resulting in rises in groundwater tables, which in turn exacerbated the extent of flooding and reliance on farm and agricultural drainage. Over the following decades, vegetation on the banks of waterways were removed, lower riverine reaches were de-snagged, the rivers were altered from their natural course and deepened, a system of interconnecting drains was dug across pastoral lands, swamps and wetlands were drained, and flow regimes of rivers were altered by damming and broadscale clearing.

2.4 Status of current land use in the catchment

Land use in the Leschenault catchment is highly diversified. Residential, commercial and agricultural practices flank the estuary, while agriculture is the dominant land use activity on the coastal plain region. Stock grazing and pasture development are the most common agricultural activities, although horticulture and industry are also present. A significant portion of the catchment is serviced by Harvey Water and the Preston Valley Irrigation Cooperative has a developed network of drains. Approximately 33 per cent of the total catchment is cleared with areas within the coastal plain likely to be significantly higher. The land east of the Darling Scarp remains largely forested and several rivers and tributaries in the region have been dammed, of particular note being the Wellington Dam on the Collie River. The land to the east of the plateau is cleared largely for stock grazing, pasture development and cereal crops.

Runoff from the total catchment area of 467, 709 hectares enters the Leschenault Estuary via the Collie and Preston rivers and the Parkfield Drain. Approximately 95 per cent of the runoff occurs between May and October. The lower Collie catchment has been extensively cleared and drained for agriculture. Irrigated pastures in the central and eastern portion support grazing of dairy and beef cattle, while horticulture, industrial and residential development characterise the western portions in proximity to the Leschenault Estuary and towards the coastline. Land use within the Preston catchment ranges from broadscale agriculture practices of cropping and grazing, to intensive orcharding, viticulture and horticulture.

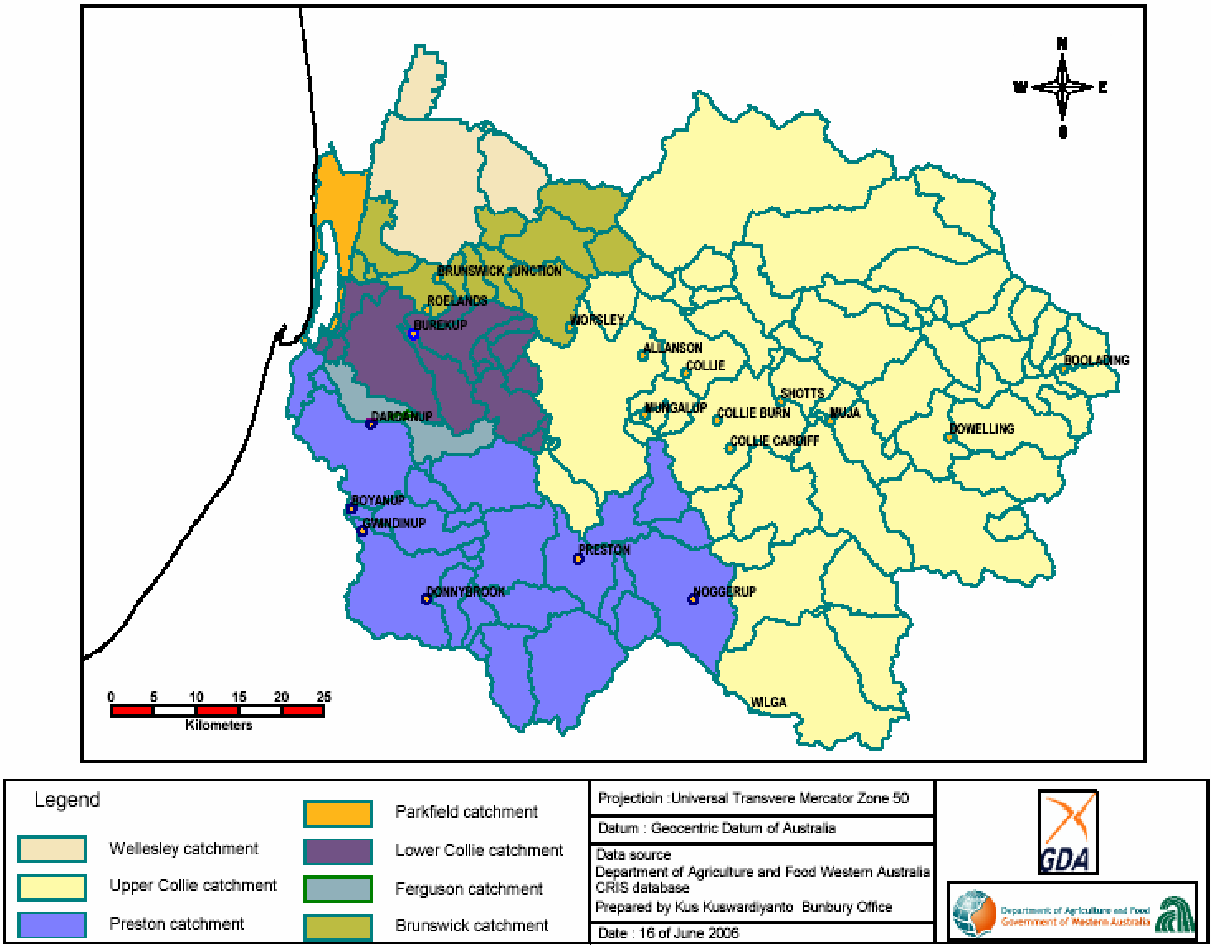


Figure 4. Leschenault sub-catchment boundaries.

Table 2. Leschenault sub-catchment area and vegetative cover as of December 2005**.

Catchment	Brunswick	Ferguson	Lower Collie	Parkfield Coastal	Preston	Upper Collie	Wellesley	Total
Area (Ha)	30,584	6,743	30,917	6,344	103,359	282,726	26,589	**487,262**
Area (Ha) vegetated	18,763	2,020	13,160	3,119	58,815	222,516	6,872	**325,265**
Area (Ha) cleared	11,821	4,723	17,757	3,225	44,544	60,210	19,717	**161,997**
% Cleared	39%	70%	57%	51%	43%	21%	74%	**33%**

Table 3. Land use in the Brunswick catchment as of December 2005**.

Brunswick Catchment	
Land use	**Area (Ha)**
Strict nature reserves	2447.6
Managed resource protection	8324.4
Other minimum intervention use	807.3
Remnant native cover	8933.8
Plantation forestry	734.9
Hardwood plantation	406.4
Softwood plantation	99.3
Grazing and improved pastures	5096.2
Hay and Silage	4.3
Seasonal horticulture	16.2
Intensive animal production	3.6
Dairy	1813.6
Residential	55.1
Services	31.3
Mining	86.7
Water storage and treatment	148.3
Total	**29009.1**
Variance*	5%

Table 4. Land use in the Ferguson catchment as of December 2005**.

Ferguson Catchment	
Land use	**Area (Ha)**
Managed resource protection	1359.3
Other minimum intervention use	53.1
Remnant native cover	235.0
Hardwood plantation	135.6
Grazing and improved pastures	2396.1
Seasonal horticulture	384.4
Irrigated Vine fruits	78.1
Intensive animal production	103.9
Dairy	885.5
Residential	1.3
Mining	51.6
Total	**5683.9**
Variance*	15%

Table 5. Land use in the Lower Collie Catchment as of December 2005**.

Lower Collie Catchment	
Land use	**Area (Ha)**
Strict nature reserves	1.1
Managed resource protection	9049.5
Other minimum intervention use	526.3
Remnant native cover	3156.0
Hardwood plantation	819.9
Grazing and improved pastures	7653.2
Hay and Silage	35.3
Seasonal horticulture	555.0
Irrigated Vine fruits	241.0
Intensive animal production	42.7
Dairy	5450.0
Residential	446.2
Services	99.2
Mining	46.7
Water storage and treatment	0.6
Total	**28122.6**
Variance*	9%

Table 6. Land use in the Parkfield Coastal catchment as of December 2005**.

Parkfield Coastal Catchment	
Land use	**Area (Ha)**
Strict nature reserves	512.6
Managed resource protection	414.7
Other minimum intervention use	461.8
Remnant native cover	2362.2
Hardwood plantation	293.1
Grazing and improved pastures	666.6
Seasonal horticulture	786.8
Residential	173.7
Rural Residential	86.0
Mining	15.8
Total	**5773.1**
Variance*	9%

Table 7. Land use in the Preston Catchment as of December 2005**.

Preston Catchment	
Land use	**Area (Ha)**
Nature conservation	81.4
Strict nature reserves	748.4
Managed resource protection	42365.7
Other minimum intervention use	1475.5
Remnant native cover	11118.5
Plantation forestry	2184.6
Hardwood plantation	1585.8
Softwood plantation	353.2
Grazing and improved pastures	22689.7
Cropping	869.0
Seasonal horticulture	6930.0
Irrigated Tree fruits	359.5
Irrigated Tree nuts	105.1
Irrigated Vine fruits	799.7
Intensive animal production	153.5
Dairy	2273.5
Residential	536.8
Services	569.0
Mining	444.7
Aquaculture	137.7
Total	**95781.2**
Variance*	7%

Table 8. Upper Collie catchment as of December 2005**.

Upper Collie Catchment	
Land use	**Area (Ha)**
Nature conservation	25100.0
Strict nature reserves	1391.1
Managed resource protection	137646.5
Other minimum intervention use	1643.4
Remnant native cover	59619.2
Production forestry	1430.5
Plantation forestry	2793.3
Hardwood plantation	5886.8
Softwood plantation	1456.3
Grazing and improved pastures	19619.1
Cropping	17777.8
Seasonal horticulture	26.4
Residential	393.9
Services	190.4
Mining	702.7
Water storage and treatment	2383.7
Total	**278061.2**
Variance*	2%

Table 9. Land use in the Wellesley catchment as of December 2005**.

Wellesley Catchment	
Land use	**Area (Ha)**
Strict nature reserves	1599.8
Managed resource protection	1959.5
Other minimum intervention use	608.8
Remnant native cover	3079.1
Plantation forestry	0.0
Hardwood plantation	189.4
Softwood plantation	6.1
Grazing and improved pastures	5661.9
Hay and Silage	530.0
Seasonal horticulture	739.6
Irrigated Vine fruits	117.1
Intensive animal production	117.6
Dairy	10164.1
Residential	2.0
Services	35.7
Mining	467.3
Total	**25277.9**
Variance*	5%

* Variance = Difference between land use total and catchment area total (can be attributed to the area of road reserves, urban development and other areas not mapped during the land use capture).

** Source: Department of Agriculture and Food, Western Australia.

3 Environmental condition of the Leschenault Estuary: estuarine reaches

3.1 Introduction

The Leschenault Estuary represents the broad definition of an estuary as a semi-enclosed coastal body of water where:

- salt from the open sea mixes with freshwater draining from the land;
- where waters with different salinities mix; and,
- where marine and fluvial sediments occur together.

The Australian Geological Survey Organisation (AGSO Geosciences Australia) Estuary Assessment 2000, assessed the Leschenault Estuary as being “severely/extensively modified” based on assessment of key geomorphological processes, covering physical forces (wave, tide and river energies) driving the form and function of estuaries.

The significant anthropological impacts on the Leschenault Estuary are listed in Table 10.

Table 10. Significant anthropological changes which have impacted upon the Leschenault Estuary.

Alteration	Date
Settlement and commencement of clearing and subsequent agricultural farming	1839
Wellington Dam (Collie River) constructed	1933
Original Outlet to the estuary filled (known as “The Plug”)	1951
“The Cut” opened	1951
Wellington Dam (Collie River) Raised	1960
Inner Harbour development	1967-1976
Reclamation of old inlet channel near inner harbour	1967-1976
Preston River Channel redirected	1969-1970
Dredging of boat channel from lower estuary to Koombana Bay	1974
Parkfield Drain constructed	1977

The impact of these changes on the physical and biological environment of the Leschenault Estuary is described in the following sections.

3.2 Hydrodynamics

The creation of the Bunbury Inner Port and the ‘Cut’ at Turkey Point transformed the Leschenault Estuary from a tidally influenced estuary to that dominated by wave influences as the impact of direct oceanic inputs were no longer diffused through lateral movement from the original ocean exchange at Point Macleod. As a wave dominated estuary, the Leschenault Estuary represents a coastal bedrock embayment that has been partially infilled by sediment derived from both the catchment and marine sources, in which waves are the dominant force shaping the gross morphology (Geoscience Australia *et al.*, website).

The Leschenault Estuary exhibits a number of key features associated with wave-dominated estuaries:

- A diverse range of marine and brackish, sub-tidal and intertidal estuarine habitats are supported.
- Narrow entrance restricting the capacity of the estuary to be wholly flushed or for the interchange of estuarine waters.
- River flows are typically high, and flooding may flush material from the estuary.
- Turbidity, in terms of suspended sediment, is naturally low except during extreme wind or fluvial runoff events.
- Central basin is an efficient ‘trap’ for terrigenous (land origin) sediment and pollutants.
- Long residence time encourages trapping and processing of terrigenous nitrogen loads through denitrification.
- ‘Semi mature’ in terms of evolution; morphology will change rapidly over time due to infilling, resulting in shallowing of central basin, and expansion of fluvial delta.

Circulation patterns within the estuary are considered to result in well-mixed fresh and saline water during the summer months, and a positive estuary in winter along both the south-north lagoon transition and the east-west Collie River to the ‘Cut’ transition as a consequence of increased rainfall and flood events (Semeniuk *et al*, 2000). Positive wave dominated estuaries have lower salinities towards their head, with the central basin and water next to the inlet approaching that of the adjacent ocean water. As a consequence of freshwater inflows from the Preston and Collie/Brunswick river catchments, some stratification occurs in the water column in the lower-to mid regions of the estuary lagoon and in each of the lower river systems as buoyant low salinity fresh water floats above the intruding, denser marine water. The seawater/freshwater interface is generally regarded to extend upstream to approximately the interception with the Bunbury Bypass Road in summer (some four km up the Collie River), with a variable downstream movement in winter to reflect increased freshwater flows over these months.

Circulation patterns are similar for summer and winter conditions, with sea breezes appearing to have little influence on circulation patterns. The circulation patterns and wind-driven currents would result in a strong component of transport of fine suspended sediment that would move to the tidal areas in the north of the estuary (Charteris and Deeley, 2000).

Barometric pressure imparts greater influence on water level within the estuary than tides, with high-pressure systems in summer contributing to low tides, and low pressure in winter producing a general rise in sea level (Wurm and Semeniuk, 2000). Tides in the Leschenault Estuary are diurnal (one tide per day) and micro-tidal, with a mean spring range of 0.5 m and a maximum range of 0.9 m but do impart some minimal changes in mean water level. While in neap periods water level in the estuary remains at approximately sea level, hydrographic modelling suggests that during spring tides the water level increases to a maximum of about 0.06 m above mean sea level (Charteris and Deeley, 2000). Similarly, during winter, higher river inflows tend to increase the mean level of the estuary to around 0.1 m above sea level (dependent on river flow). Wave trains do not generally generate sufficient height and wavelength to effect significant sediment mobility in the deep central basin (Semeniuk, 2000a). The circulation patterns for the estuary under summer and winter conditions are shown in Figure 5. A comparison of the modelled results indicate that the circulation patterns in the Leschenault Estuary are similar for summer, winter and summer breeze conditions; dominated by water movement between the ‘Cut’ and the mouth of the Collie River.

The hydrodynamics (and the associated salinity fields and gradients) of the Leschenault Estuary are now largely controlled by the interplay of the restricted exchange with the ocean through the ‘Cut’, freshwater inputs during winter and evaporation – with the area of influence decreasing as you extend further north up the estuary. Other factors that have contributed to changes in hydrology patterns of the Leschenault estuarine system include the construction of the Wellington Dam on the Collie River which reduces fresh water flows into the estuary during winter, irrigation district overflows during summer, and the Parkfield Drain which empties directly into the north of the estuary.

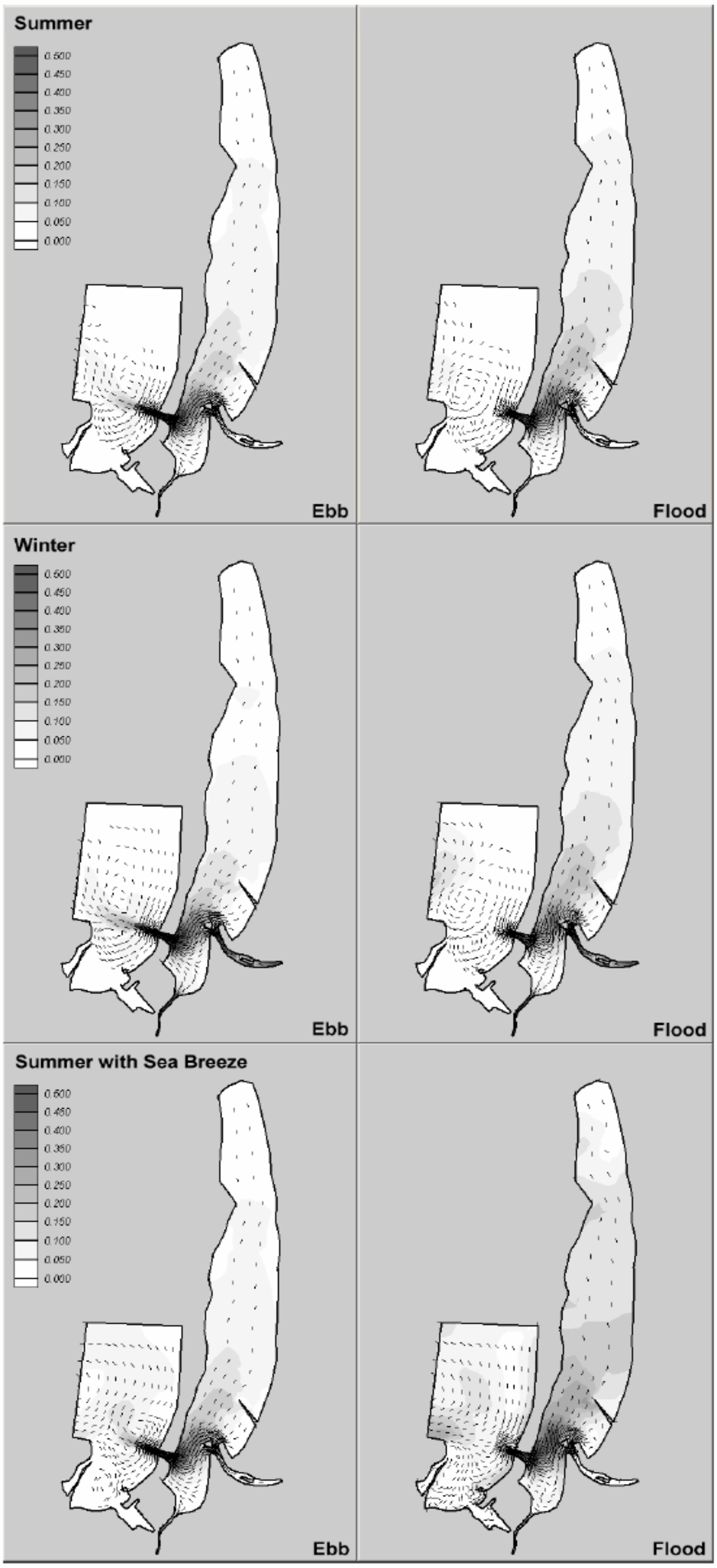


Figure 5. Circulation patterns, ebb and flood tides, for summer versus winter conditions, and summer conditions with a sea breeze. Arrows indicate direction of current. Graded shades of grey indicate magnitude of current in metres per second (Charteris and Deeley, 2000).

3.2.1 Recommendations for further investigation

Investigate the impact of decreasing freshwater catchment flows, in terms of sediment and nutrient delivery, and salinity stratification (including anoxic conditions, algal blooms and raised temperatures) to reflect climate change, allocation limits, water trading, and potential damming of the Brunswick River as identified under the *State Water Strategy*.

3.3 Water quality

Water quality in the Leschenault Estuary is generally considered to be good, and is strongly influenced by surface waters draining in from the Collie (including the Brunswick and Wellesley Rivers) and Preston River (including the Ferguson River) catchments, groundwater seeps and surface water drainage found predominantly to the north, and tidal movements regulated through the ‘Cut’.

The marine influence on water salinity, while substantially regulated by movement through the ‘Cut’, changes seasonally and with distance from the ‘Cut’. Freshwater inputs from winter rainfall and subsequent surface water flows from the catchment reduces salinities across the estuary, while in summer the northern section of the estuary becomes hypersaline due to the limited tidal influence and the concentration of salts with evaporation. Over the 2000-06 November to May sampling period, salinities in proximity to the ‘Cut’ generally fluctuated between 33-43 ppt (peaking to 47 ppt in January 2001); whereas sampling undertaken in the northern estuary over the same period exhibited hypersaline conditions with fluctuating salinities generally between 37-47 ppt (peaking to 53 ppt in January 2001 and 2002) (Ramsay, 2006). Water temperatures also fluctuate daily and seasonally, generally rising and falling proportionally to that of the ambient air temperature. The water temperature can rise to approximately 25^{0}C in summer and fall to about 14^{0}C over winter (Brearley, 2005).

Estuary waters are generally well-oxygenated throughout the year through tide, wave and wind movements, with dissolved oxygen concentrations generally over five mg/L. The highest recorded oxygen concentrations were found at well-vegetated sites in shallow water. Even though the solubility of oxygen decreases with temperature, high oxygen concentrations frequently occur with high water temperature at shallow sites, reflecting the increased plant metabolism under warm conditions, resulting in greater oxygen release into the water column (Wurm and Semeniuk, 2000). Overall, there appears to be no clear correlation between oxygen concentration and other water parameters, with oxygen concentration appearing to vary independently of temperature and salinity.

The Leschenault Estuary system with its tidal marine exchange is considered to be a nitrogen limiting system. This means that when the internal natural nitrogen cycling is disrupted by excessive inputs of nitrogen, conditions for increased plant growth prevail. Nutrient concentrations, while slightly elevated to those expected under a normal state, are acceptable given the developed nature of the catchment and do not appear to be rising (Brearley, 2005). During the 2000-06 November to May sampling period, nutrient concentrations were regarded as generally being ‘Low’ in Total Nitrogen (TN) concentrations with all but one sample below the maximum recommended guideline of 0.75 mg/L for south west Australian estuaries (ANZECC/ARMCANZ, 2000). While the estuary is considered to have a ‘Low’ TP concentration status, a collective 28 per cent of the total samples recorded exceed the maximum recommended ANZECC/ ARMCANZ (2000) value of 0.03 mg/L. The ratio of N to P is relatively low and is facilitated by the good tidal exchange experienced at both sites (Ramsay, 2006).

3.4 Sediment

Sedimentation in estuaries and catchments is a natural process. Some natural controls on sedimentation rates experienced by coastal waterways include climate (rainfall, seasonality), geology, topography, vegetation and catchment size. Several studies have demonstrated that sediment loading to estuaries has increased in response to waterborne erosion (gully, streambank/streambed and sheetwash erosion) in catchments in which large areas of native vegetation have been cleared to accommodate intensive agriculture and urban development (Geoscience Australia *et al*., website). As a consequence, modern infilling rates in some coastal waterways are at least double those experienced in the late Holocene period. The National Land and Water Resources Audit (NLWRA) found that sediment loading in many Australian rivers was up to 20 times more than natural levels, and that there was significant sediment delivery to coastal waters (Marston *et al*., 2001). It could be further expected that the rate of infilling in the Leschenault Estuary may have been further accelerated during the last few decades commensurate with catchment development and exacerbated by the wave-dominated nature existing in the estuary since the construction of the ‘Cut’ in the 1960s, promoting sediment retention with the central basin acting as a ‘sink’ for fine sediments.

Sediment is also important in nutrient cycling in estuarine systems because of its capacity to store large amounts of nutrients, which may be released when the concentration in the overlying water is low. In this context, sediments can be significant, either as a source or sink, adjusting nutrient concentrations in the water column and hence potentially controlling primary production and the possibility of algal blooms (McCombe *et al*., 2000). This is the case where sediment from the catchment forms deltas of high biological activity as a consequence of bound nutrients. This in turn attracts and supports higher faunal species.

The movement of sediment into estuaries is natural. Sediment in the Leschenault Estuary generally comes from two sources – the catchment, and the ocean through the ‘Cut’. The sediment types exhibited within the estuary are deposited from a number of sources including:

- quartz sands eroded from the eastern Eaton Sand Ridge, the western barrier dunes of the Leschenault Peninsula, and in flood waters from the Collie and Preston rivers;
- layered silicate clays from flood waters from the Collie and Preston rivers, and the Bunbury Basalt and Australind formations at the southern end of the estuary;
- silts formed within the estuarine lagoon by the decomposition of calcareous skeletons of invertebrate fauna and other biota, and by accumulation of marine and estuarine diatoms.
- degrading plant material within the estuarine lagoon; and
- shell gravel and fragments within the estuarine lagoon by shelly benthic biota (Semeniuk, 2000).

Thus, the Leschenault Estuary is filling with sediment of aeolian, fluvial and biological origin (Wurm and Semeniuk, 2000).

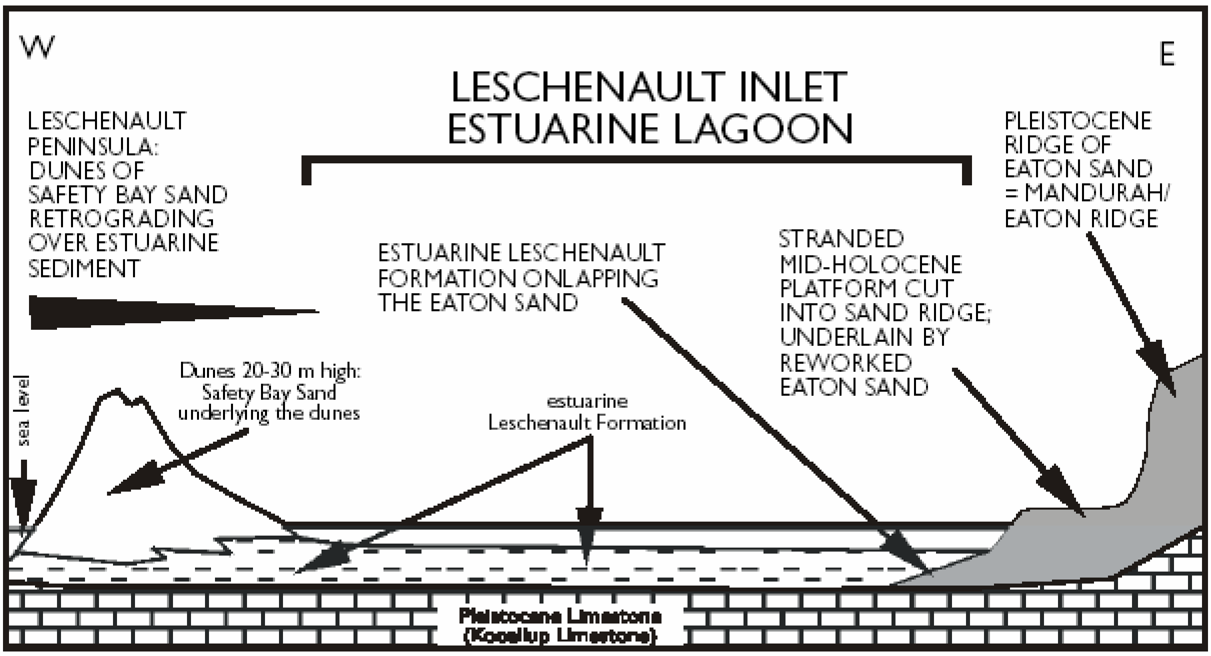


Figure 6. Stratigraphic framework of the Leschenault Estuary (Semeniuk *et al*, 2000).

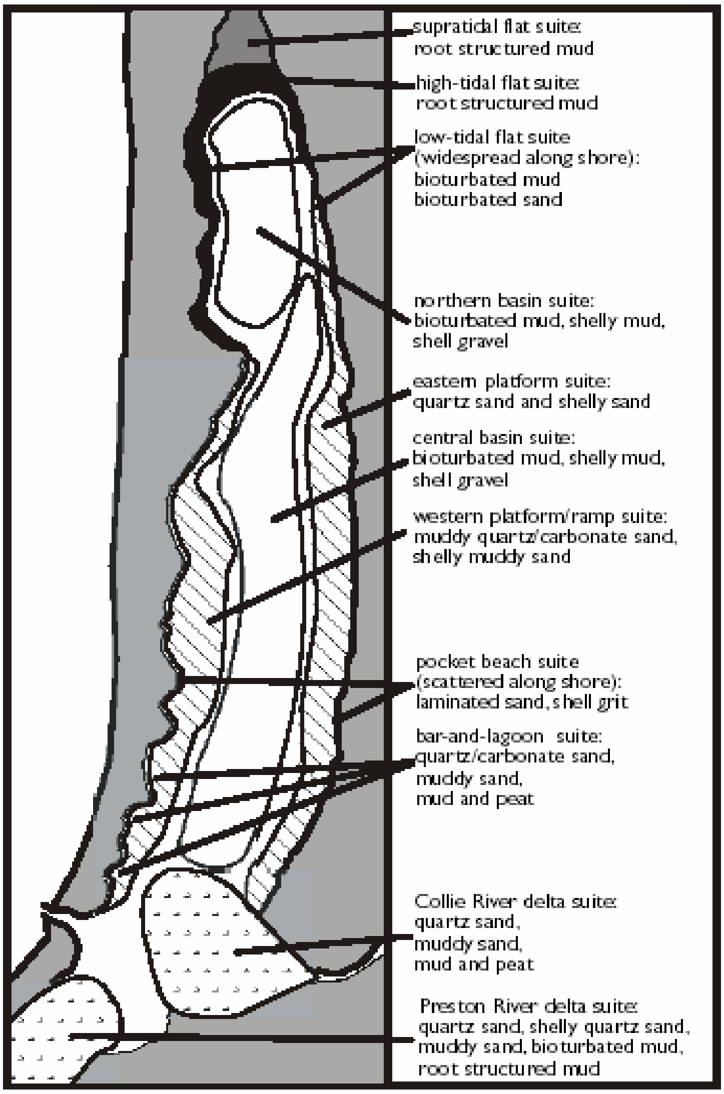


Figure 7. Sedimentary patterns in the Leschenault Estuary showing the main sediment types (Semeniuk *et al*, 2000).

Increased sedimentation in the Leschenault Estuary, as with other wave dominated estuaries, could reasonably be expected to have contributed to bringing about the following changes in form and function;

- Shallowing of the estuary.
- The rise and rapid growth of fluvial deltas and shoreline progradation as coarser sediment accumulates in proximity to river outlets.
- The development of mud flats as fine sediments derived from the catchment and produced within the estuary flocculate and settle in the margins of the estuary.
- Changes in the size and distribution of habitats such as mangroves, salt marshes and seagrass meadows.
- Impacts on benthic invertebrate and fish assemblages caused by the smothering of habitat, the clogging of gills and reduced feeding efficiency and food quality.
- Increased turbidity levels, limiting light penetration and photosynthesis.

- Increased loads of sediment-bound nutrients, trace elements and other toxicants entering estuaries from catchments, potentially leading to periods of eutrophication.
- An overall reduction in biodiversity, health and integrity.

The rate of sedimentation in the Leschenault Estuary is dependent upon the amount of material (organic and mineral) deposited as a consequence of the hydrology within the estuary over a given interval of time. A bathymetric survey was undertaken within the Leschenault Estuary in June 2005 to determine the vertical accumulation of sediment. The survey was conducted to reflect the previous survey completed in 1978 by the then Department of Transport. Vertical accumulation is a determination of changes in the rate at which estuaries have been vertically filling up with sediment, and can provide a useful insight into the functionality and health of an estuary. The colour differential plot for the southern portion of the Leschenault Estuary, indicating the relative changes in depth between the two surveys, is presented in Figure 7. This map has been presented as the area most subject to change due to historical dredging and most impacted upon by hydrodynamic influences from the catchment river systems and the ‘Cut’. The colour differential plots for the balance of the Leschenault Estuary are presented in Appendix 1.

Table 11. A history of dredging in the Leschenault Estuary and adjacent areas (Department of Planning and Infrastructure records).

Date	Location	Volume (m3)	Disposal Area
1949-1950 and 1952	The Cut	580,000	Beach north of Cut*
11/1954 – 05/1955	Collie River Mouth	5,000*	Bar Island*
09/1961 – 01/1962	Collie River Mouth	13,000	Bar Island*
01/1962 – 09/1962	Blind Channel	8,100	
09/1962 - ?	Turkey Point Channel	2,600	
10/1965	North of Turkey Point	5,000*	
1965	Preston River Mouth	51,000	
1965	Collie River Mouth	23,000	Pelican Point
Early 1969	Paris Rd Boat Ramp	30,000*	Basin disposed to southern foreshore, Channel disposed either side of channel
1969	Upstream of Collie River bride around Eaton Island	7,000*	Low lying area immediately upstream of bridge
1969	Collie River Mouth	15,000*	Shire of Harvey land
? - 07/1975	Collie River Mouth	15,000*	
1983	The Cut	90,000	North side of the Cut
1982-1983	Collie River Mouth	20,000*	Pelican Point Resort

* = Unconfirmed record

The colour differential plots need to be considered in the context of the historical dredging which has taken place during this period (Table 11) and the hydrodynamic modelling of the estuary presented in Figure 5. Overall, sediment accretion across the estuary has generally been minimal with +/- 20 cm being the norm, a figure that could be accounted for by statistical and practical errors in undertaking the surveys. However, there are a number of areas in which the change in depth is substantially more prominent.

Areas of pronounced change include:

- *Accretion alongside the old Laporte pipeline levee, which protrudes across the mid-estuary regions:* The levee acts in the same manner as that of a sea groyne, whereas sediment is trapped alongside the groyne as water velocities and the impacts of tidal movements are reduced, allowing suspended sediments to fall and settle out of suspension.
- *Accretion in proximity to the mouths of the Preston and Collie rivers:* Sediments carried in high energy winter surface flows from the catchment disperse and settle as the energy of riverine flows dissipates as it enters and adds to the deltaic areas at the confluence of the river mouths with the estuary.
- *Accretion to the south and deepening to the north of the entrance of the 'Cut' into the estuary:* The accretion could be considered as deposition of marine sands and sediment re-worked and deposited through tidal movements and exchange with marine waters into shallow areas, in which little hydrodynamic or climatic influence is imparted. The low energy nature of this area precipitating sediments out of the water column. In contrast, the northern deepening may reflect an area in which flood flows impart influence and scour, supported by the prevailing winds and tidal movement.

The sediment trapping efficiency of wave-dominated estuaries is very high because sediment from the catchment and marine sources is trapped in the low-energy central basin, which may capture up to 80 per cent of fine sediment (Patchineelam *et al*., 1999; Roy *et al*., 2001). Infilling with coarse marine sediment transported through the estuary entrance can also be a significant source of sediment in immature wave-dominated estuaries as sedimentary processes are dominated by the landward transport of these sediments in tidal currents (Green *et al*., 2001). These currents become locally accelerated in the constricted entrance of the 'Cut', resulting in the flood- and ebb-tidal deltas recognised within the Leschenault Estuary. Sediment can be expected to be exported to the ocean through the 'Cut', particularly during spring tides and flood events.

Fine sediments, consisting of mud, clays and organic materials, are deposited on the fringes of the central basin by river processes, tides and internally generated waves, aided by the reduction in water velocities by the presence of fringing vegetation. The infilling of estuaries is dominated by the expansion of the intertidal environments around the central basin and the fluvial deltas adjacent to the catchment river mouths, rather than expansion of the flood tide delta (Roy *et al*., 2001). An extensive tide-dominated fan delta has been developed and modified at the mouth of the Preston River as a consequence of the rivers diversion to accommodate the Bunbury Inner Harbour; and the Collie River fluvial-dominated fan delta has become more pronounced and modified by wave movements over time as catchment sediments are transported and deposited by flood flows.

These fine particle-sized surface sediments have resulted in a relatively high enrichment of surface sediments when compared to other estuaries such as the Peel-Harvey Estuary and the Swan River Estuary. The organic content of these sediments appears to show an increasing concentration from south to north as circulation patterns drive suspended sediment deposition and the influence of ocean exchange from the ‘Cut’ decreases. However, the potential for sediment phosphorous release was relatively small and low in most months when compared with these other estuaries and may reflect the rarity of large algal blooms in the Leschenault Estuary (McCombe *et al*., 2000).

The net result of increased sedimentation is an increase in the maturity of coastal waterways, and a decrease in their overall life spans with associated potential reductions in the biodiversity, health and integrity of coastal ecosystems. In order to make better-informed management decisions, there is clearly a need to assess accurately the rate and nature of sedimentation within the Leschenault Estuary and associated waterways (Brooke, 2002).

3.4.1 Recommendations for further investigation

1. Undertake spatial core sampling within the Leschenault Estuary and associated estuarine river reaches to determine sediment sources and movement within the hydrologic system by:
   - Sediment mass accumulation as a more accurate measure of sedimentation than vertical accumulation, where there are significant changes with depth in the density of estuarine sediment that may be related to compaction or changes in the composition of the sediment.
   - Geochemical analyses to identify anoxic environments, pools of nutrients or other pollutants within the cores. This is important information for managers as a consequence of the potential for the release of sediment-bound nutrients into the water column, which is also relevant where dredging work is proposed. Likewise, this data can be used to support and aid in the development of sediment transportation modelling.
2. Undertake modelling of sediment movement through the ‘Cut’ to determine the impact and distribution of marine-based sediment within the Leschenault Estuary, its contribution to changes in depth, and identification of potential management actions.

3.5 Habitats for aquatic biota

Nineteen small-scale habitat types have been proposed within the Leschenault Estuary, determined upon interactions between the large-scale geomorphic units and estuarine salinity patterns (Figure 9) (Wurm and Semeniuk, 2000). Habitat types within the estuary are generated through the interaction of geomorphology, substrate texture and detritus content and the presence of macrophytes and water salinity at a given site, with the distinction between adjacent habitats often distinguished by variances in environmental parameters such as temperature, water depth or salinity. In understanding the variability of habitat distribution, linkages can begin to be established with the distribution of fauna.

3.5.1 Geomorphic units

The predominant physical processes operating dynamically in the estuary that dictate shape and development of sediment bodies in both the estuarine environment and the peripheral geomorphic units are: 1) wind-induced wave action on shores and platforms; 2) wind-induced currents; 3) storm waves; 4) tidal flooding; 5) tidal current erosion and transport; 6) tidal current deposition; 7) riverine flooding; and 8) wind erosion and transport (Pen *et al*., 2000).

The estuary can be divided into geomorphic units based upon water depth and geological origin: central basin, northern flat, western platform, eastern platform, and the southern delta systems. The substrate type exhibited in these areas reflects proximity to the sediment source, existing processes and grain size availability, and the type and distribution of which is significant in determining the distribution of benthic fauna.

- The predominant flat, deep and elongated central basin is approximately 10 km by one km, underlain by sorted mud.
- The northern shallow flat, which occupies the northern quarter of the estuary, is also underlain by mud with sand intrusions in proximity to the eastern and western platforms.
- The shallow shore-parallel eastern and western platforms that are related to the up-slope features of relict and active dunes respectively. Sand and muddy sand predominate the eastern platform as local reworking of shore materials is facilitated in this wave-dominated environment. Various mixes of mud and sand typify the western platform where dune sand encroaches into and contributes sand to the estuary, and where more mud accumulates than on the eastern platform because of its more sheltered nature.
- The deltas of the Collie and Preston rivers intrude into the estuary and are generally underlain by fluvial sand and mud. These deltas are largely dynamic in nature due to the continuing deposition of sediment from the rivers and the reworking of sediment on their seaward edge.

3.5.2 Salinity fields

Salinity of the Leschenault Estuary fluctuates along its length both within and between years. The estuary is generally of marine salinity and vertically well-mixed as a consequence of exchange through the ‘Cut’ and wind- and tide-forced circulation. During winter, the salinity of the estuary decreases with fresh water inputs from rivers, drains, runoff from adjacent terrain and groundwater seepage from upland aquifers and deltas. Once these inputs have ceased, evaporation induced by summer temperatures and wind, in conjunction with the limited ocean exchange, strongly influence water salinity away from the 'Cut', at which time salinities in the northern estuary become hypersaline across summer.

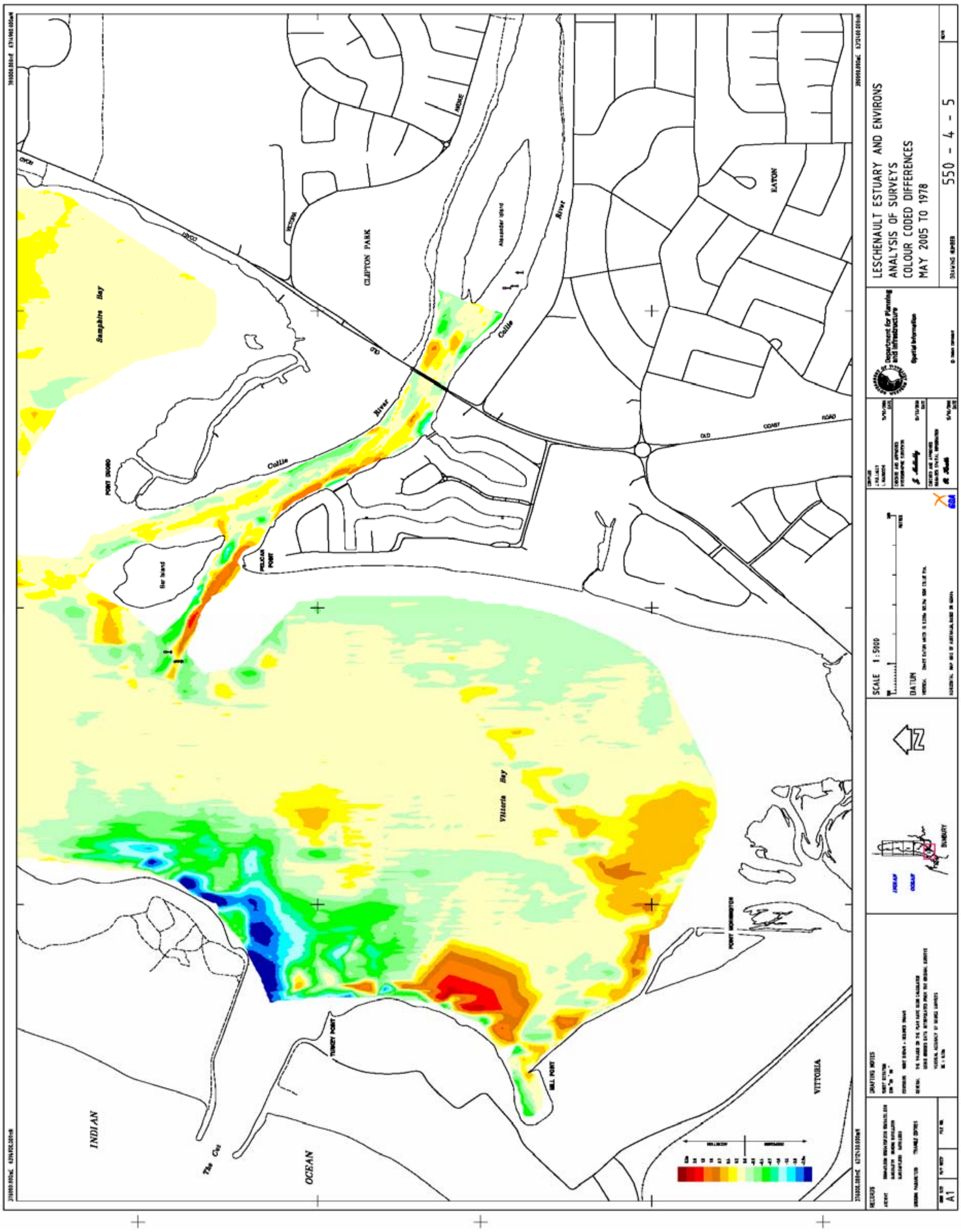


Figure 8. Colour differential plot of the lower Leschenault Estuary demonstrating changes in bathymetric depth between surveys undertaken in 1978 and 2005.

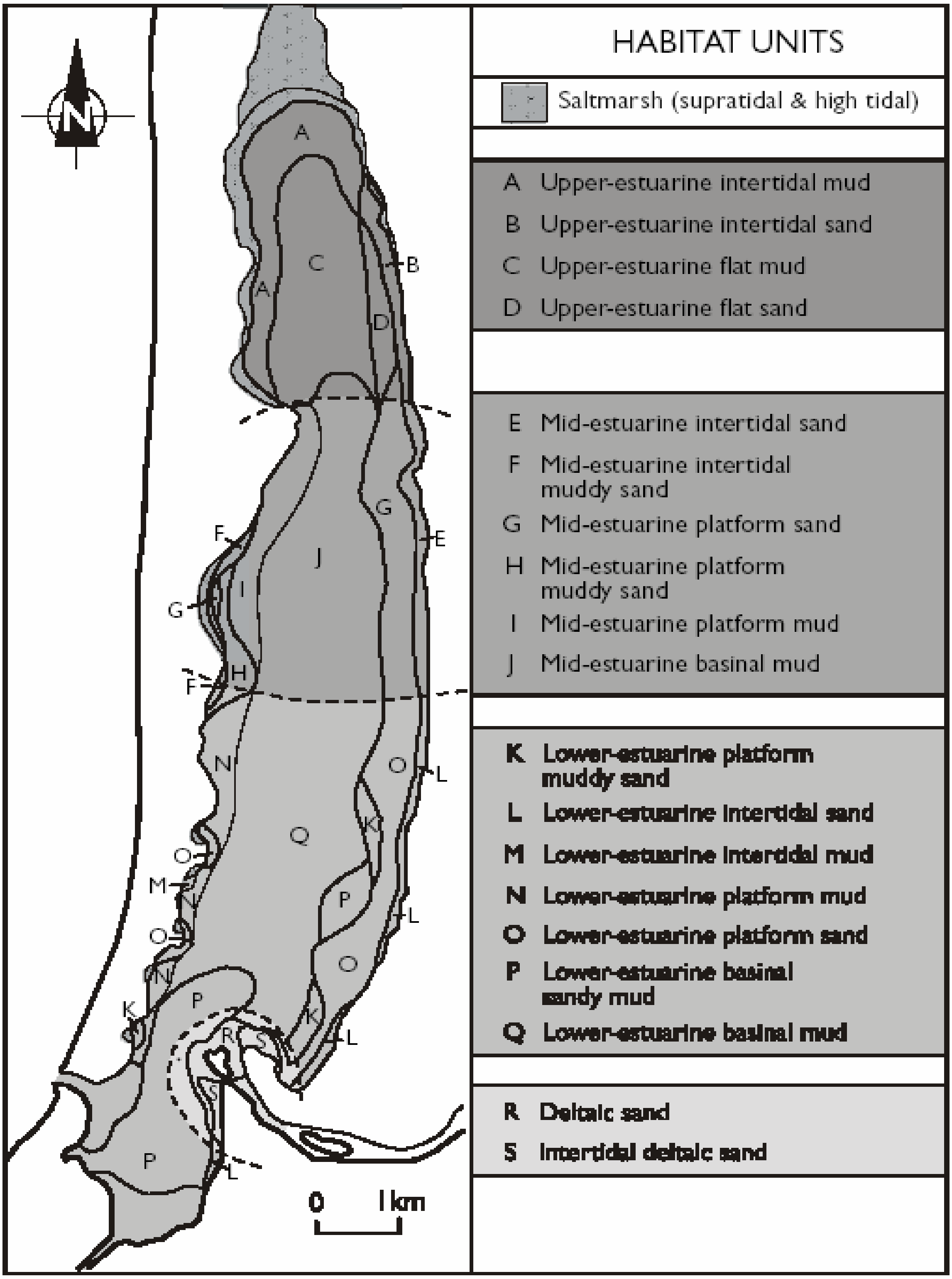


Figure 9. Habitat Units of the Leschenault Estuary. The upper, middle lower and deltaic fields are coded in decreasing shades of grey for ease of referring to the habitat units therein (Semeniuk *et al*, 2000).

It is this interaction of freshwater input and temperature/evaporation that dictates salinity within the estuary and divides it into four general salinity fields, based mainly on the seasonal variability of the estuarine waters. They are: 1) an upper estuary (northern) field where mean salinities approximate marine water but show large variation (brackish water common in winter and hypersaline water common in summer); 2) a middle estuary field where mean salinities approximate sea water but with less pronounced variation; 3) a lower estuary field close to the marine source where salinities are predominantly marine with little variation; and 4) a deltaic field where salinities are mostly marine but with marked freshwater periods during river flooding. This salinity gradient from south to north exists for most seasons (Figure 10) (Wurm and Semeniuk, 2000).

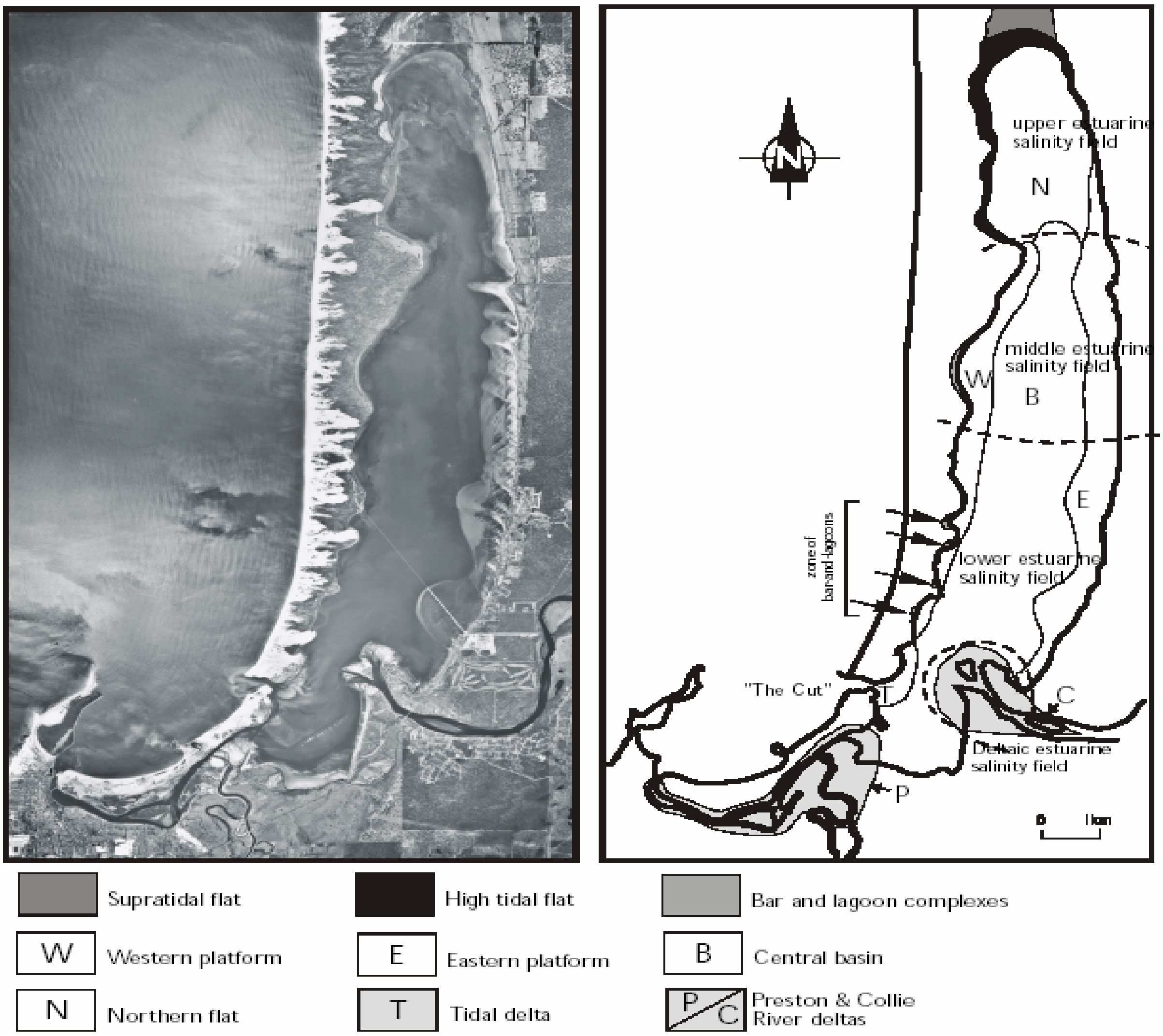


Figure 10. Aerial photograph (1966) of Leschenault Estuary and Inlet showing the elongate north-south orientated estuarine lagoon, and the deltaic complexes to the south prior to anthropological changes, of which they remain today in amended form. The map also identifies geomorphic units and salinity fields along the length of the estuary (Semeniuk *et al*, 2000).

3.6 Macrophytes

Macrophyte distribution in the Leschenault Estuary consists predominantly of seagrasses and a combination of green, brown and red macroalgae species. Total macrophyte biomass fluctuates seasonally within the estuary with macrophyte biomass expected to be lower under winter conditions of low light and temperature exacerbated by windy influences, while the macrophyte growing period (spring to autumn) is stimulated by higher temperatures and improved water clarity as turbidity caused by riverine inputs and wind stirring decreases.

Studies undertaken by Wurm and Semeniuk (2000) between 1982 and 1987 identified three species of seagrass – *Halophila ovalis, Ruppia megacarpa* and *Heterozostera tasmanica*; and seven species of macroalgae – *Chaetomorpha sp*, *Gracilaria sp, Ulva sp, Acetabularia sp* and two species of Phaeophyta (including *Hormophysa triquetta*).

Macrophyte studies undertaken by Hillman *et al* (2000) between 1984 and 1993 indicate macrophyte biomass in the Leschenault Estuary is dominated by seagrasses (>30%), then variable proportions of green and brown algae; and red algae which comprised a significant proportion (20-30%) in spring, but less than 10 per cent at other times of the year. The predominance of seagrasses suggested that overall water quality and clarity in Leschenault Estuary was comparatively better than other South West estuaries; as normally in estuaries with high nutrient loads, macrophytes are dominated by green algae. In October 2005, macroalgal blooms of *Cladophora, Ulva*, and *Rhizoclonium* were observed along the eastern foreshore of the Leschenault Estuary. These nuisance green algal species have not been observed in bloom within the estuary since a growth of *Rhizoclonium* was observed in Vittoria Bay for a week in 1988. While these growths were also present for only a week, the preferential growth of these species is likely to be indicative of high nutrient loading within the estuary as a consequence of long and persistent winter rainfall and associated catchment runoff. The subsequent turbidity generated by these increased catchment flows impacts on water clarity and hence, the growth of seagrasses.

The seagrasses of the estuary were dominated by the species *Halophila ovalis*, whose distribution is dominated in the essentially well-flushed, marine southern sections of the estuary, with the exception of the deep waters of the central basin; its exclusion is likely to be the result of turbidity effects from wind and wave impacts reducing light penetration to the deeper areas of the estuary. The highest plant biomass occurred in the northern estuary beyond Waterloo head where water depth is shallow, restricted exchange with the ocean occurs and high variability in salinity exists. These northern extents, during the 1984-93 study were dominated by the brown alga *Hormophysa triquetta*, and the dominant green alga *Chaetomorpha linum*. Red algae, dominated by *Gracilaria* species, were widespread with a general distribution to *Halophila ovalis* as some of these species occur as epiphytes attached to *Halophila*. The western and southern sections of the estuary were found to be dominated by *Halophila*, which was responsible for the large proportion of plant biomass overall in the Leschenault Estuary (Hillman *et al*., 2000).

Hillman *et al* (2000) indicated that, based on limited tissue analysis conducted on algae in Leschenault Estuary, the growth of macroalgae may not be limited by the availability of nutrients, and may be governed more by water clarity. However, the research cautions against the impact of nutrient inputs from the Parkfield Drain which discharges into the northern estuary suggesting any increase in the nutrient loading to the northern sections of the estuary has the potential to result in the proliferation of nuisance green algae. Nutrient enrichment can have the impacts of increased growth of submerged macroalgae or increased production of opportunistic seagrass species. Phytoplankton and macroalgae are generally better competitors for light than benthic plants and excessive growth of opportunistic plant species can also cause the loss of seagrasses through smothering by macroalgal blankets or through reduced light levels caused by increased epiphyte biomass (Hosja and Deeley, 2000).

A ‘snapshot’ survey of *Halophila ovalis* biomass, as the predominant seagrass species, was undertaken in May 2005 (Semeniuk, 2005) to provide comparative data with that undertaken previously by the V and C Semeniuk Research Group in 1982 and 1998 (Figure 11 and Table 12). While sites CD1, CD2, CD6, CD7, and 8C (Figure 11), have consistently been devoid of seagrass, other sites have consistently supported seagrass meadows, viz., CD3, 3, 5, 6, 8A, 8B, albeit in low density. In relation to the seagrass-depauperate period of May 1998, the seagrass cover of May 2005 is moderate; though not occurring at all sites, and is less dense than the sampling period of 1982.

The comparison between 1982 and 2005 shows that while a number of sites in 2005 are devoid of, or depauperate in seagrass, overall seagrass at many of the sampling sites is equivalent in density to earlier sampling times (sites CD3, 3, 5, 8A), and some sites though covered in seagrass, are less densely covered (sites 1, 2, 6) than previously recorded.

Seagrasses respond to natural variations in light availability, nutrient and trace element availability, grazing pressure, disease and weather patterns. The dynamic nature of seagrass meadows in response to natural environmental variation complicates the identification of changes by anthropological causes. Changes in seagrass areas indicate major changes in environmental characteristics, and as such, are an important indicator for State of the Environment reporting (Geoscience Australia *et al*., website).

Variation in macrophyte biomass between samples is likely to primarily reflect nutrient inputs from freshwater flows into the estuary and hence, reflect rainfall variability. The eco-hydrodynamics of the estuary are strongly influenced by catchment runoff of freshwater from the associated river systems and through freshwater seepage. As climatic cyclic periods of higher rainfall occur, a proportional volume of freshwater inputs and associated sediment and nutrient inputs occur. This increase in nutrient availability stimulates seagrass growth and results in a proportional increase in macrophyte biomass. Hence, while it is recognised that nutrients bound to sediment will promote plant growth in some areas of the estuary and limit it in other areas, nutrient availability in surface water flows is the key limiting factor for macrophyte growth in the Leschenault Estuary. Seagrass meadows can also change in response to chemical (eg salinity and pH), thermal, structural and biological disturbances caused by freshwater extraction

(Geoscience Australia *et al*., website), which further supports the influence of freshwater inputs from the catchment on seagrass density and distribution.

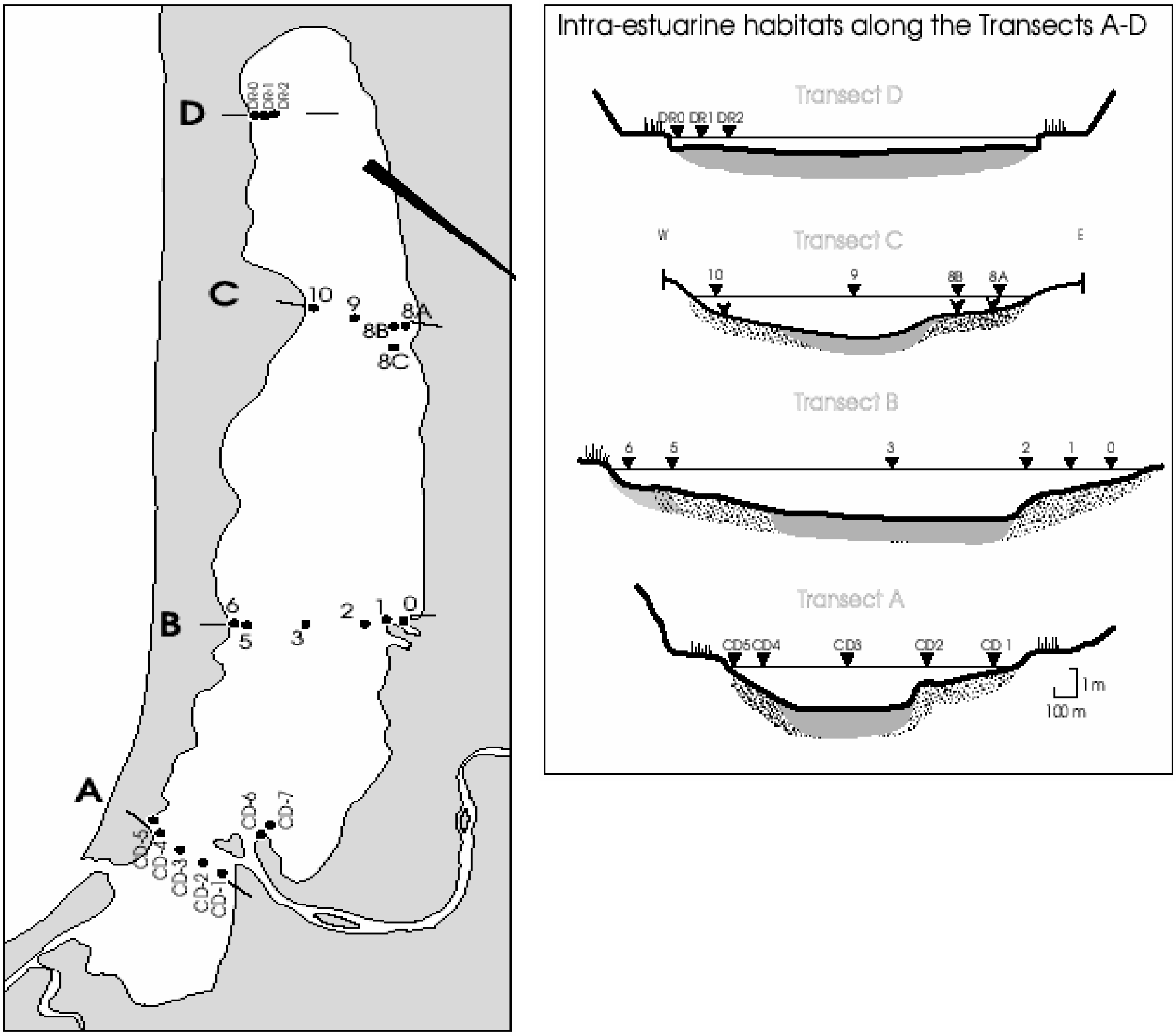


Figure 11. Location of Leschenault Estuary study sites for May 2005 macrophyte and benthic invertebrate fauna snapshot surveys including location of study sites along transects (Semeniuk, 2005).

Furthermore, considering the variability in occurrence of seagrass over a number of sites, particularly the identification of seagrass at sites not previously identified (Sites 9 and DR2), it can be concluded that *Halophila ovalis* is quite robust in being to able to readily colonise sediment and withstand some smothering and light limitation impacts imparted by suspended sediment inputs.

Fluctuations in seagrasses can also be influenced by the following factors:

- Light availability – The most widespread and pervasive cause of seagrass decline is a reduction in available light. Seagrasses have high minimum light requirements because: 1) they have a high respiratory demand to support a large non-photosynthetic biomass (eg roots, rhizomes); 2) they lack certain pigments and therefore can utilise only a limited spectral range; and 3) they must regularly oxygenate their root zone to compensate for anoxic sediment. The most prevalent causes of reduced light penetration in the Leschenault estuary relate to pulsed turbidity events during floods and enhanced suspended sediment loads facilitated by the wave-dominated nature of the estuary.

- Trace metal contamination can exert direct toxic effects on some seagrass species as they are able to bioaccumulate trace metals, which in turn can impact upon species that graze upon seagrasses.
- Seagrass meadows may also contract when mangrove areas expand in response to increased suspended sediment loads.

While is it expected that turbidity and enhanced sedimentation, trace metal contamination as a consequence of untreated stormwater discharges, and the extension of mangrove colonies into the northern reaches of the estuary, may all contribute to variations in seagrass distribution, the impact of these factors has yet to be quantified for the Leschenault Estuary. Wurm and Semeniuk (2000) did identify that at depths of greater than 1.5 m, the distribution of seagrass in the Leschenault Estuary became restricted and patchy, most likely as a consequence of reduced light penetration at depth.

Table 12. Dry weight (g/m^2) of *Halophila ovalis* at the sampling sites.

	February 1982	**May 1998**	**May 2005**
Site	**x ± σ**	**x ± σ**	**x ± σ**
CD1	0	0	0
CD2	0	0	0
CD3	30.2 ± 12.6	9.6 ± 25.6	29.6 ± 9.9
CD4	38.9 ± 25.9	0	0
CD5	9.0 ± 2.6	0	0
CD6	0	0	0
CD7	0	0	0
0	0.2 ± 0.5	0	0
1	64.0 ± 13.1	0	17.9 ± 14.0
2	41.6 ± 13.1	0	12.4 ± 20.1
3	7.1 ± 15.8	1.6 ± 3.2	6.8 ± 3.1
5	19.8 ± 12.8	8.0 ± 12.8	24.7 ± 13.2
6	67.2 ± 19.2	6.4 ± 11.2	8.5 ± 4.4
8A	9.3 ± 14.9	4.8 ± 8.0	4.5 ± 10.2
8B	11.8 ± 7.4	3.2 ± 11.2	0
8C	0	0	0
9	0	0	46.3 ± 12.1
10	12.8 ± 6.4	0	0
DR0	0.1 ± 0.1	0	0
DR1	0	0	0
DR2	0	0	9.1 ± 8.2

x ± σ = mean plus or minus the standard deviation

The results of the seagrass surveys tabled above cannot be compared in detail with the results of Hillman *et al* (2000) because these authors present whole-of-estuary total biomass and hence there are no site-specific data. However, the graphs of Hillman *et al* (2000) showing mean areal macrophyte biomass over the period 1984-93 provide useful information. Leaving aside the fact that there was no sampling by Hillman *et al* (2000) in the estuary in 1986 and 1987, the sampling in 1984 and 1985 shows, for the macrophytes (seagrasses and macroalgae), a decline in total biomass, and specifically a decrease in biomass of *Halophila*, at a time when a similar general decline in diversity and abundance of benthic invertebrate fauna was identified.

Seagrass meadows are very productive, support complex food webs and are valued as a habitat, nursery ground and refuge for a number of aquatic organisms including fish, crustacean and mollusc species. It would appear, therefore, that macrophytes are an important part of maintaining benthic invertebrate faunal diversity and abundance in the estuary. For example, at the times when the V and C Semeniuk Research Group surveyed the estuary (1982-87, 1998 and 2005) invertebrate fauna was recorded as absent, or in low abundance or diversity, when seagrasses were also noted as being absent.

3.6.1 Recommendations for further investigation

1 Undertake periodic macrophyte surveys of the Leschenault Estuary to determine distribution, density and diversity of various seagrass species as an indicator of nutrient retention and habitat for aquatic fauna; and macroalgal species as a measure of risk for nuisance blooms.

2 Identify heavy metal contamination in stormwater and estuarine sediments radially from urban drainage discharge point sources to quantify the impact of trace metals upon seagrass distribution.

3 Identify measures to manage nutrient inputs from Parkfield Drain and associated catchment to reduce risk of nuisance macroalgal blooms in the northern estuary including promotion of best management practices and drainage management.

3.7 Phytoplankton

Studies undertaken by Hosja and Deeley (2000) between 1984 and 1986 found the phytoplankton, or microalgae, community of the Leschenault Estuary was dominated by marine and estuarine diatoms for most of the year, although freshwater diatoms and other groups such as dinoflaggelates, cyanophytes and cryptophytes are observed for short periods during winter. These species, having an affinity towards fresh water conditions, may have been transported into the estuary in winter runoff from rivers and waterways within the catchment. A high proportion of normally epiphytic or benthic species occurred in surface waters consistent with shallow water depths and significant wind mixing for much of the year (Hosja and Deeley, 2000).

The prevalence of annual phytoplankton distribution within the Leschenault Estuary is represented in Figure 12.

The predominance of diatoms may be attributed to nutrient enrichment, which results in increased primary productivity in phytoplankton, particularly diatoms. In severe cases, potentially harmful dinoflagellates and cyanophytes can occur, but to date this has not occurred within the estuary. The last recorded phytoplankton bloom in the Leschenault Estuary was a non-toxic bloom of the diatom *Cyclotella* in December 2000.

In the period December 2005 to June 2006 (no sampling was undertaken between July and December 2005), the Leschenault Estuary exhibited phytoplankton species and abundance consistent with Figure 12, with the small dinoflagellate species *Katodinium* becoming the predominate species as summer progressed; with the marine planktonic diatom species, *Nitzschia, Rhizosolenia, Chaetoceros*, as the secondary species. By early-autumn the transition to a diatom-dominated population occurred, with dinoflagellate species in the minority. Numbers of both diatom and dinoflagellate species began to decline from mid-autumn.

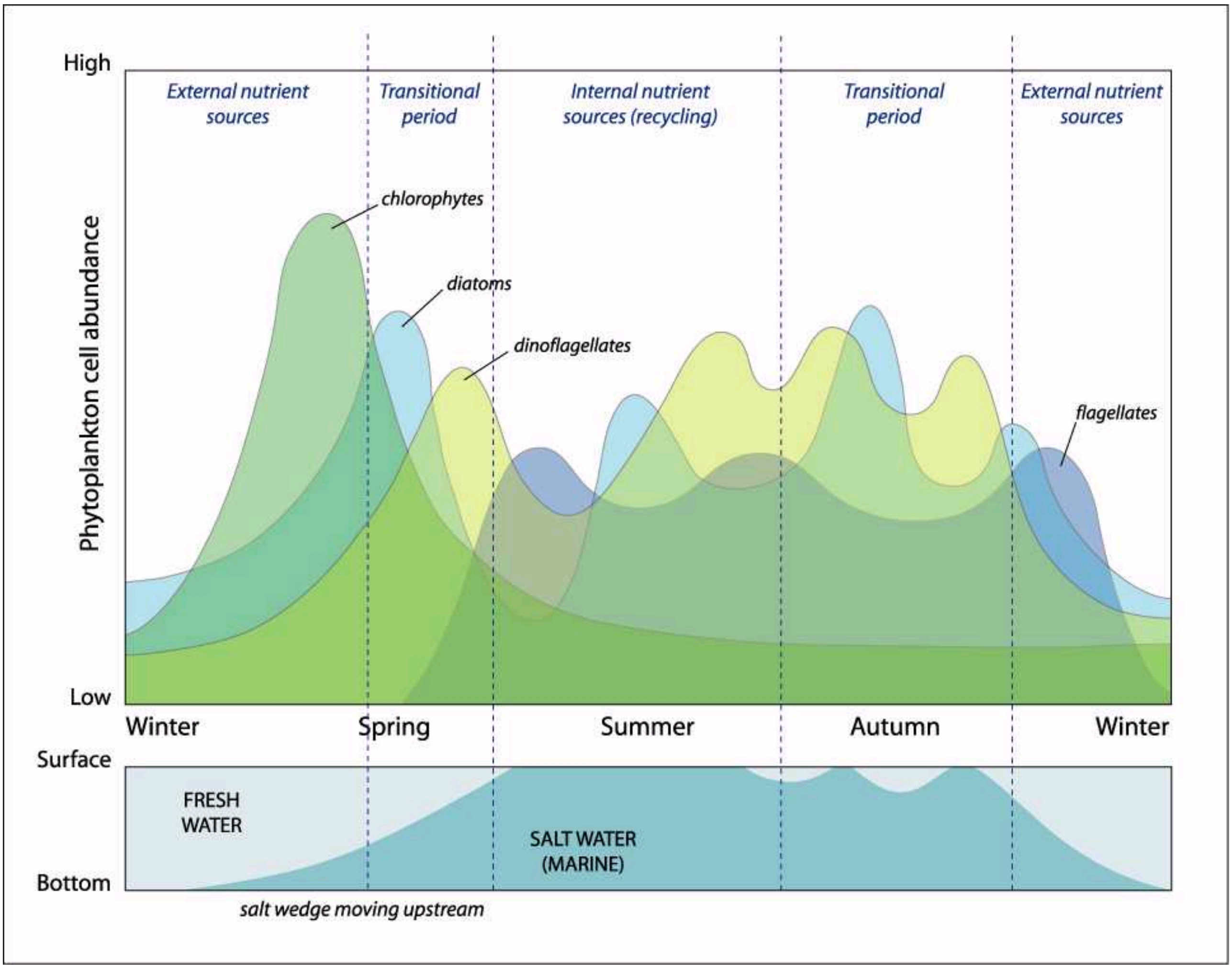


Figure 12. Typical seasonal fluctuations in phytoplankton species and abundance in an estuarine system (Geosciences Australia, website).

3.7.1 Recommendations for further investigation

1 Determine the Department of Water’s role in implementing the State-wide Algal Management Strategy.

3.8 Fringing vegetation

The fringing vegetation of the Leschenault Estuary can be divided into five types based on structure, salinity of habitat and location relative to the shore:

1 *Saltmarsh formations* comprising samphire flats and heath, and open to closed sedgelands, rushlands and herblands that develop in saline tidal areas. *Juncus kraussii* closed rushland and *Sarcocornia quinqueflora* saltmarsh complexes predominate.

2 *Estuarine fringing forest,* typically of the small saltwater sheoak (*Casuarina obesa*), saltwater paperbark (*Melaleuca cuticularis*), paperbark (*Melaleuca viminea*), and swamp paperbark (*Melaleuca raphiophylla*), occurs as the elevation increases and where soil water salinity is not as extreme.

3 *Fringing vegetation* consists of emergent sedge, and sedge and mat grass formations that live more or less permanently in shallow water. *Schoeneoplectus validus* closed sedgeland and *Paspalum vaginatum* low closed grassland are common examples.

4 *Sandy rise vegetation* occurs on the crest of barrier sand bars, on margins of high coastal sand dunes, or on low estuarine beach dunes. The diversity of habitat areas along the estuary give rise to a number of complexes, including *Jacksonia furcellata* open-closed scrub, *Eucalyptus rudis-Meleleuca raphiophylla* woodland, *Acacia saligna* low closed forest and *Juncus kraussii-Isolepis nodosa* low closed sedgeland.

5 *Freshwater vegetation* occurs in proximity to the estuary in areas receiving substantial freshwater input, either from surface flows (ie drains, creeks) or from groundwater seepage which typically occurs at the base of the ridge or the sand dune. This group is represented by predominantly *Baumea juncea* sedgeland and *Meleleuca raphiophylla* open-closed forest (Pen *et al*., 2000).

3.8.1 Changes in fringing vegetation 1941-1989

The distribution and changes in fringing vegetation has been undertaken by Pen *et al* (2000) through comparison of historic aerial photography from 1941 with field observations and mapping undertaken in 1989. During this time, the extent of fringing vegetation in 1941 comprised some 700 ha, of which about 350 ha remained in 1989.

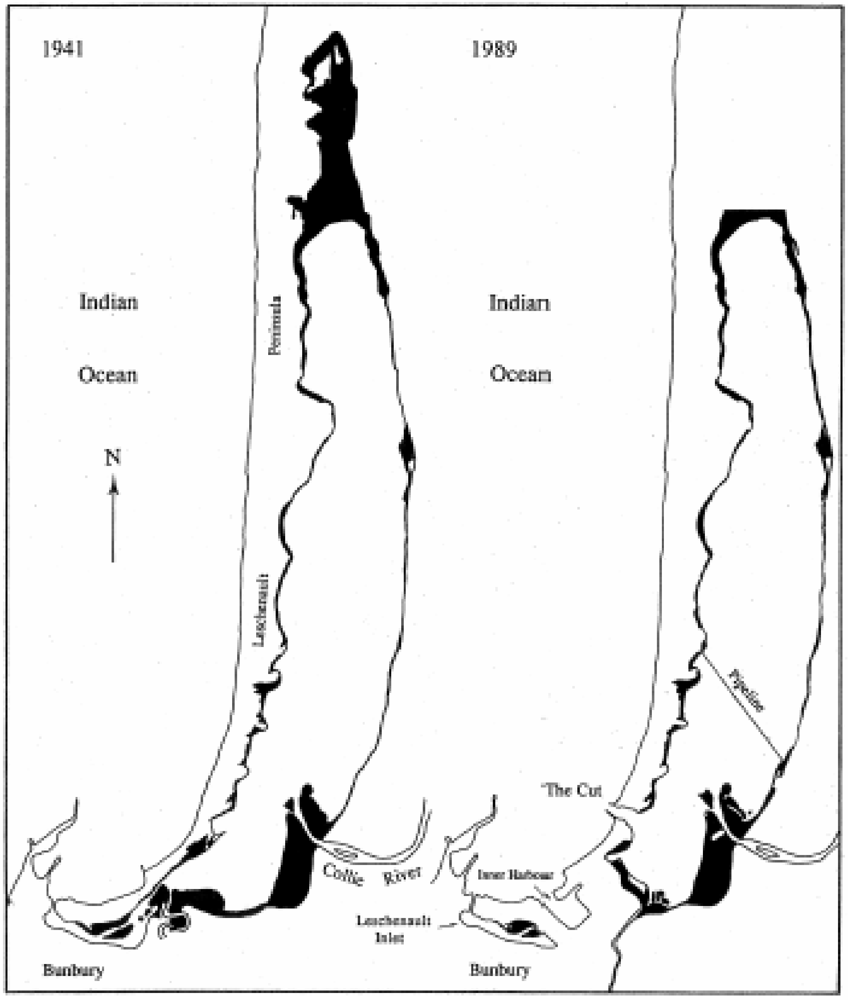


Figure 13. Extent of fringing vegetation along the Estuary and the latter Leschenault Inlet in 1941 and 1989 (Pen *et al*, 2000).

Changes in the vegetation since 1941 have occurred within the vegetation alone, without changes in the habitats, and some have been induced by changes in estuarine coastal landforms, and anthropogenic changes. These changes are described below:

1 *Clearing of fringing vegetation.* The development of the near-estuarine environment over time has had a dramatic impact upon fringing vegetation as a variety of land uses has been accommodated since the 1941 photography. Large areas of samphire, which colonised dredging spoil and artificial lagoons along the southern end of the estuary (including most of the original estuary mouth), have been destroyed by land reclamation to facilitate the Bunbury Inner Harbour development. Loss of fringing forests of probably saltwater paperbark (*M. cuticularis*), swamp paperbark (*M. raphiophylla*) and peppermint (*Agonis flexuosa*), would also have been expected to be lost in this area. The loss of this fringing forest was also likely to have occurred in the area north of Buffalo Road, in addition to areas of closed heath, through clearing and drainage for agriculture. Much of the narrow fringing vegetation along the eastern foreshore has been cleared on the landward side corresponding to the elevated platform, which includes the Old Coast Road to accommodate road reserve and

recreational areas. However, the fringing vegetation on the western shore associated with the Leschenault Peninsula Park remains largely intact.

2 *Decline of estuarine fringing forest.* Fringing forests of various paperbark species have in many cases been replaced by saltmarsh and mixed, unstructured plant assemblages as a consequence of alteration of localised drainage patterns and artificial drainage associated with urban development. The impact has been to shift the salinity/freshwater balance towards increasing salinity that favours saltmarsh at the expense of fringing forest.

3 *Encroachment of Juncus kraussii closed rushland.* Most populations of *J. kraussii* have been identified since 1941 as encroaching into the estuary, moving across samphire flats, and sandy substrates. This encroachment may be caused by the reduction in mean water level over the winter months as a result of the construction of the ‘Cut’ exposing new favourable lower tidal sites. This encroachment rate has been suggested as being 5-20 m over the past 40 years (Pen *et al*., 2000).

4 *Colonisation of river deltas.* The colonisation of deposited river sediments by fringing vegetation has occurred on both the deltas of the Collie and Preston rivers. Samphire has predominantly colonised the sand deposits associated with Bar Island at the mouth of the Collie River since 1975, and *J. kraussii* and *S. quinqueflora* have established on the Preston River delta and the enclosed mud flat at Point Mornington, created when the original outlet from the estuary was filled for the harbour development.

5 *Tidal lagoons along the Leschenault Peninsula.* The Leschenault Peninsula represents an eastward-moving parabolic dune system that erodes naturally at the rate of approximately one metre annually, with the most marked erosion occurring in the southern parts towards the ‘Cut’, and to a lesser extent at the northern end of the peninsula. The peninsula is underlain by dune sand, which in turn is underlain by muddy estuarine sediments. Pronounced areas of foreshore that appear to reach out into the estuary are referred to as dune sand fingers. These fingers extend into the muddy environments of the estuary as part of the dune movement towards the east. Muddy sediments accumulate between these dune promontories, which in turn are inundated with sand to begin development of another sand finger that extends out further into the estuary. This process occurs continuously over time, but is responsible for the undulating coastline and formation of tidal lagoons along the Leschenault peninsula. Changes in the peripheral vegetation reflect changes in the salinity gradient and in response to the amount of freshwater seepage from the adjoining dunes throughout this process.

6 *Weed Invasion.* The predominant species invading and replacing fringing estuarine vegetation include couch (*Cynodon dactylon*), kikuyu (*Pennisetum clandestinum*), salt water couch (*Paspalum vaginatum*), buffalo grass (*Stenotaphrum secundatum*), pigface (*Carpobrotus edulis*), coojong (*Acacia saligna*), bullrush (*Typha orientalis*) and club rush (*Bolboschoenus caldwellii*). The most significant invasion is the spread of weeds such as couch, kikuyu, saltwater couch, buffalo grass and pigface into fringing *J.* kraussii formations from adjacent parkland areas. The invasion of these species is also likely to have excluded and replaced the native vegetation assemblages on the landward side of the foreshore, excluding them from the higher and drier ground. Bullrush and native club rush colonisation along the foreshore has been limited to areas of localised reduced salinity as a result of freshwater inputs from drains or freshwater seepages at the base of dunes.

3.8.2 Changes in fringing vegetation 1989-2005

Land clearing to accommodate urbanisation and a canal development associated with Pelican Point on the south sector of the Collie river delta undertaken in the 1990s, represents the greatest loss of peripheral fringing vegetation from that identified as remaining in 1989. Other than this development, and local small-scale clearing for car parks on the south-eastern shore of the estuary, the peripheral vegetation in May 2005 is largely similar in distribution to that surveyed in 1989 (Figures 16 to 34). However, some changes have occurred, and these relate to natural community adjustments (eg replacement of *Frankenia pauciflora* by *Salicornia quinqueflora*) and the dieback of fringing freshwater trees and shrubs in response to increased saline conditions. The types of changes are described and interpreted in Table 13 below.

Table 13. Interpretation of the changes in the peripheral vegetation of the estuary.

Change in peripheral vegetation between 1989 and 2005	Interpretation for change	Reference
Salicornia quinqueflora died back, replaced by “salt pans”	natural population adjustments, probably compounded by increased salinity	Figure 36
Frankenia pauciflora and *F. pauciflora - S. quinqueflora* in local patches along NW shore contracted and replaced by *S. quinqueflora*, or wholly replaced by *S. quinqueflora* or mixed *S. quinqueflora* and *H. halocnemoides*	natural population adjustments probably compounded by increased salinity	Figure 37
Samolus repens along NW estuary died back and replaced by “salt pans”	natural population adjustments and increased salinity	Figure 37
M. rhaphiophylla and *M. viminea*, on E and W shore, as indicators of freshwater conditions, have died back	increased salinity	Figure 38 and 40
NE estuary locally changed from *J. kraussi* to mixed *J. kraussi*, halophytes, and *G. trifida*	increased local freshwater seepage from fringing land drainage	Figure 39
zoned *J. kraussi* and *S. quinqueflora* along mid-eastern shore changed to *J. kraussi*	increased salinity	Figure 40
Southern sector of Collie River delta markedly altered by urbanisation	land development into canal and hosing developments	Figure 41

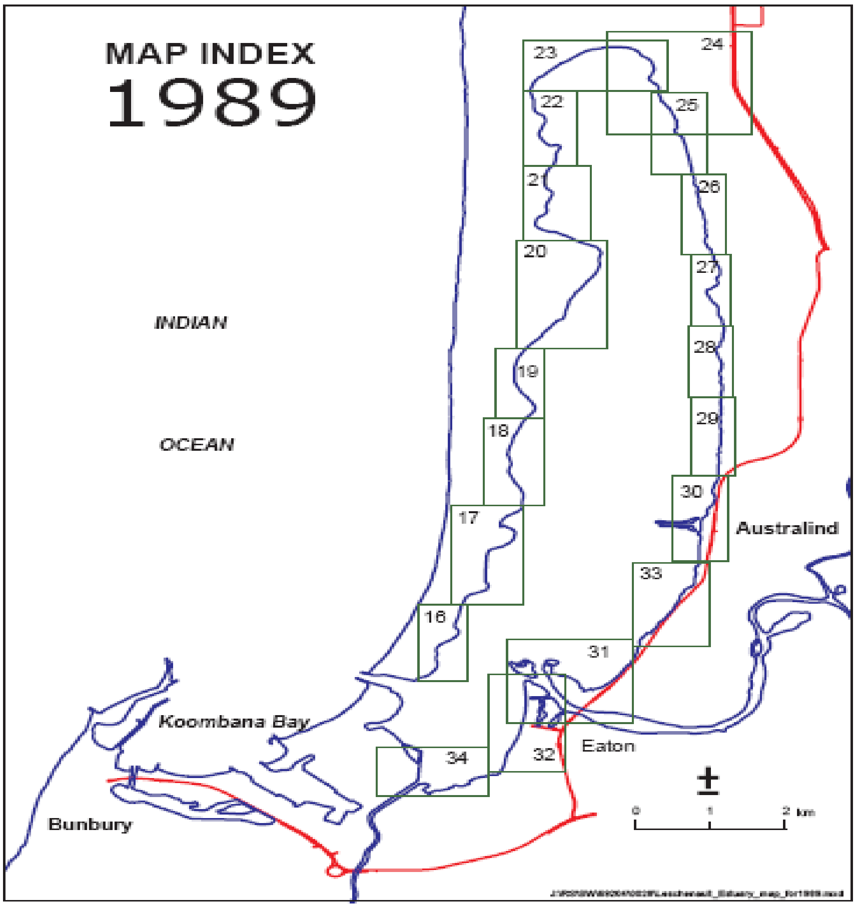


Figure 14. Location of Detailed Maps.

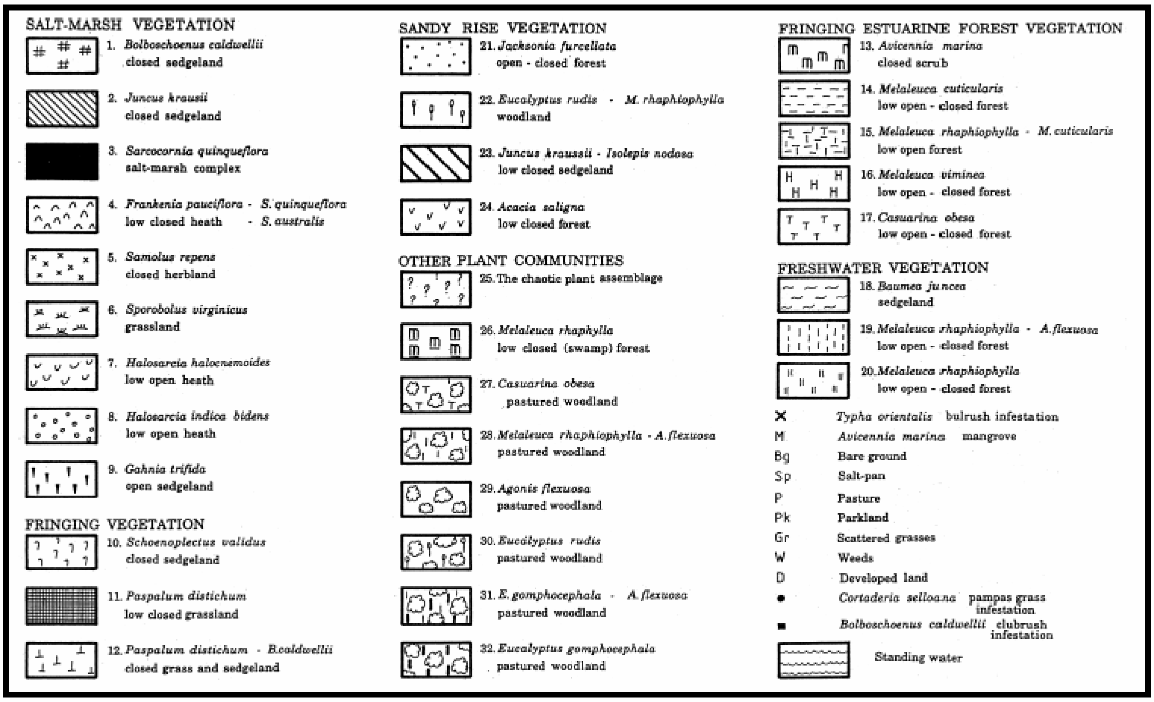


Figure 15. Key to vegetation units identified in peripheral areas of the Leschenault Estuary (Pen *et al*, 2000).

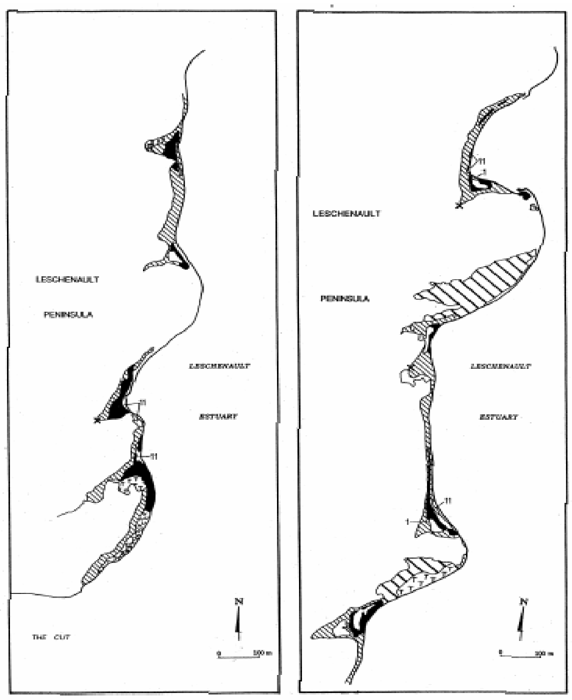


Figure 16-17. South-western estuarine shore showing vegetation units (Pen *et al*, 2000).

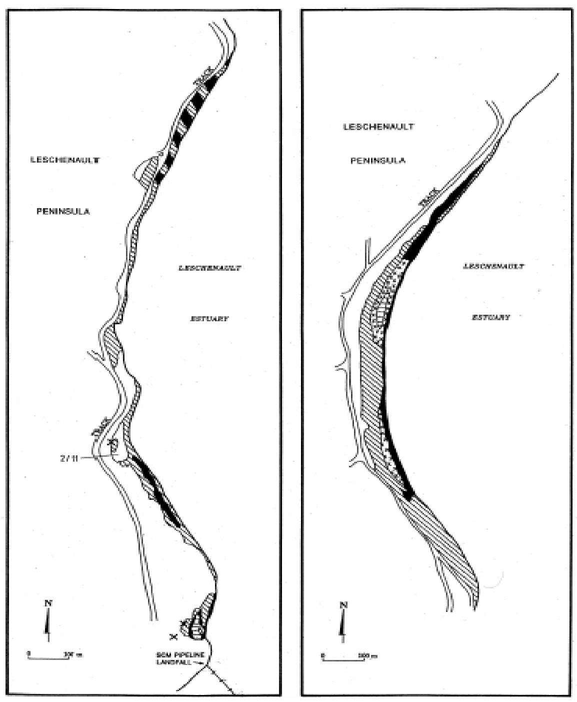


Figure 18-19. Western estuarine shore showing vegetation units (Pen *et al*, 2000).

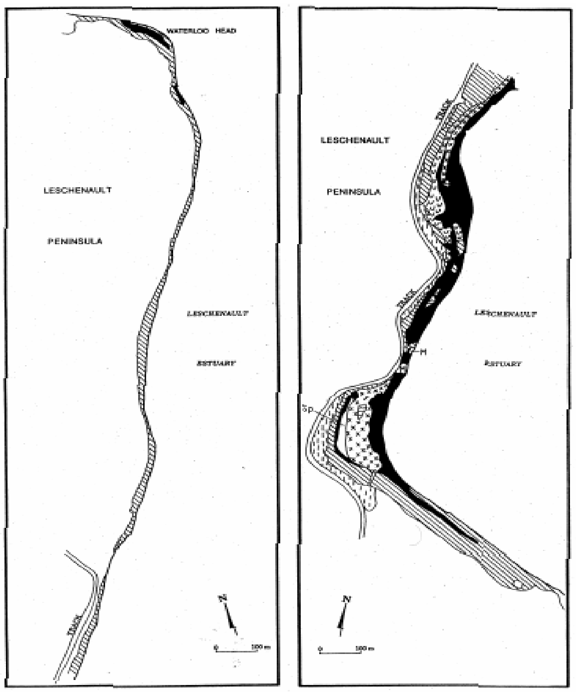


Figure 20-21. Western estuarine shore showing vegetation units (Pen *et al*, 2000).

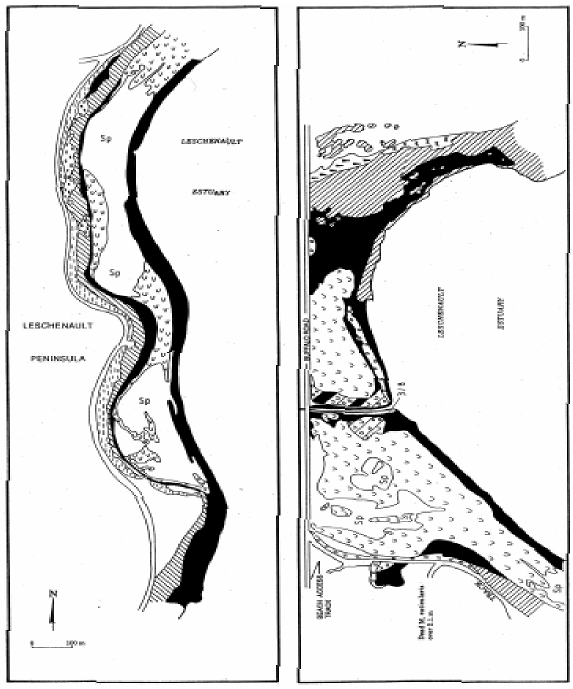
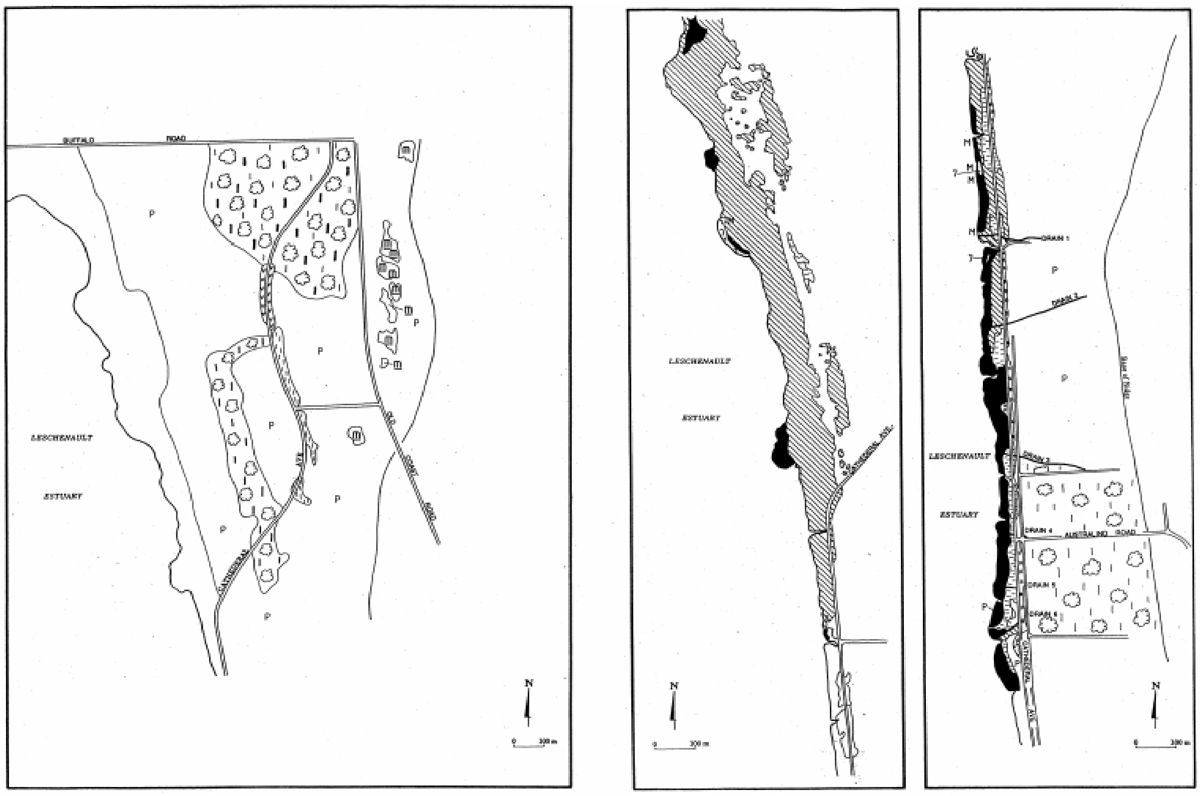
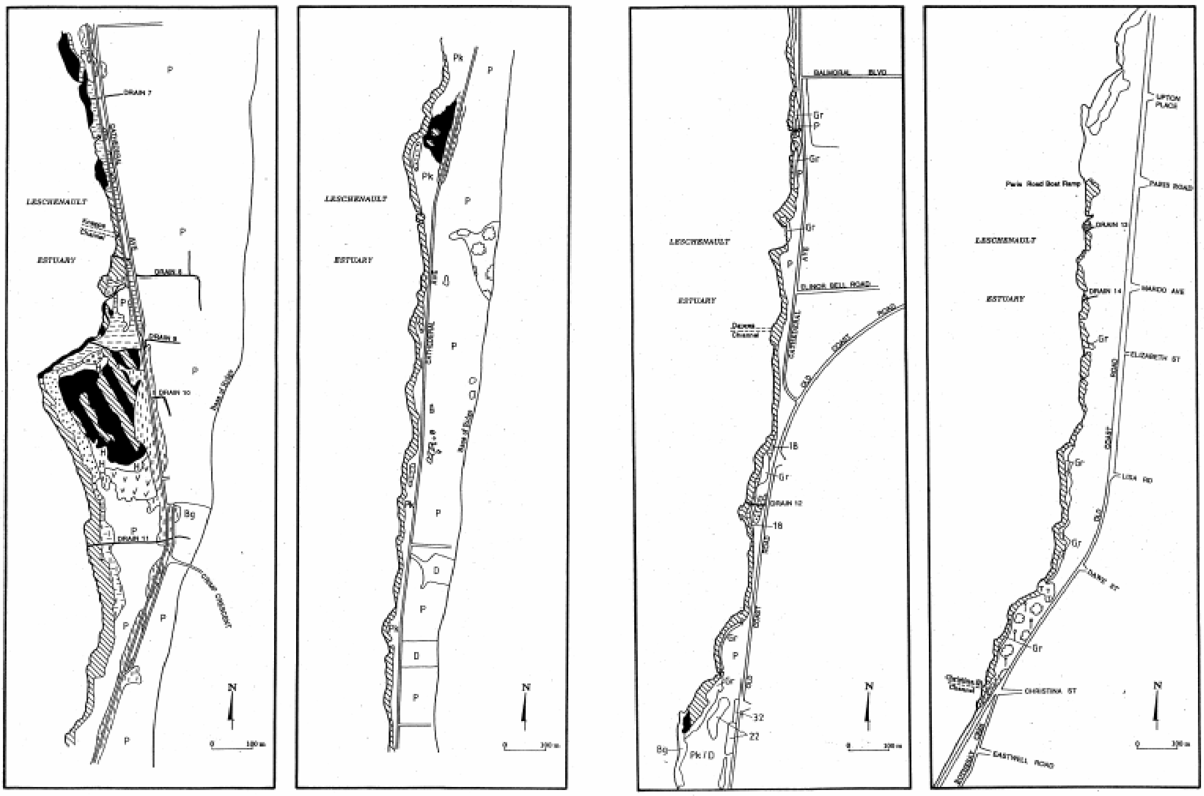


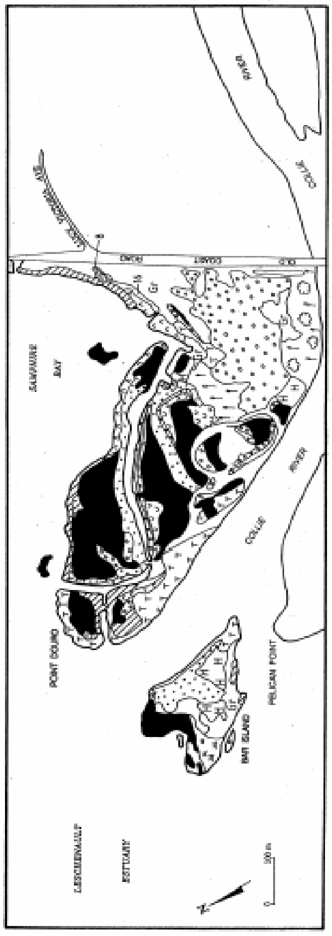
Figure 22-23. North-western estuarine shore showing vegetation units (Pen *et al*, 2000).

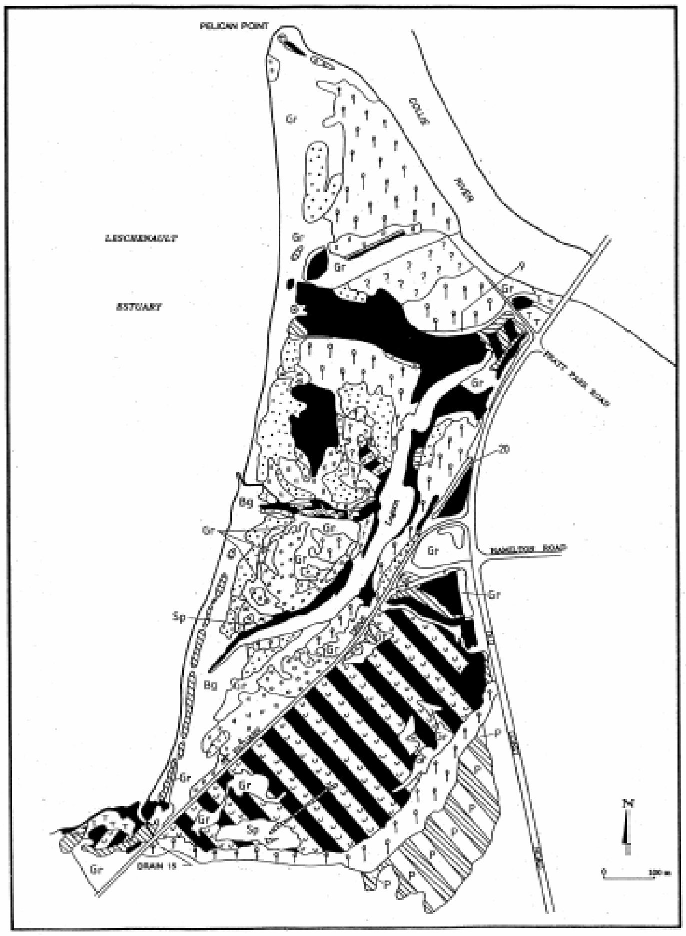


Figures 24-26. North-eastern estuarine shore showing vegetation units (Pen *et al*, 2000).

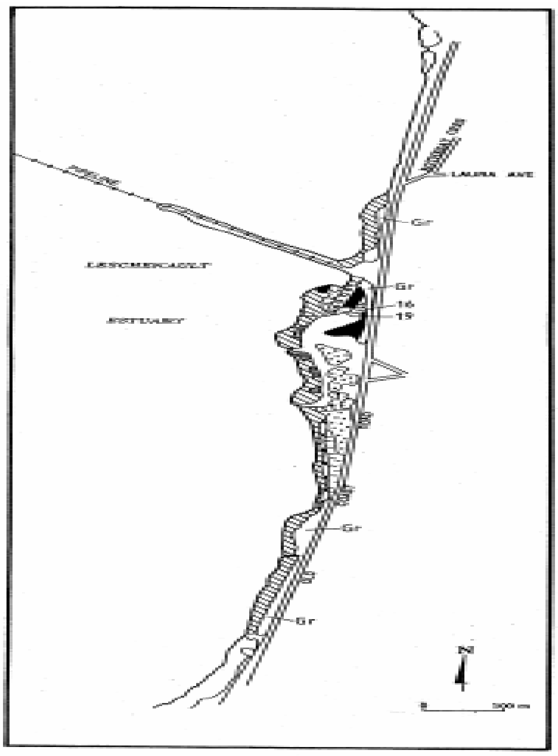


Figures 27-30. Eastern estuarine shore showing vegetation units (Pen *et al*, 2000).





Figures 31-32. Collie River delta showing vegetation units (Pen *et al*, 2000).



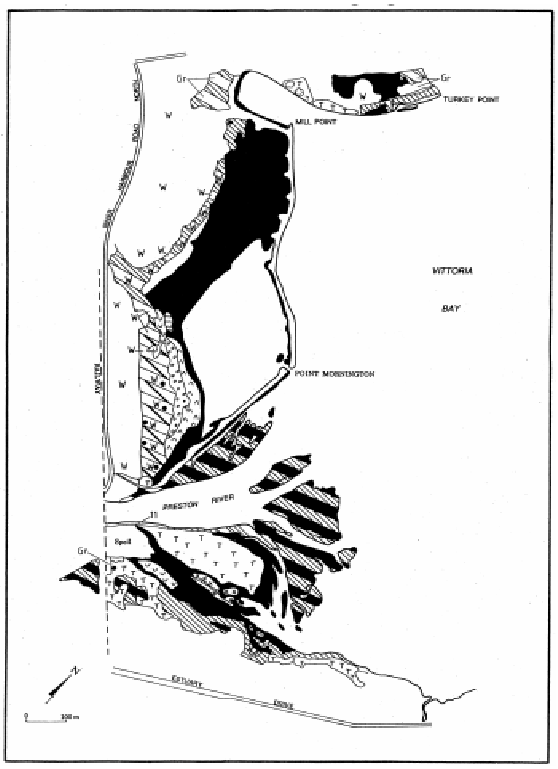


Figure 33. South-eastern estuarine shore showing vegetation units (Pen *et al*, 2000).

Figure 34. Southern estuarine shore showing vegetation units (Pen *et al*, 2000).

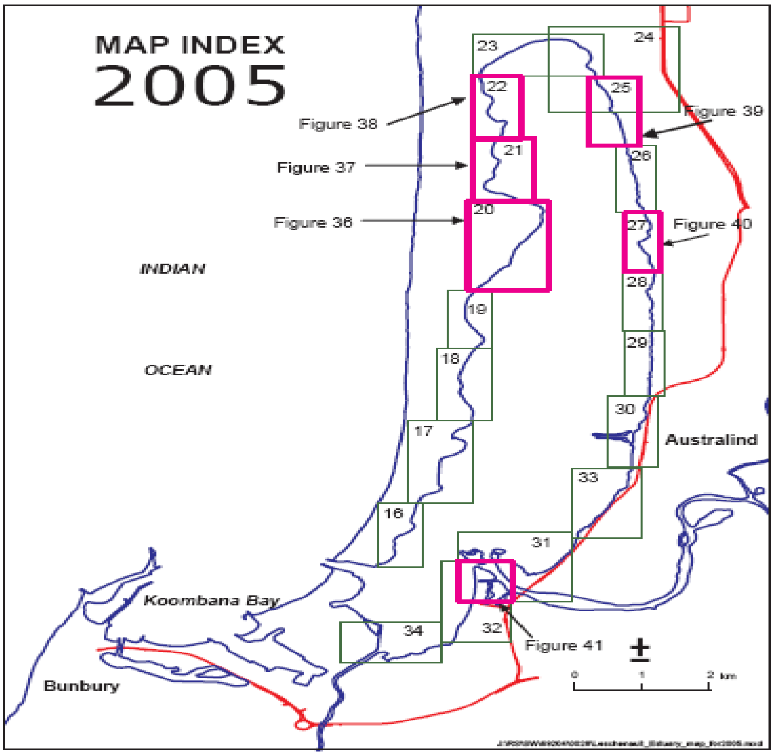


Figure 35. Location of detailed maps showing vegetation changes identified 2005.

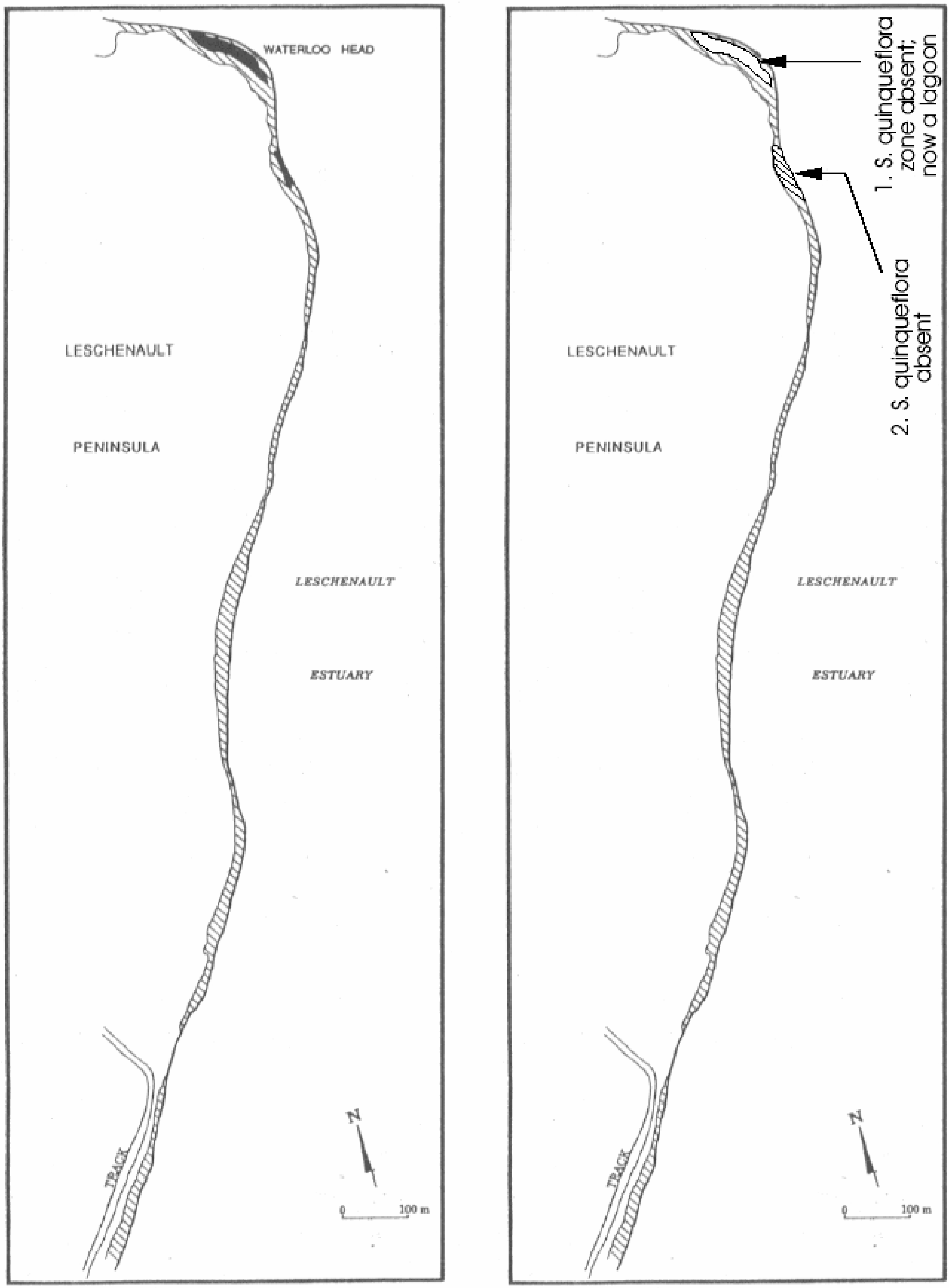


Figure 36. Changes in peripheral vegetation in western shore Leschenault Estuary between 1989 and 2005 (Semeniuk, 2000).

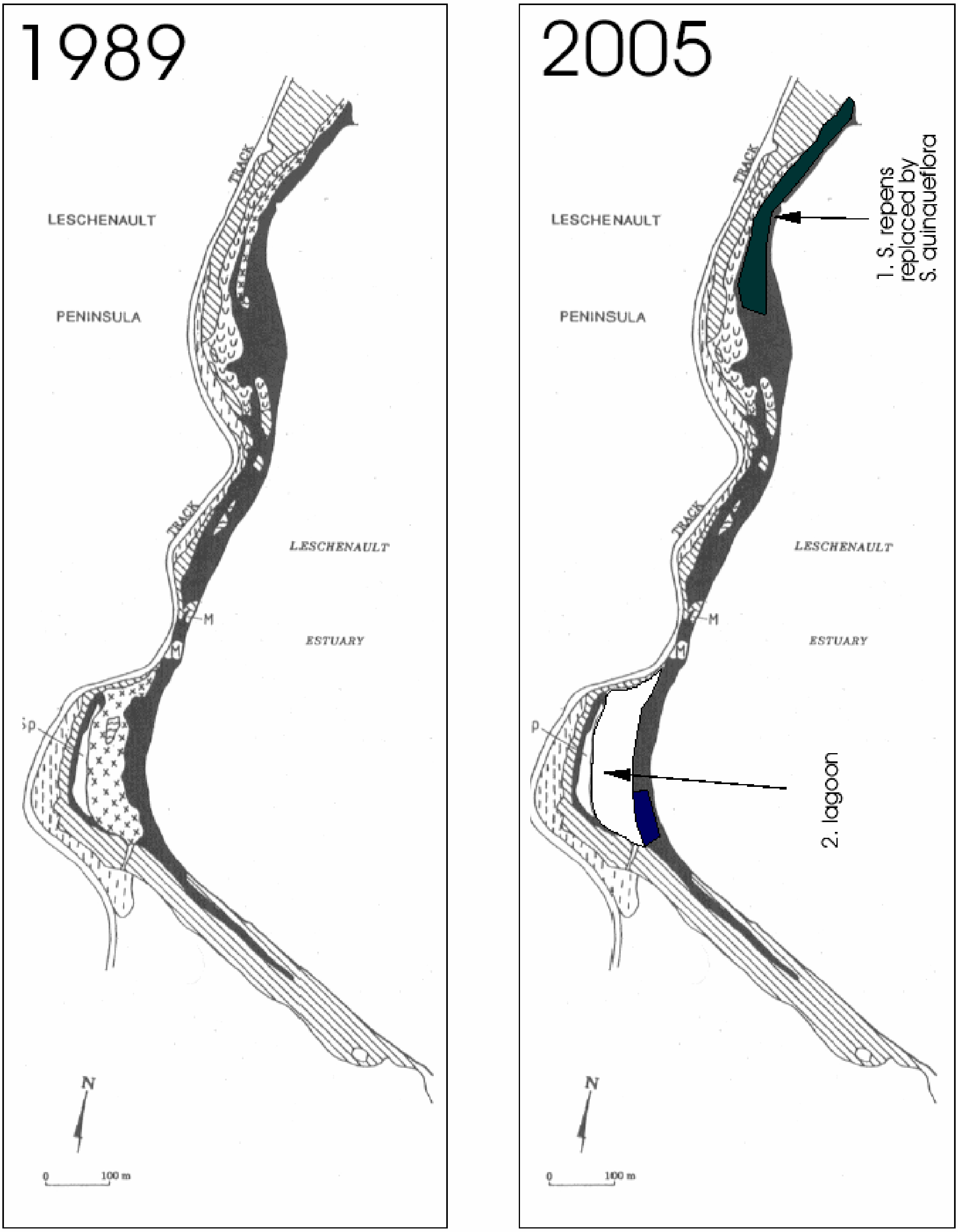
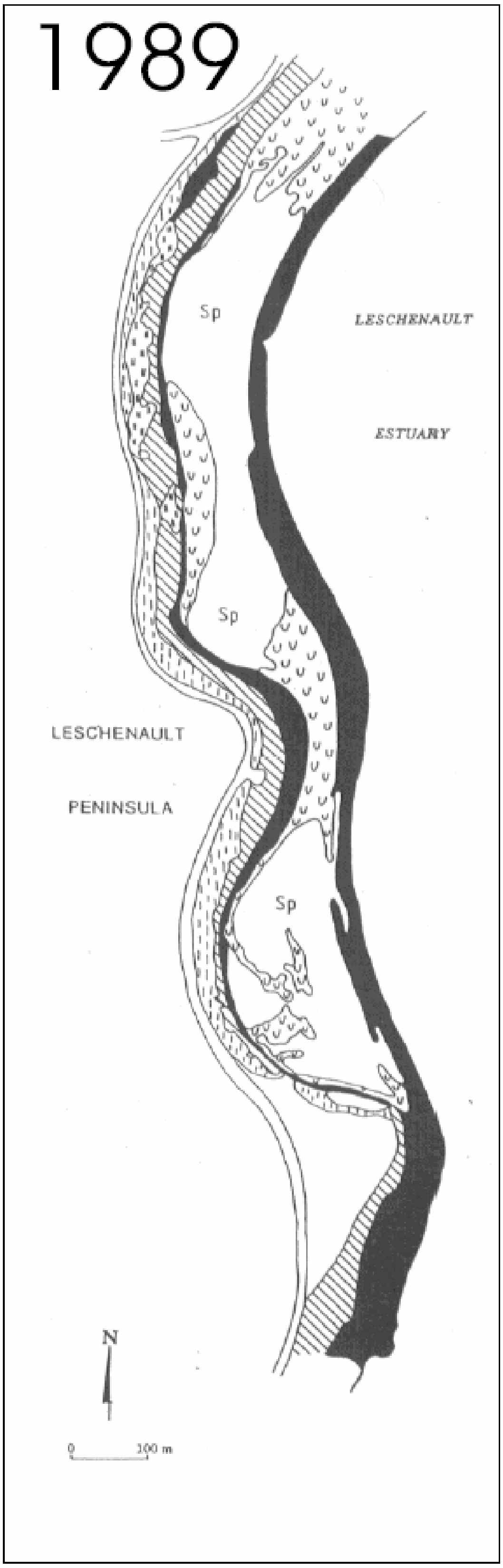


Figure 37. Changes in peripheral vegetation in western shore Leschenault Estuary between 1989 and 2005 (Semeniuk, 2000).



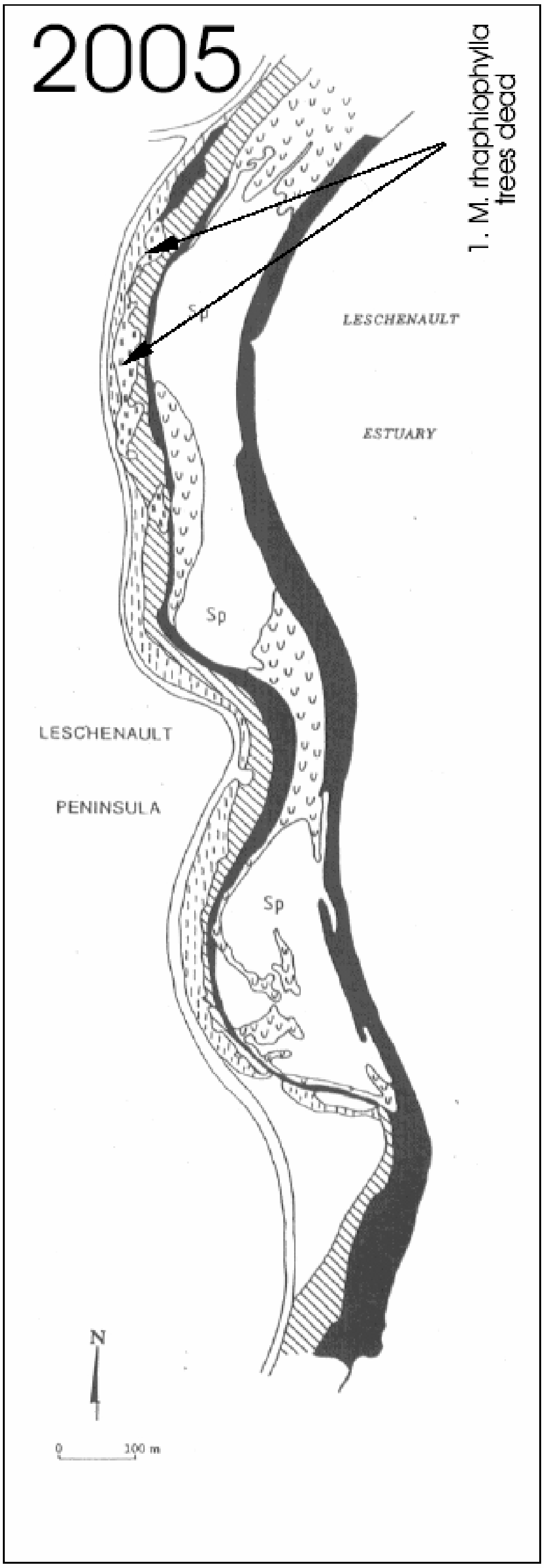


Figure 38. Changes in peripheral vegetation in north-western shore Leschenault Estuary between 1989 and 2005 (Semeniuk, 2000).

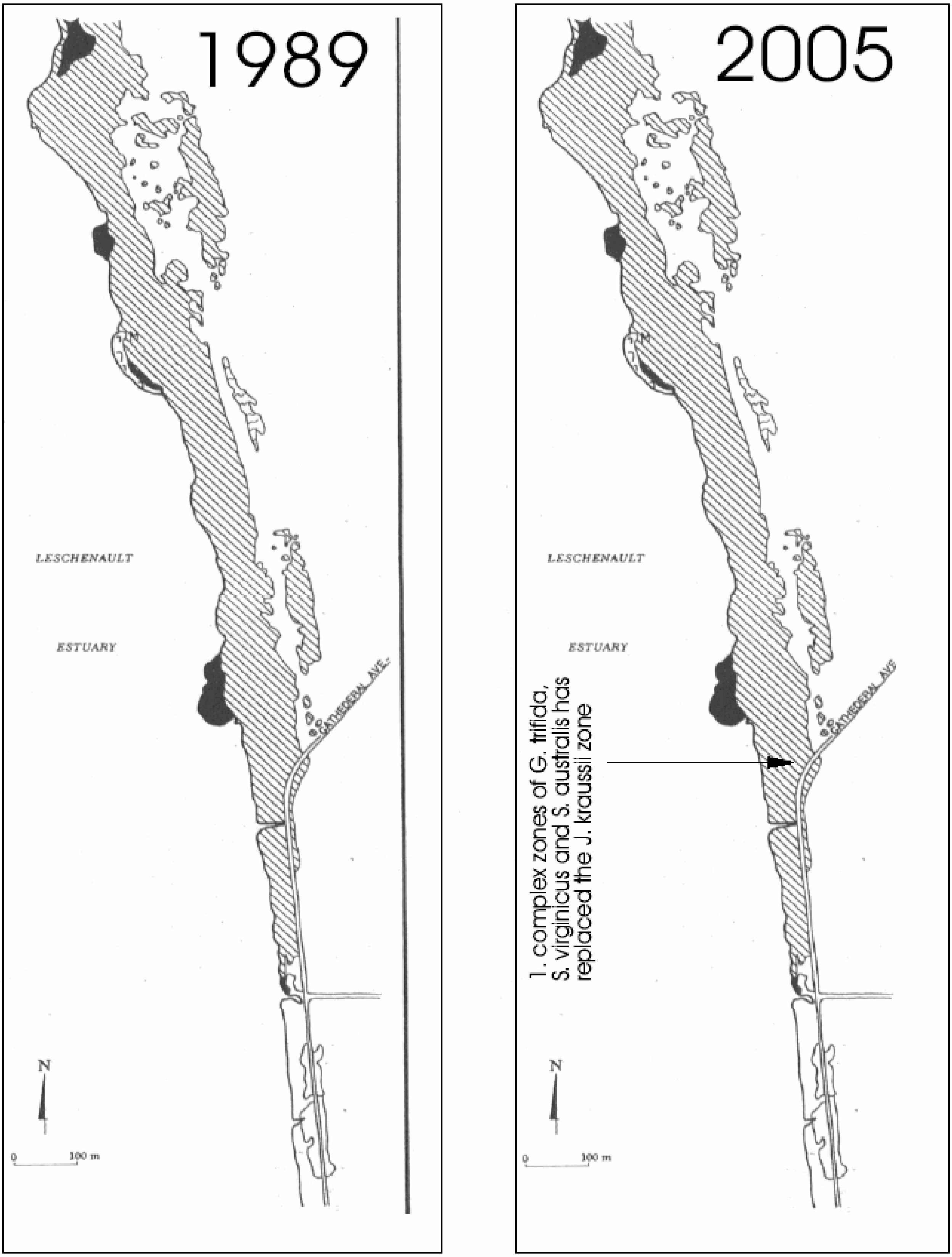


Figure 39. Changes in peripheral vegetation in north-eastern shore Leschenault Estuary between 1989 and 2005 (Semeniuk, 2000).

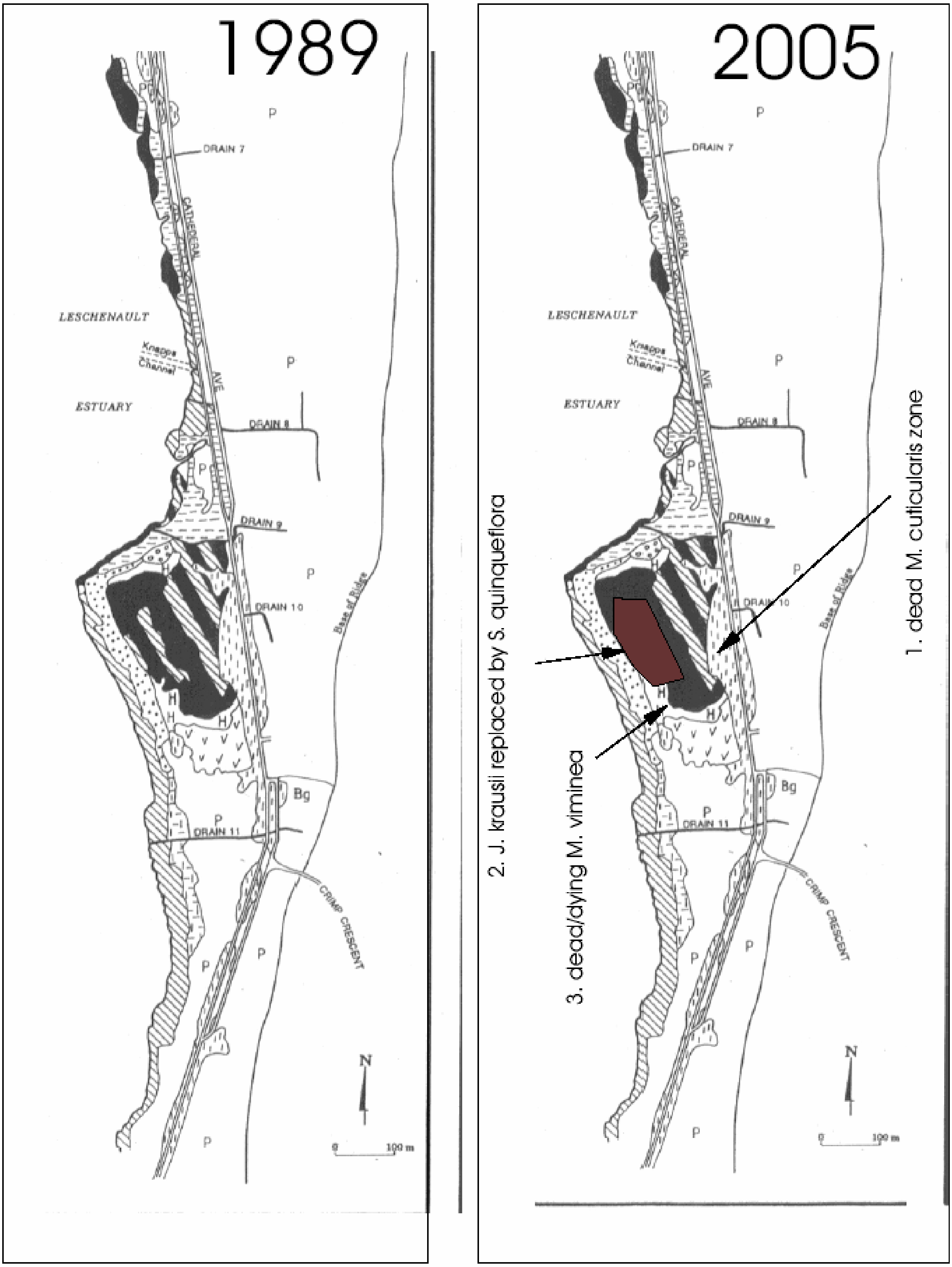


Figure 40. Changes in peripheral vegetation in eastern shore Leschenault Estuary between 1989 and 2005 (Semeniuk, 2000).

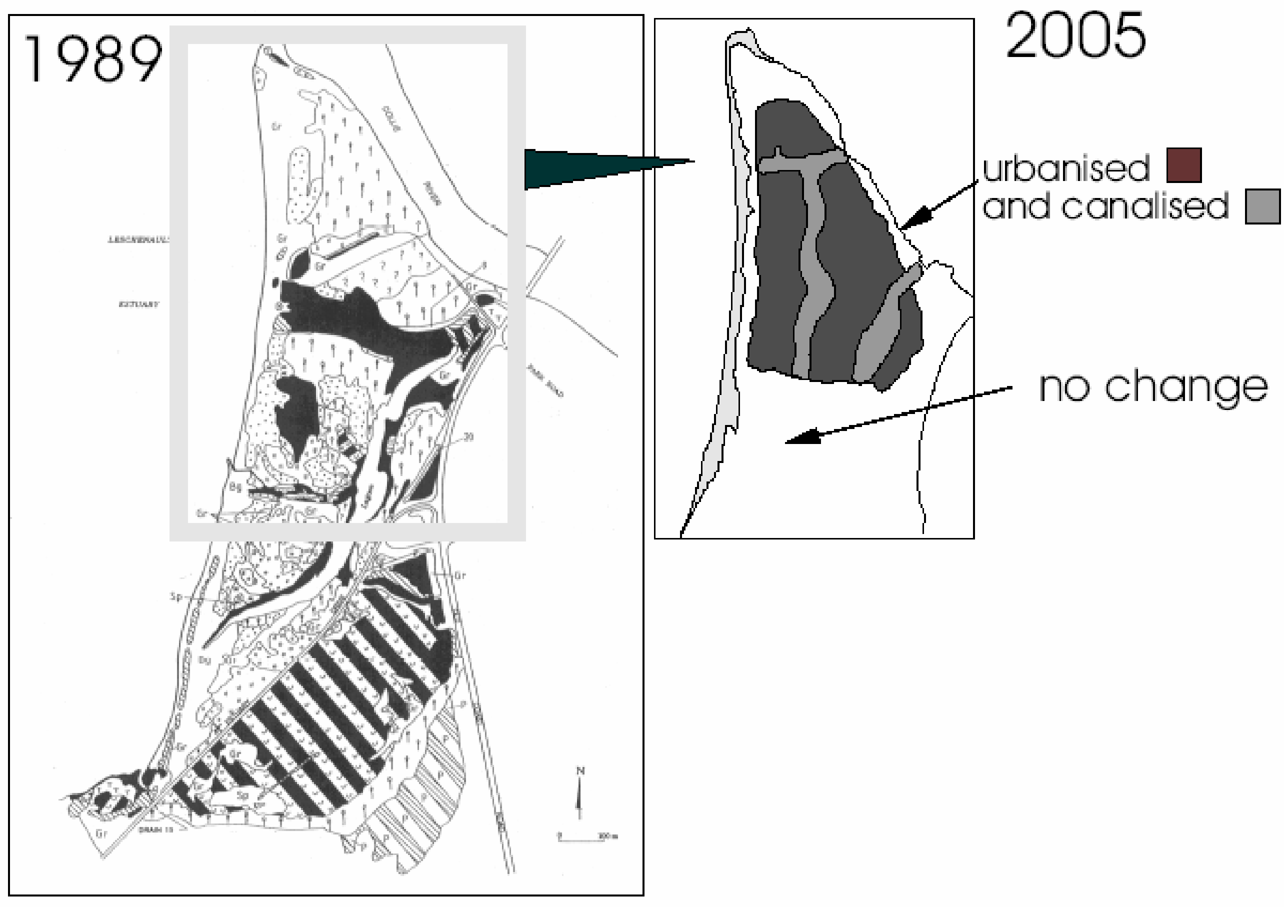


Figure 41. Changes in peripheral vegetation at the Collie River mouth in the Leschenault Estuary between 1989 and 2005 (Semeniuk, 2000).

The results above show that there have been changes in estuarine peripheral vegetation communities in the Leschenault estuary over the decades, a feature of the estuary that was described by Semeniuk *et al* (2000). The changes in the structure/floristics of the peripheral vegetation described and interpreted in Table 13 are related to several factors. There is the component of natural adjustments in vegetation structure and composition, which needs to be addressed when interpreting effects deriving from direct or indirect-and-subtle anthropogenic impacts. Anthropogenic effects may relate to altered drainage, and groundwater hydrodynamics brought about by draining, clearing, dewatering, urbanisation, dredging and spoil dispersal, and road construction. These effects can variably and locally change the recharge dynamics, discharge dynamics, and salinity of coastal habitats, resulting in the changes in assemblage composition, and mortality of some species (Pen *et al*, 2000). Urban developments and clearing for car-parks clearly have direct and immediate impacts as they involve removal of vegetation, but other current or past anthropogenic activities that triggered changes in peripheral vegetation are not so readily disentangled, as they are superimposed on natural effects, or act in concert together.

In some cases, some such impacts have taken decades to manifest themselves, eg increase in the prevailing estuarine salinity, as a result of the ‘Cut’, has taken decades to manifest itself in the composition of the peripheral vegetation and the increase in mangroves in the northern estuary. Adding to this type of effect is the depletion of freshwater seepage in some locations as a result of anthropogenic structures such as roads; the results of which are die-back of freshwater-dependent species along the upper shore, and a change to more salt-tolerant species in the vegetation in the mid-lower shore. In other locations, particularly on the eastern shore, rather than there being a depletion of freshwater seepage, there has been a general rise in the water table because of clearing, and hence there has been increased freshwater seepage and localised changes to some freshwater vegetation complexes (Semeniuk, 2005).

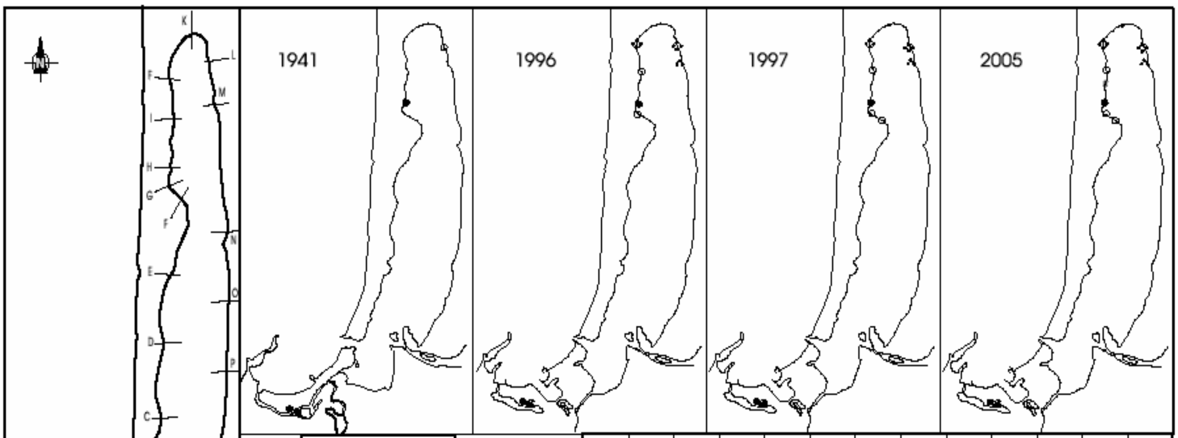
3.8.3 Mangroves

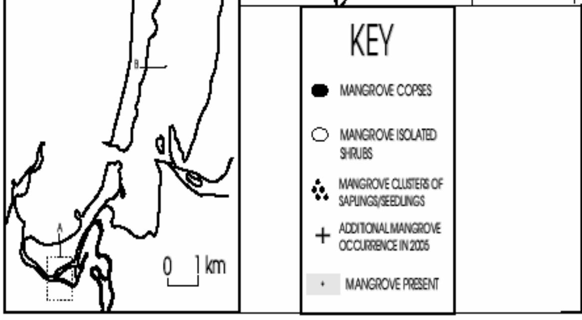
The white mangroves of the Leschenault Estuary and Inlet, *Avicennia marina*, are scientifically important in that they represent the most southerly occurrence of this mangrove species in Western Australia; the nearest location of this species being some 500 km to the north at the Houtman Abrolhos islands offshore of Geraldton. It is hypothesised that the mangroves became established by the delivery of mangrove propagules from these northern populations by the warm waters of the Leeuwin Current. The mangroves of the Leschenault Inlet will be discussed later in this document.

The shore types of the Leschenault Estuary that host mangroves include the high tidal flats and the steep dune shores along the eastern Leschenault peninsula. Both habitats are located in the northern estuary where they are supported by a salinity regime that varies from brackish to hypersaline. The extent of mangrove distribution in these areas has continued to increase over time but at a slow expansion rate. Mangrove abundance is greater at the steep dune areas as a consequence of freshwater seepage from the adjacent dune diluting localised hypersalinity; whereas freshwater seepage in the high tidal flats is more erratic resulting in scattered and isolated small individual plants.

The slow expansion of mangrove populations and development of these communities may be linked to the slow general increased salinity of the estuary following the excavation of the ‘Cut’ and the blocking, through landfill of the original Preston River Delta for the harbour, from its freshwater source. These engineering and hydrochemical changes, and the slow responsiveness to change of Avicennia populations suggest that anthropogenic changes may take decades to manifest (Semeniuk *et al*., 2005a). Therefore, it could be reasonable to suggest that the mangrove population of the estuary will continue to evolve until such time that an equilibrium state is achieved with the changing environment.

For the white mangrove, only two changes to the population were identified in May 2005 when compared with the previous work of Semeniuk *et al* (2000a) which concluded in 1996: 1) most of the seedlings noted in Semeniuk *et al* (2000a) had grown to a sapling and small shrub size; and 2) there were local new occurrences of mangrove as saplings/seedlings at two sites in the mid-west to north-west estuary. The addition of mangrove saplings and small shrubs to the upper estuary shows that the trend described in Semeniuk *et al* (2000a) continues; that mangroves are colonising the mid to upper estuary; that existing plants are growing larger; and that the mangroves are slowly, progressively and incrementally increasing in abundance in response to increasing salinities.





SITE	1941	1962	1971	1974	1976	1976-82	1983	1984-88	1996	1997	1999	2005
A	+	+	+	+	+	+	+	'	+	+	+	+
B												
C												
D												
E												
F										+	+	+
G									+	+	+	+
H	+	+	+	+	+	+	+	+	+	+	+	+
I									+	+	+	+
J									+	+	+	+
K										+	+	+
L	+	+	+	+	+	+	+	+	+	+	+	+
M								+	+	+	+	+
N									+	+	+	+
O												
P												

Figure 42. Mangrove distribution along the shores of the Leschenault Estuary and Inlet between 1941 and 2005 (Semeniuk 2005).

The proliferation of mangroves in the northern sections of the Leschenault Estuary gives further credence to the assumption on gradual increasing salinities within the estuary as a delayed consequence of the excision of the 'Cut'. It is noted that the fringing vegetation of the estuary continued to exhibit changes between 1989 and 2005, predominantly influenced by increasing salinities, while mangrove proliferation occurred between 1989 and 1996 (identification at 3-4 sites to 8 sites respectively) favoured by the alternating brackish to hypersaline salinities in the northern estuary waters and elevated salinities in the soil moistures in these areas. It could reasonably be concluded that the impact of salinity increase as a consequence of the incision of the 'Cut' may have begun exerting considerable influence in the period 1989-96 to reflect the changes in fringing vegetation and mangroves.

3.8.4 Recommendations for further investigation

1 Permanent replicate quadrats, supplemented by on-ground photography, along shore-perpendicular transects for peripheral vegetation should be established along key transects, effectively placing a transect within each of the map areas illustrated in Pen *et al* (2000). The quadrats would represent five to 10 replicate 1 m x 1 m quadrats for low herb vegetation, and 10 m x 10 m quadrats for trees. The data obtained would provide quantitative results to gauge the changes that may be occurring in the peripheral vegetation of the estuary by ascertaining any long-term changes in vegetation floristics (and structure) of the peripheral vegetation, whether naturally driven, or (indirectly) anthropogenically driven.

2 Permanent transects be established to monitor shoreline salinity (following Cresswell *et al* (2000)) to supplement and help interpret the results from any monitoring of the peripheral vegetation in terms of shoreline (groundwater) salinity changes and the effect of freshwater seepage in maintaining shoreline vegetation.

3.9 Benthic invertebrate fauna

Seasonal and annual variations in faunal communities and assemblages reflect the dynamic nature of the estuarine environment. Aspects of variations in habitats influencing biotic assemblages and species associations over time include changes in estuarine hydrochemistry, which may reflect variations in rainfall and nutrient loading; and changes in hydrodynamics driven by wind and storms that influence sediment transport and sedimentation. In addition, variability in the population dynamics of primary producers (dispersion of marine algae, the dispersion of seagrass beds, and variable densities of phytoplankton), recruitment, migration and mortality rates associated with life and food cycles will also impact on invertebrate faunal diversity and densities.

South west estuaries have been found to be biologically depauperate in their natural condition as a consequence of very low levels of nutrients; and high variability in salinity means that faunal assemblages under these conditions would be expected to have a high proportion of opportunistic species. Equally, a high proportion of opportunistic species represents a symptom of anthropogenic disturbance (Hosja and Deeley, 2000). Therefore, it is difficult to detect the impacts of human disturbance on a highly changed estuary such as the Leschenault where the system has been subjected to a high level of natural disturbance in terms of salinity through interchange with the ocean.

A comparison of changes between selected benthic invertebrate fauna sampling sites for the 1982-87 and 2005 sampling periods is described in Table 14.

3.9.1 Molluscs

Studies undertaken by Semeniuk and Wurm (2000) and Cresswell *et al* (2000) between 1982 and 1987 identified 31 species of mollusc in the Leschenault Estuary, of which seven were considered to be common. In order of decreasing abundance these seven most common species were: *Arthritica semen, Tellina deltoidalis, Nassarius burchardi, Spisula trigonella, Hydrococcus brazieri, Acteocina sp* and *Bedeva paivae*. The remaining 24 species were identified as occurring sporadically or rarely over the study period, often associated with short resident times or with specific or unique habitat conditions (ie such as within local mangrove environments or immediately adjacent to the ‘Cut’).

The dynamic nature of the Leschenault Estuary can produce variable responses in biota in the patterns of abundance and population maintenance, with population diversity fluctuating greatly and independently of seasonal and habitat considerations. Although most of the more abundant mollusc species occurred at least rarely across most habitat types, the relative abundance of a given species is governed by habitat type, substrate and to a lesser degree salinity regimes. Salinity and temperature generally are important limiting factors for mollusc distribution. For example, the hypersaline and high summer water temperatures of the northern, upper estuarine field are limiting even for truly estuarine mollusc species (Semeniuk and Wurm, 2000). Molluscs were found to respond differently to salinity gradients along the estuary, with most of the common species increasing in abundance along the south-north salinity gradient (*Arthritica semen, Tellina deltoidalis, Hydrococcus brazieri* and *Acteocina sp*), while others were found to decrease in abundance along the gradient (*Bedeva paivae*) (Cresswell *et al*., 2000). Furthermore, the abundance of some species could be influenced by parameters such as local population explosions and recruitment, food supply, and predator/prey relationships with fish and birds.

Figure 43 shows that in May 2005, in contrast to the wide variety of molluscs recorded by Semeniuk and Wurm (2000) in the estuary between 1982 and 1987, molluscs were represented only by very scattered *Tellina deltoidalis, Nassarius burchardi* and *Spisula trigonella*, all in low numbers in comparison with the 1982-87 occurrences. (Note: Given the wide temporal variation in mollusc density between 1982 and1987, the data in Figure 43 reflects the maximum density of a given species over that period and to be readily comparable with the data for molluscs presented by Semeniuk and Wurm (2000), has the May 2005 data reduced to similar area, ie numbers of individuals per 80 cm^2).

3.9.2 Benthic crustacea

Twenty-one species of benthic crustaceans were recorded in the Leschenault Estuary by Semeniuk (2000) between 1982 and1987. The most abundant species identified were the amphipod *Corophium sp* and the isopod *Tanais sp* that were both regarded as being widespread across the estuary habitats. These species displayed density variation with respect to salinity and substrate, whereas other less common species with restricted distribution displayed a correlation with salinity and vegetation. This reflects a habitat preference between species in which water depth, oxygen saturation of the sediment, temperature and food sources are expected to play a role.

Overall, species diversity was regarded as low, with the highest species diversity occurring in regions with close to normal marine salinities and stable temperatures. High species diversity was also recorded in the upper estuarine field and the deltaic region of the Collie River; areas of greatest salinity and temperature fluctuation. Lowest diversity correlated with the mid-estuarine area, which typically exhibits higher than normal marine salinities and relatively stable temperatures.

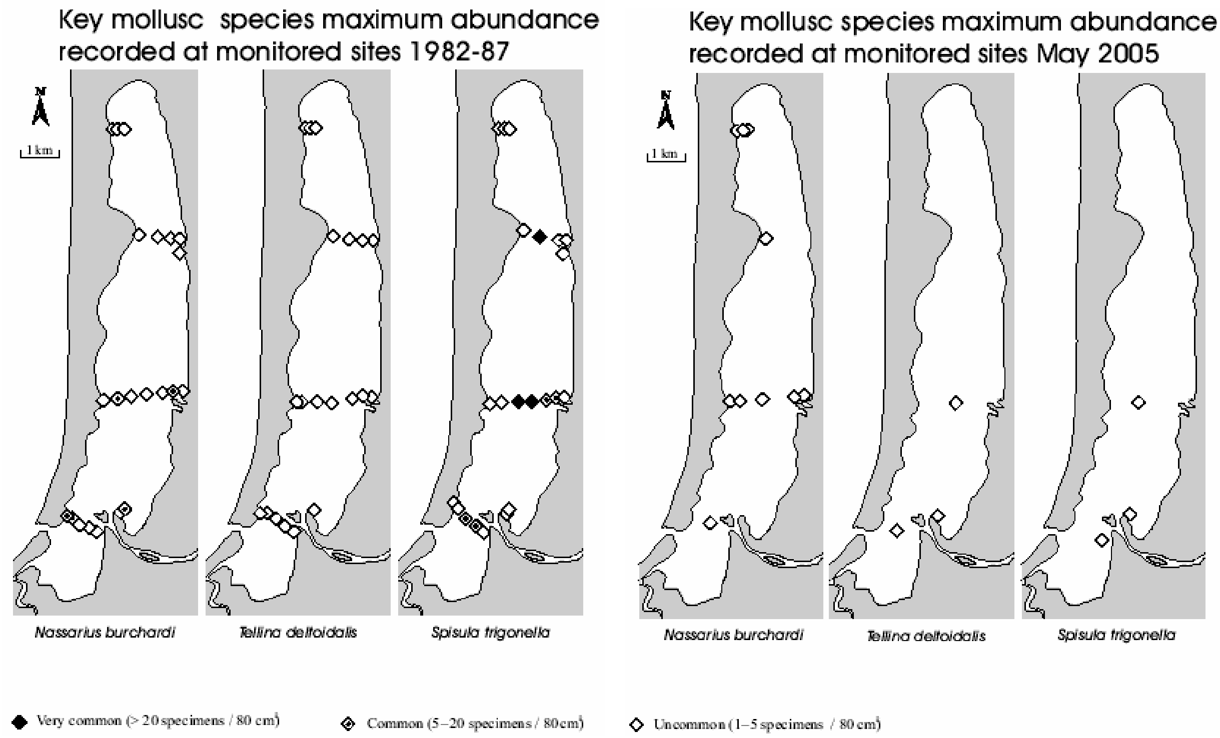


Figure 43. Comparison of key mollusc species abundance in the Leschenault Estuary between studies conducted in 1982-1987 (Semeniuk and Wurm, 2000) and 2005 (Semeniuk, 2005).

Over the sampling period, there was an overall decline in numbers of both the dominant species, which could possibly represent a shift in environmental conditions within the estuary. This decline, coupled with the identification of new (not previously recorded) species towards the end of the study and increased algal biomass, indicated a compositional change in the estuary likely to be the result of nutrient enrichment. The Leschenault Estuary was first reported as being mildly eutrophic in 1991 (Hill *et al*., 1991). Nutrient enrichment can result in changes in chemical conditions and the composition of primary producers, eg an initial increase, then a decrease in seagrass density, an increase in macroalgae, and a decrease in available oxygen in water and sediment columns (Semeniuk, 2000).

The change in species composition and decline in abundance of the predominant benthic crustacean species of the Leschenault Estuary identified in this study is most consistent with an environmental shift over time, rather than with patterns arising from large fluctuations in local conditions between years.

Figure 44 shows that the small benthic crustacea in the estuary in May 2005 were represented mainly by the amphipods *Corophium* and *Caprella,* also in low numbers compared with the 1982-87 occurrences. (Note: As with the mollusc data, to be readily comparable with the data for small crustaceans presented by T A Semeniuk (2000), Figure 44 has the May 2005 data reduced to similar area, ie numbers of individuals per 80 cm^2).

3.9.3 Polychaetes

Studies undertaken by Durr and Semeniuk (2000) between 1982 and 1987 identified 15 species of these elongated marine worms in the Leschenault Estuary. The most abundant species identified were *Ceratonereis aequisetis, Naphtys gravierei* and *Capitella cf capitata* with peak abundances generally occurring in late summer to autumn. *Scoloplos simplex* was also commonly identified in samples from sandy regions of the lower and middle estuary. Overall, species diversity of the estuary was considered low given the predominantly marine environment, but the total species number was comparable with other south-west estuaries, with diversity decreasing along the south-north salinity gradient to the upper salinity field dominated by a single species, *C. aequisetis*.

The relatively low polychaete diversity as compared with the marine environment was considered to be due to the absence of seagrasses of *Posidonia, Zostera*, and *Ruppia* species, to which polychaetes show preferential habitation and species diversity. The relationship of polychaete diversity and seagrasses such as *Halophila*, which is the predominant species in the Leschenault Estuary, is poorly understood (Durr and Semeniuk, 2000).

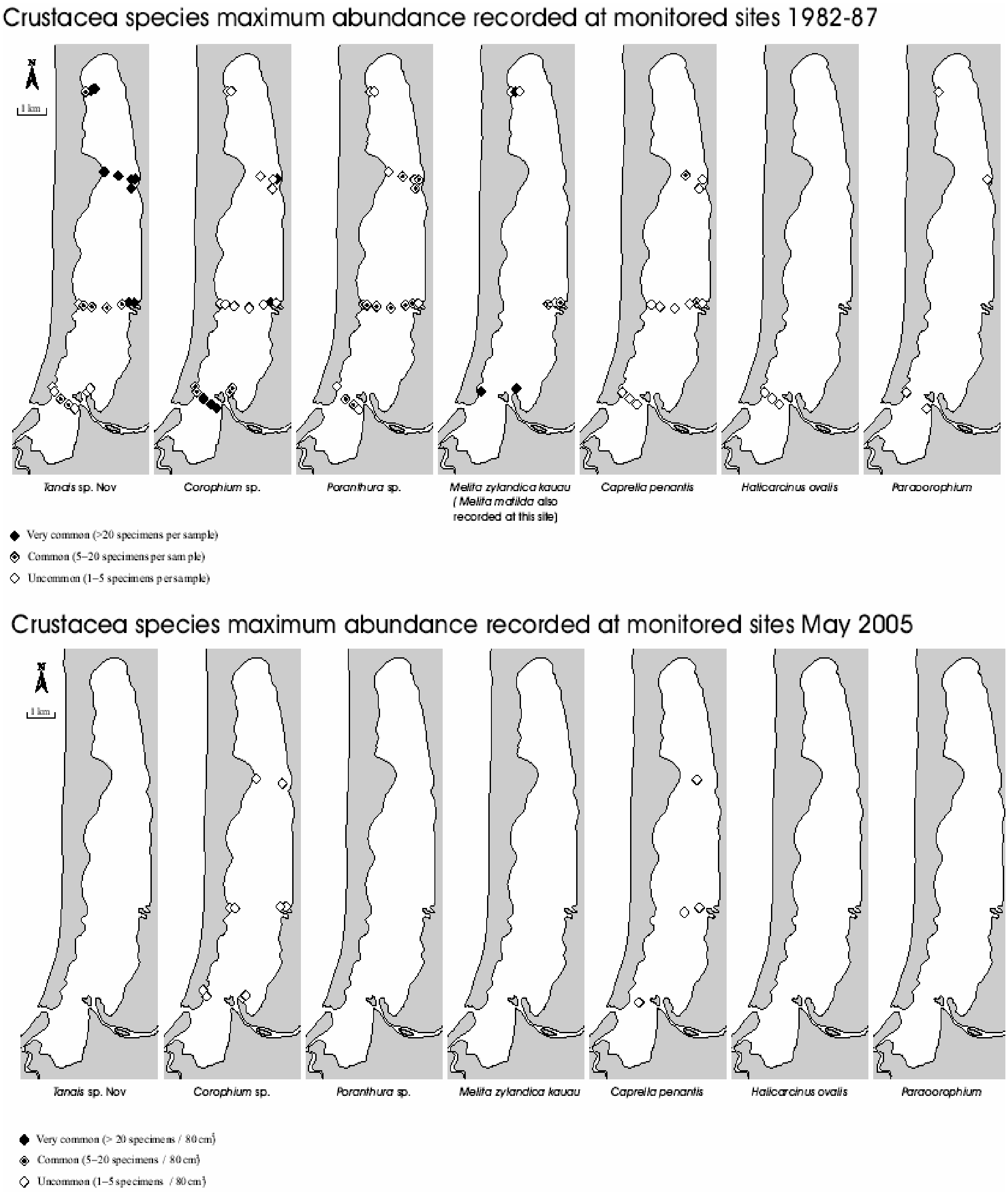


Figure 44. Comparison of key crustacea species abundance in the Leschenault Estuary between studies conducted in 1982-1987 (Semeniuk, 2000) and 2005 (Semeniuk, 2005).

The distribution of the dominant polychaete species could be linked to localised habitat conditions of salinity, water depth and substrate, which identified three polychaete assemblages: 1) *Ceratonereis – Naphtys – Capitella – Scoloplos* assemblage inhabiting the sediments of the deltaic regions and shallow fringing platforms of the lower to mid-estuarine sections of the estuary; 2) *Naphtys – Capitella – Scoloplos* assemblage inhabiting the mid-estuarine deep water basin mud, and; 3) *Ceratonereis – Capitella* assemblage of the salinity variable, northern region of the estuary.

Figure 45 shows that in the May 2005 'snapshot' survey, polychaetes were represented only by *Capitella cf capitata, Ceratonereis aequisetis, Diapatra dentata, Glycera cf americana* and *Nephtys gravieri*, though only *Ceratonereis aequisetis* and *Diapatra dentata* were in significant numbers throughout the estuary. (Note: Again, to be readily comparable with the data for polychaetes presented by Durr and Semeniuk (2000), Figure 45 has the May 2005 data reduced to similar area, ie numbers of individuals per 80 cm^2).

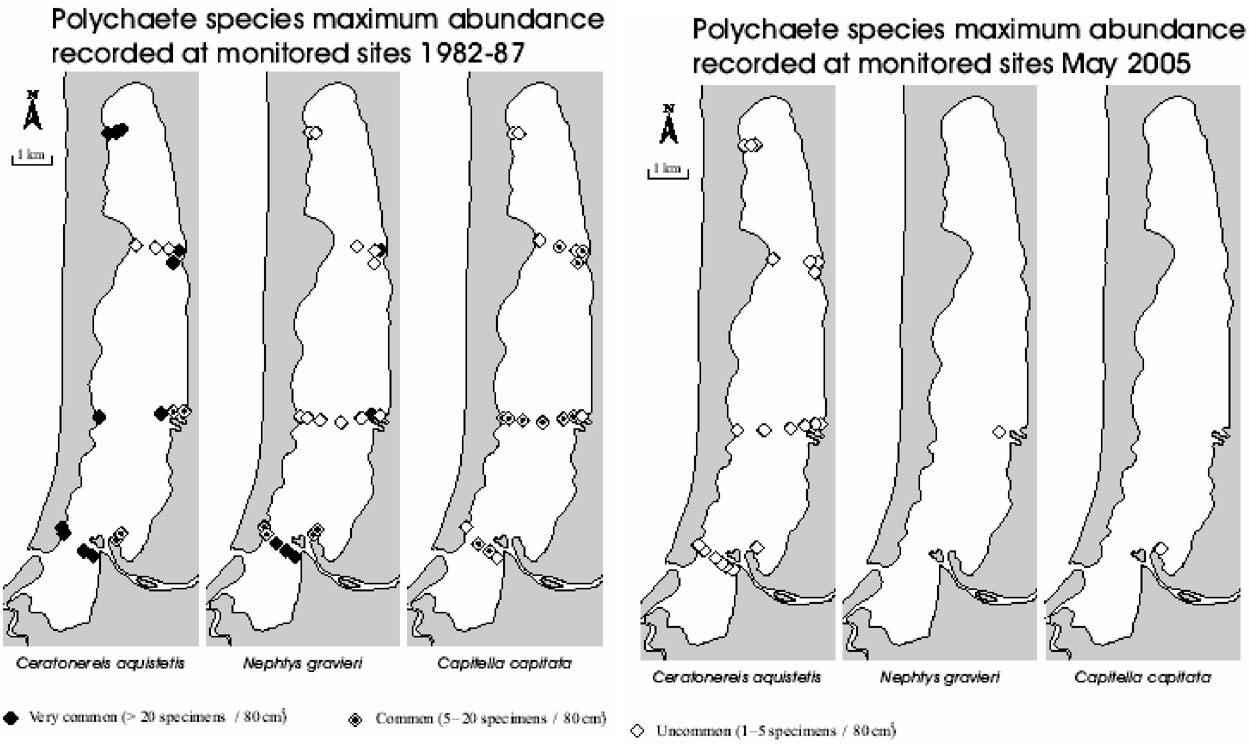


Figure 45. Comparison of key polychaete species abundance in the Leschenault Estuary between studies conducted in 1982-1987 (Durr and Semeniuk, 2000) and 2005 (Semeniuk, 2005).

3.9.4 The brittle star – Amphipholis squamata

The brittle star, *Amphipholis squamata*, is an echidnoderm that resembles a starfish but has long slender arms. Its occurrence within the Leschenault Estuary, as identified by Unno (2000) between 1982 and 1987, is of significance as the Leschenault Estuary is beyond its expected biogeographic range, and as most other records of the species in Western Australia are from oceanic environments.

A. squamata occurs in the Leschenault Estuary as an opportunistic colonising species that inhabits the typically marine-like habitats consisting of shallow muddy water substrates, moderate to warm temperatures and less fluctuating salinities of the northern estuary. Its migration into the Leschenault may be the result of a mechanism termed "rafting dispersal", where the animal attaches to floating weed; or lives or grows attached to jellyfish (Unno, 2000). Generally, the presence of this species in the estuary, while significant, demonstrated low abundance and limited distribution.

The ophiuroid *Amphipholis squamata* presents a special case as an ecosystem indicator in the Leschenault Estuary. For the period 1982 to 1987, it was consistently present in site 9 (see Figure 11), and while there have been population explosions of this species, as described by Unno (2000), that provided extensions of the species to other parts of the estuary, the preferred habitat site of the ophiuroid appears to be site 9. In this context, the abundance of the species in May 2005 at site 9, and its restriction only to site 9, was similar to the prevailing situation in 1982-87.

3.9.5 Changes in invertebrate fauna

A comparison of data on molluscs, small benthic crustaceans and polychaetes in 1982-87 with the 'snapshot' survey undertaken in May 2005 data is described below. In regards to the invertebrate fauna, the sampling in May 2005 showed that there had been fundamental changes in the assemblages of molluscs, polychaetes, and crustaceans in the Leschenault Estuary. The more diverse assemblages of 1982-87 for the three invertebrate groups had been reduced to less numbers, and to more simple assemblages.

The environmental changes and a summary of the invertebrate faunal status and changes, over three periods (1982-87, May 1998, and May 2005) are summarised in Table 14. These results indicate that the estuary in 2005, similar to the results of 1998, was biologically depauperate in relation to 1982-87.

During the 1982-87 study period Semeniuk (2000) and Semeniuk and Wurm (2000) identified a long-term decline in abundance of small benthic crustaceans and some mollusc species respectively, which was consistent with the decreasing trend in abundance of polychaetes.

The decline in both diversity and abundance of molluscs, polychaetes and invertebrate crustaceans can be reflective of macrophyte availability. An increase in macrophyte biomass, driven by nutrients in freshwater flows from the catchment, promotes favourable conditions for the growth of benthic invertebrate fauna through development of grazing, detrital and habitat values. In periods of low rainfall, the lack of nutrient inputs from the catchment is reflected by poor seagrass and macrophyte representation and hence faunal abundance and diversity.

The simplistic assemblages identified in the May 2005 survey are considered to be the result of sustained periods of unfavourable macrophyte growth. These assemblages also reflect changes in the estuarine food cycle; some species are predators and are reliant upon primary consumers (ie herbivores and detritivors) and their numbers decrease as those of the primary producers decrease. Other species are plankton feeders, and a reduction in nutrient inputs in the water column results in a decrease in intra-estuarine plankton productivity (V. Semeniuk, pers. comm.).

The macroalgal blooms of *Cladophora, Ulva* and *Rhizoclonium* (green algae) identified along the eastern platform of the Leschenault Estuary in October 2005, in response to nutrient loading associated with high rainfall and catchment runoff, demonstrated conditions suitable for an increase in macrophytic abundance. While no measurements of invertebrate abundance and diversity was undertaken at this time, the prevalence of macrophytes could reasonably be expected to result in a similar increase in benthic invertebrates as food resources became available.

Amphipholis squamata is identified consistently at site 9 (Figure 11), even under changing conditions of variable macrophyte growth and fauna associations, and as an ecosystem indicator. While the species persistence indicates its robust nature to change, any significant change in the species abundance at this location will reflect a significant change in the conditions and habitat in which it lives, and hence a significant change in the Leschenault estuary environment.

3.9.6 Recommendations for further investigation

A minimum of 10 permanent aquatic sites should be established and monitored in May at five-year intervals for benthic invertebrate fauna and seagrass using replicate box cores or short cores. These sites should be placed on the west platform, east platform and central basin in the deltaic field, lower estuarine field, middle estuarine field, and upper estuarine field, viz sites CD2, CD3, CD4, 2, 4, 5, 8B, 9, 10, and DR1 (as per Figure 11). This would provide a measure of the long-term status of the estuary, and the results could be interpreted against the backdrop of faunal temporal variability provided by previous studies.

3.10 Environmental conditions of concern

The Leschenault Estuary has been subject to a number of significant anthropogenic changes that has influenced environmental attributes of the system. Changes such as the infilling of the original Preston River delta to accommodate the Bunbury Port, the excision of the ‘Cut’ through the Leschenault peninsula, and the damming of the Collie River have all realised environmental conditions of concern. Similarly, land use continued to intensify within the surrounding catchment and increased recreational pressures were imposed upon the inlet as a consequence of a rapidly increasing population. Some of these conditions, such as changes to water quality, have occurred quite rapidly whereas others such as sedimentation have taken years to manifest into problematic concerns.

A summary of the present environmental conditions of concern in the Leschenault Estuary is summarised in Table 15.

3.11 Interim report card

The ‘report card’ provides a broad assessment of the Leschenault Estuary, indicates the overall management response currently undertaken and identifies areas that may require further investigation or research.

3.12 Summary

A summary of hydrological and biological activity in the Leschenault Estuary is described in Figures 46-48.

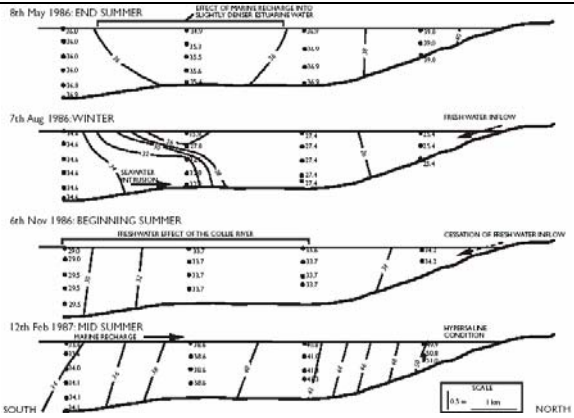
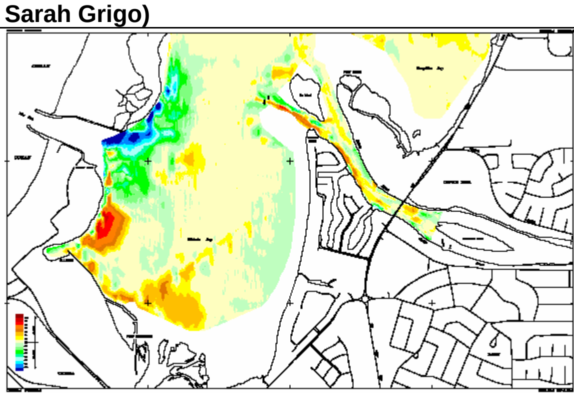
The creation of the Bunbury Inner Port and the ‘Cut’ at Turkey Point transformed the Leschenault Estuary from a tidally influenced estuary to that dominated by wave influences as the impact of direct oceanic inputs were no longer diffused through lateral movement from the original ocean exchange. This change has resulted in increased salinities and sedimentation in the estuary that has imparted changes on fringing and aquatic vegetation that in turn impacts upon faunal abundance. These changes were precursored by extensive changes in land use in the catchment as land was cleared and subsequently developed for agriculture and more recently for expanding urbanisation.

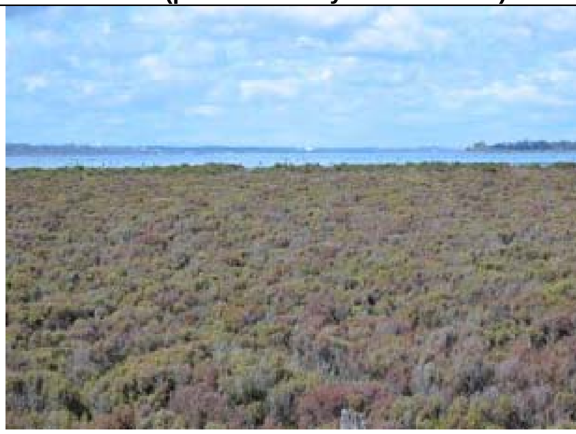
South-western Australian estuaries have been found to be biologically depauperate in their natural condition because of low levels of nutrients and a general absence of seagrass (Hosja and Deeley, 2000; Semeniuk, 2005). Subsequently, in these systems there exists a low diversity and abundance of invertebrate fauna. The Leschenault Estuary reflects a system receiving catchment nutrient inputs which has led to seagrass development and invertebrate faunal associations. The abundance and diversity of macrophytes and benthic fauna appears to have a proportional relationship with the nutrient loading of the estuary from catchment runoff and hence is reflective of rainfall and climatic patterns. However, water quality in the estuary is relatively consistent and below accepted standards for nutrients as a consequence of the location and flushing capacity of the ‘Cut’. Changes in salinity stratification, invertebrate diversity and abundance, and sedimentation all reflect a system that is continuing to evolve from the changes associated with the incision of the ‘Cut’ and the on-going development of the catchment. However, it is clear that the diversity and abundance of biota within and associated with the estuary are strongly influenced by catchment inputs and cyclic climatic factors.

Table 14. Comparisons between 1982-1987, May 1998 and May 2005 in environmental conditions and biota for selected sites (refer Figure 11) in the Leschenault Estuary.

Site	Description 1982-1987	Description May 1998	Description May 2005	Habitat changes 1998-2005
CD5	shallow water platform: dense seagrass cover, moderate to abundant invertebrate fauna	no seagrass, molluscs and benthic small crustacea absent, low abundance of polychaetes	no seagrass, molluscs absent; benthic small crustacea *Corophium*) in low numbers; generally, low abundance and low diversity of polychaetes, with *Ceratonereis aequisetis* in moderate numbers	muddy sand habitat remained similar
1	shallow water platform: dense seagrass cover, moderate to abundant invertebrate fauna	no seagrass, molluscs and benthic small crustacea absent, low abundance of polychaetes	low density of seagrass; low abundances and low diversity, or absence of molluscs, benthic small crustacea and polychaetes; *Corophium* and *Ceratonereis* locally moderately abundant	muddy sand habitat remained similar
3	deep water basin: low to no seagrass cover, generally moderate to low abundance of invertebrate fauna, except for the Spisula invasion	no seagrass cover, absence of invertebrate fauna	low density of seagrass, low abundances and low diversity of molluscs, benthic small crustacea and polychaetes	mud habitat remained similar
5	shallow water platform: dense seagrass cover, generally moderate to abundant invertebrate fauna	no seagrass, molluscs and benthic small crustacea absent, low abundance of polychaetes	low density of seagrass, low abundances and low diversity of molluscs, benthic small crustacea and moderate abundances and low diversity polychaetes; *Diapatra* locally abundant	muddy sand habitat remained similar
8A	shallow water platform: dense seagrass cover, moderate to abundant invertebrate fauna	no seagrass, molluscs and benthic small crustacea absent, low abundance of polychaetes	low density of seagrass, low abundances and low diversity of molluscs, benthic small crustacea and moderate abundances and low diversity polychaetes; *Ceratonereis* locally abundant	muddy sand habitat remained similar
9	deep water basin: low to no seagrass cover, generally moderate abundance of invertebrate fauna	no seagrass cover, absence of invertebrate fauna	moderate density of seagrass, general absence of molluscs, benthic small crustacea and polychaetes; *Caprella* locally abundant	mud habitat remained similar
10	shallow water platform: dense seagrass cover, generally moderate to low abundance of invertebrate fauna	no seagrass, molluscs and benthic small crustacea absent, low abundance of polychaetes	absence of seagrass, general absence of molluscs, benthic small crustacea and polychaetes; low diversity of invertebrate fauna; *Ceratonereis* and *Corophium* locally moderately abundant	in May 2005, the 2-3 cm of mud in 1998 that covered the sandy mud habitat of 1982-1987 has since been removed by wave action

Table 15. Environmental conditions of concern in the Leschenault Estuary as at June 2006.

Region	Condition	Example
Leschenault Estuary	Strong seasonal **salinity stratification** and variability over a north-south gradient. Increasing trend of salinity particularly evident in the northern estuary.	 **North to south seasonal salinity profiles for the Leschenault Estuary (Semeniuk *et al*, 2000)**
	Decreasing **fringing vegetation** and **erosion** as a consequence of urbanisation and unregulated public access.	 **Damage to fringing estuarine vegetation due to unregulated vehicle access (photo taken by Mike McKenna)**
	Macroalgal blooms observed along the eastern shoreline of the estuary (September 2005) *Chladophora/ Ulva/ Ruppia and Rhizoclonium*	 ***Chladophora* (left) and *Rhizoclonium* bloom in the northern estuary September 2005 (photo taken by Sarah Grigo)**
	Sediment deposition from catchment discharges and natural processes, potentially smothering benthic habitats and restricting boating access. The re-diversion of the lower Preston River is also likely to exacerbate this process.	 **Colour differential plot showing sediment accretion in the lower Leschenault Estuary between 1978 and 2005 (refer Figure 8)**

	Abstraction and regulation of freshwater inflows from catchment rivers.	 **Wellington Dam on the Collie River overflowing in October 2005 (photo taken by Judith Carter)**
	Nutrient inputs from **Parkfield Drain** into poorly-flushed northern estuary.	 **The Parkfield Drain passes through the samphire flats into the open waters of the northern estuary (photo taken by Mike McKenna)**

Interim Report Card 2006

Subject : Ecosystem Health in Leschenault Estuary

Environmental Quality Indicators		Management Response*	Comments
Physical and Chemical Measures	Turbidity/Light Attenuation Dissolved Oxygen pH Salinity Temperature		1996-1999: Monthly sampling of 4 sites 2000-2006: Fortnightly sampling of 2 sites between November and May Salinity stratification pronounced during summer in the absence of catchment freshwater inputs.
Indirect Biological Measures	Algal Growth Potential Total Nitrogen (TN) Total Phosphorous (TP) Nitrate Nitrite Ammonium Filtered Reactive Phos.		Sampling regime as above. Mean Total Nitrogen – 0.19 mg/L Mean Total Phosphorous – 0.02 mg/L (based on 2004-2006 moving median) Nutrients considered to be 'Low' in concentration.
Direct Biological Measures	Phytoplankton Blooms Identify Phytoplankton Chlorophyll a, b and c Seagrass		Fortnightly sampling of 4 sites within estuary between November and April. Last bloom was a non-toxic bloom of the diatom *Cyclotella* in December 2000. See Recommendation for further investigation # 4 (Section 3.6.1) for research requirements.
Fish Kills	Response and Investigation		No fish kills recorded to date. Management response as required.
Toxicants in Water	Metals and Metalloids Organics Pesticides Herbicides and Fungicides Hydrocarbons		Absence of previous studies. See Recommendation for further investigation # 5 (Section 3.6.1) for research requirements.
Toxicants in Sediment	Metals and Metalloids Organics Pesticides Herbicides and Fungicides Hydrocarbons Algal Spores		Absence of previous studies. See Recommendation for further investigation # 5 (Section 3.6.1) for research requirements.

LEGEND
* Management Response (Note: All management responses are subject to funding)

Monitor – Below guideline; continue monitoring
Investigate – Investigate and where necessary, take precautionary action
Action Required – above standard; initiate response
Research – Additional information required to establish environmental state and/or criteria

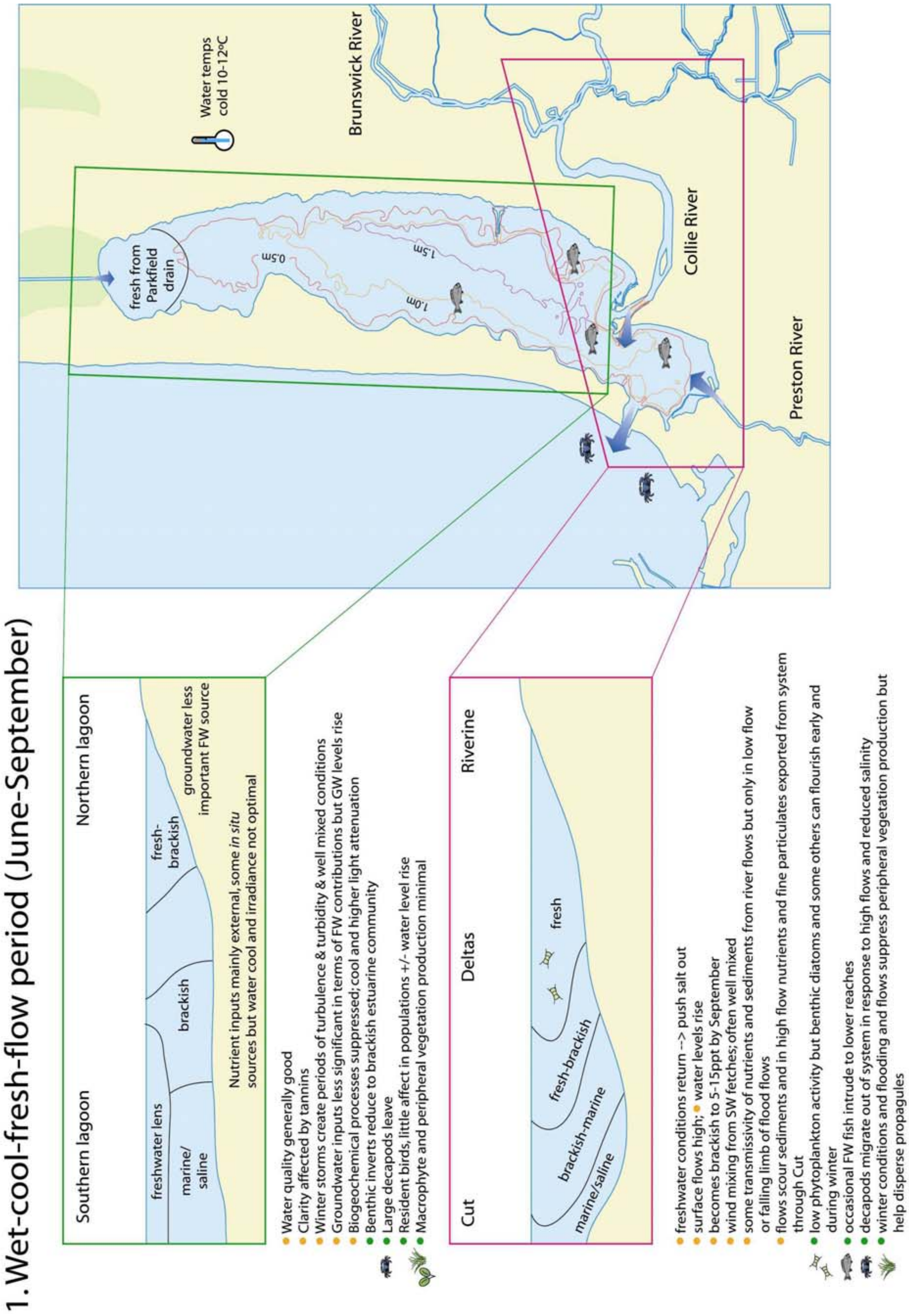


Figure 46. Summary of hydrological and biological activity in the Leschenault Estuary and associated lower estuarine-influenced river systems for June to September (Rose, 2004).

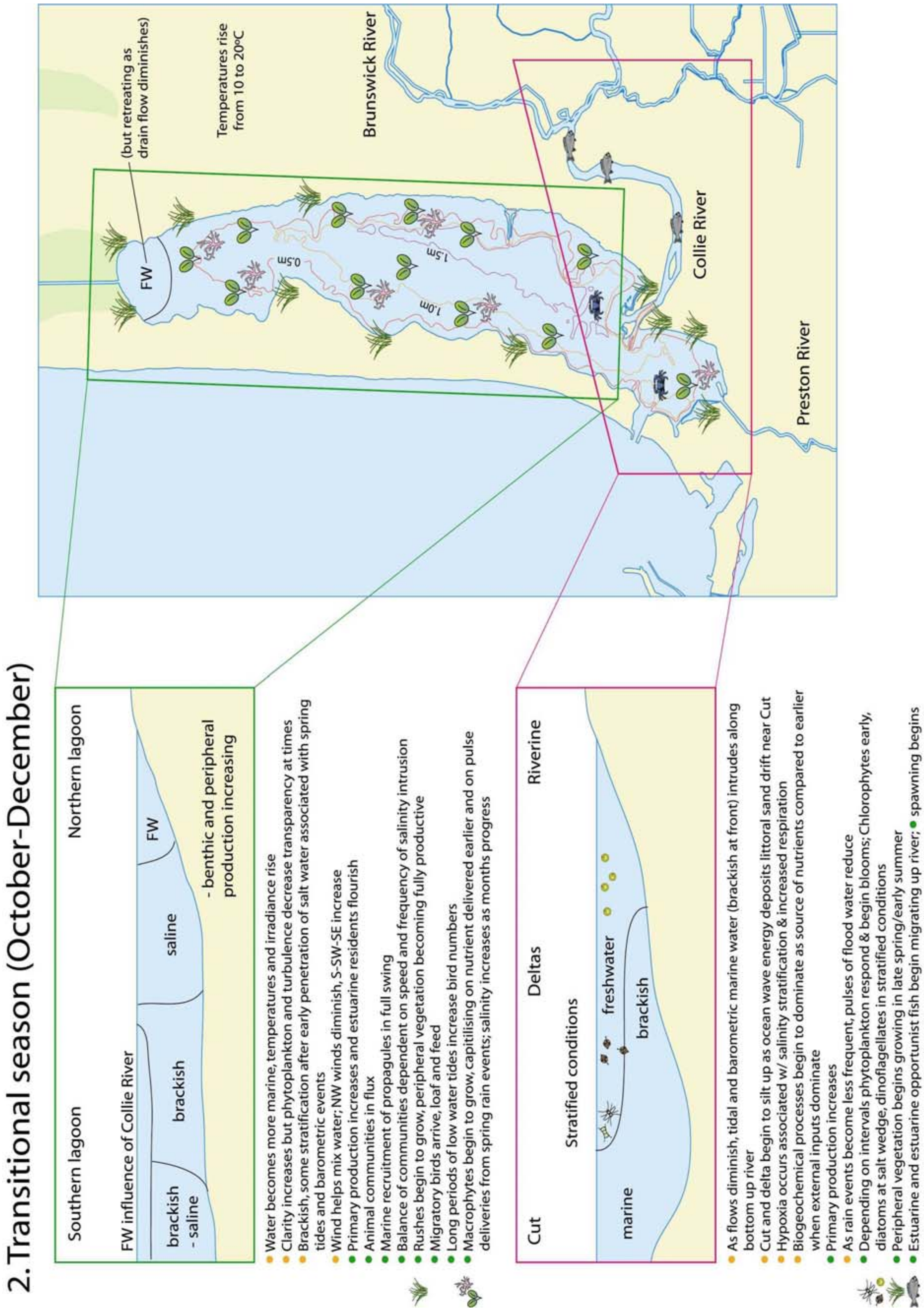


Figure 47. Summary of hydrological and biological activity in the Leschenault Estuary and associated lower estuarine-influenced river systems for October to December (Rose, 2004).

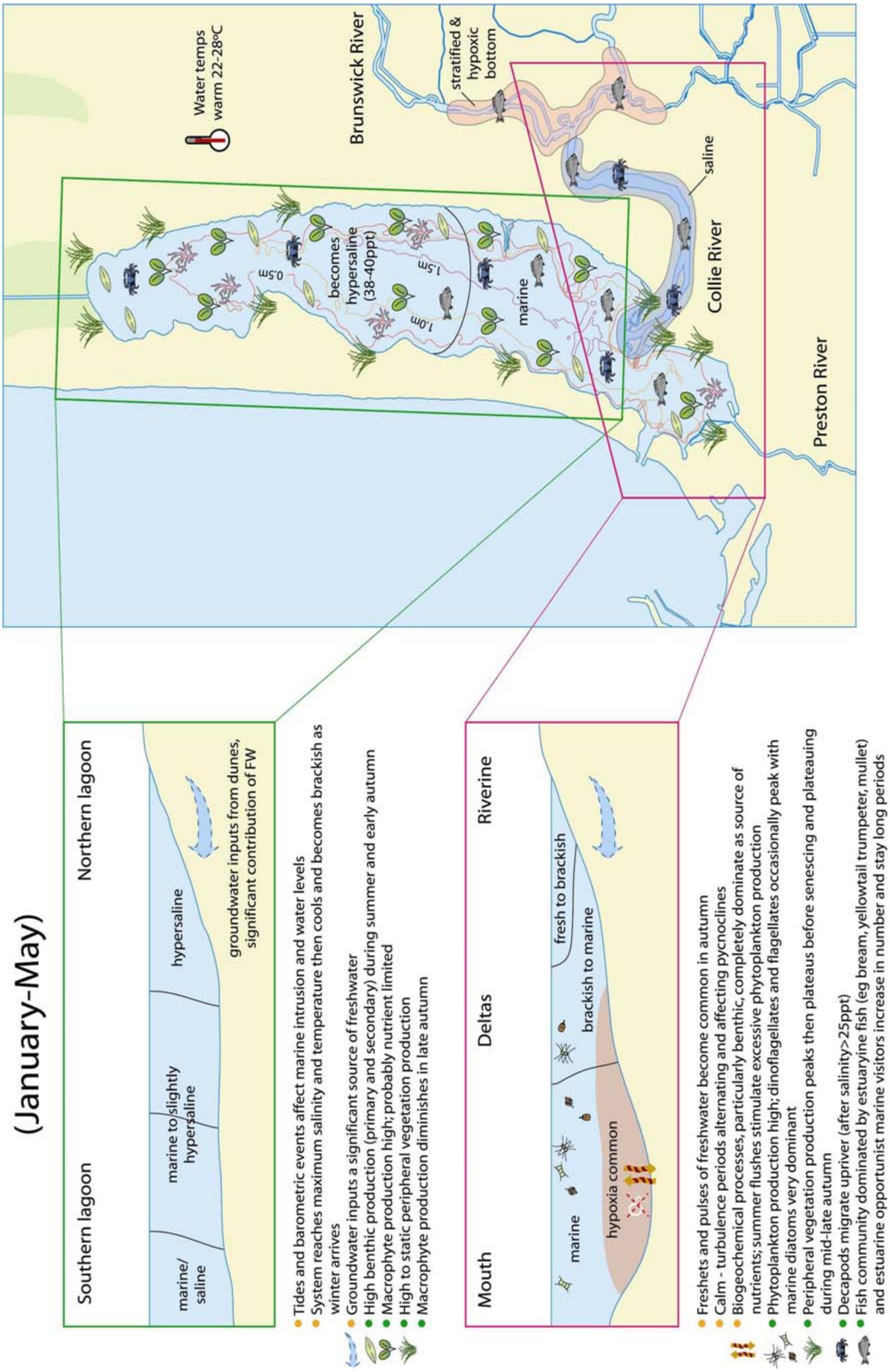


Figure 48. Summary of hydrological and biological activity in the Leschenault Estuary and associated lower estuarine-influenced river systems for January to May (Rose, 2004).

4 Environmental condition of the lower Collie, Brunswick and Preston rivers

4.1 Background

The water catchment which drains into the Leschenault Estuary has an area of 1,981 square kilometres and includes the drainage catchments of the Collie River, incorporating the Brunswick and Wellesley rivers; and the Preston River, including the Ferguson River (Figure 4).

This water catchment, for the purposes of this document, considers only that portion of the Collie River downstream of the Wellington Dam. The construction of the dam in 1933 and the subsequent raising completed in 1960 for water storage provision, substantially decreased the contribution of the upper Collie River catchment to the total river flow observed discharging into the Leschenault Estuary. Contribution from the upper catchment is now restricted to overflow events and scour releases, in accordance with Water Corporation operating strategy to address salinity concentrations in the dam. Irrigation overflow events from water drawn from the Wellington Dam for the Harvey Water irrigation scheme also contribute to summer flows in the Wellesley, Brunswick, Collie and Ferguson rivers.

The lower reaches of the Collie, Brunswick and Preston River systems is considered to be bounded by the intersection with the Bunbury Bypass Road which delineates the existing urban areas associated with the Collie and Brunswick rivers, and the Bunbury Port Authority boundary for the Preston River.

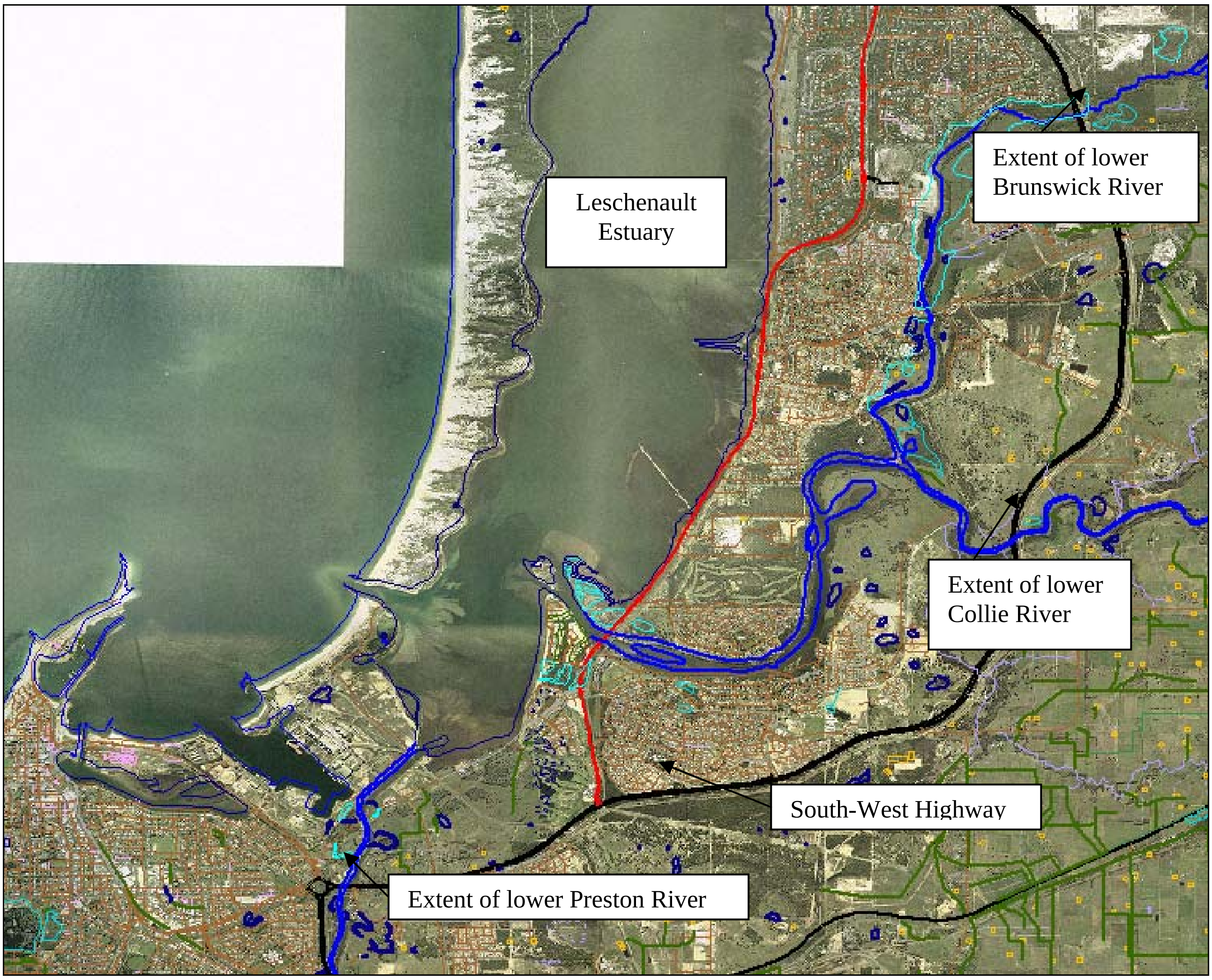


Figure 49. Aerial photograph of the lower Preston, Collie and Brunswick rivers as delineated by the South West Highway.

Very few studies have been undertaken to identify the physical and biological attributes of these areas. Most of the captured data reflects surface water quality monitoring undertaken in these areas as part of the Department of Water's catchment monitoring program. No studies have been undertaken to identify groundwater contribution to water quality in the lower river reaches of the Leschenault system.

The hydrodynamics of the lower river systems is governed by tidal influences from the estuary but more strongly from climatic patterns of rainfall and catchment runoff. Salinity stratification occurs in each of the lower river systems as buoyant low salinity fresh water 'floats' above the intruding, denser marine water. The seawater/freshwater interface is generally regarded to extend upstream to approximately the interception with the Bunbury Bypass Road in summer (some four km up the Collie River), with a variable downstream movement in winter to reflect increased freshwater flows over these months. The lower river reaches experience fresh flushing flows off the catchment during the winter months but as summer progresses salinity stratification begins to develop. The dense saline marine water moves along the bottom of the river channels with the tide, overlayed by the freshwater inflows. Salinity stratification diminishes as catchment flow increases.

Sediment distribution in the estuarine reaches of the Collie, Brunswick and Preston rivers would be difficult to determine accurately, as these watercourses will display variability in particle size as a consequence of changing velocities of flows around river bends, across banks and in depressions on the river bed. For example, seasonal flood flows of silty water from the Brunswick River are discharged into the Collie River where the merging of the two streams increases scouring of the riverbed downstream. This forms ‘high energy’ sites which preferentially favour sedimentation of larger and coarser sediments, and ‘low energy’ sites which favour sedimentation of finer particles. Differences in flow velocities and ‘energy’ levels across the river, based upon volumes and geomorphology, would identify areas where sediments are well sorted in some areas and poorly in others (McCombe *et al*., 2000). Erosion is problematic along the lower river systems where sediment has filled in pools with sand and fluvial material, exacerbating thermal regimes in the lower reaches as well as making the river shallower than historically recorded. Actively mobile sand slugs are migrating downstream creating constant degradation pressure.

Although no fish and invertebrate studies have been done in the more estuarine and marine portions of the lower river systems, estuarine “visitors” can be found in late spring through to late autumn, until freshwater flows push out the more saline waters. Fish species such as hardyheads, euryhaline gobies, mullet and black bream could be expected. Similarly, the invertebrate community is likely to reflect salinity changes as well as contain temporary opportunistic residents such as more estuarine-marine polychaetes, crustaceans and molluscs. These visitors or temporary residents are also highly seasonal, with seasonality driven more by salinity rather than by flow and presence of water (Rose, 2004).

4.2 Lower Collie River

The lower Collie River acts as a sink for sediment and nutrient discharges from the Brunswick and Wellesley river catchments in addition to inputs from within its own catchment boundaries. The development of the lower reaches to accommodate canal and urban subdivision has imposed additional inputs and associated recreational pressures on the area.

Water quality of the lower Collie River is problematic as a consequence of nutrient enrichment and chronic hypoxia at depth. The problematic nature of lower Collie River water quality is alleviated by freshwater inputs from the catchment over winter and early-spring which provides a flushing action within the lower reaches of the system.

Total Nitrogen (TN) and Total Phosphorous (TP) concentrations are regarded as being generally ‘Moderate’ to ‘High’ over the summer and autumn periods of 2000-06 when higher water temperatures often triggered algal activity to produce blooms of both dinoflagellates and diatoms in most years (Ramsay, 2006). Median TN concentrations demonstrate the variability within the system with 65 per cent of samples recorded exceeding the recommended ANZECC/ARMCANZ (2000) guideline of 0.75 mg/L for south west Australian estuaries. There is a distinct shift in 2005 and 2006 sampling with up to 60 per cent of samples falling below this guideline, potentially as a consequence of reduced rainfall resulting in reduced catchment runoff. A slight decreasing TP trend is evident between 2000 and 2006 with initial median concentrations in 2000 bordering a ‘High’ phosphorous concentration status at nearly 0.1 mg/L to a final concentration in the lower portion of the ‘Moderate’ status at 0.06 mg/L in 2006. Nearly 95 per cent of all samples recorded over the 2000-06 period exceeded the recommended maximum ANZECC/ARMCANZ value of 0.03 mg/L with over 10 per cent of all samples classified as exhibiting a ‘Very High’ TP concentration (Ramsay, 2006).

The concentration of TN and TP often reflects phytoplankton density, so distinguishing between possible reducing nitrogen components or plant activity without the fractional measures (nitrate, nitrite and ammonium and filterable reactive phosphorous as the bioavailable forms of nutrients) is difficult to quantify and generally inconclusive. The phytoplankton blooms may be associated with rapid deoxygenation of waters that trigger fish kills, which have been recorded in June 2002, June 2003 and most recently May 2004.

Saline stratification of the lower riverine reaches prevents exchange of oxygen between the surface and bottom waters, promoting oxygen depletion of bottom waters. Decomposing organic material washed in from episodic storm events utilise the remaining oxygen, depleting concentrations below ANZECC guidelines for healthy estuaries of five mg/L, and in extreme cases below the ANZECC value critical to ecology of two mg/L (Ramsay, 2006). This is a common occurrence in the lower Collie River in the context of the contribution of fish kills.

Organochlorine pesticide residue concentrations were reported for the length of the Collie River between 1974 and 1981 by Atkins (1982) and from 1981 to 1985 by Government Chemical Laboratories (GCL) as described by Klemm (1989). Organochlorine pesticides were used extensively in agricultural practice to control insect pest species, which impacted upon vegetable and fruit crops. They are chemically stable, are not broken down by micro-organisms, enzymes, heat or UV light, and thus often persist in soils, aquatic environments, and plant and animal tissue (Brearley, 2005).

The indicator organochlorine pesticide reported (Dieldrin) exceeded the criteria for maintenance and preservation of aquatic ecosystems (<0.03 ug/L) in 20 per cent and 18 per cent of samples over these periods respectively. Detections of Aldrin and Heptachlor were also identified within the Collie River by GCL above the 0.03 ug/L criteria over the 1977 to 1985 period in 33 per cent and four per cent of samples respectively. However, the location at which these samples were taken was not identified. It could reasonably be expected that those samples exceeding the criteria would be taken in areas in proximity to intensive agricultural practices, which are located beyond the reaches designated in this report as the lower Collie River.

All organochlorine pesticides were de-registered for agricultural use in July 1987 with a transition towards the use of organophosphorous pesticides as a consequence of increased awareness of working practices and reduced soil storage. This transition was likely to produce a reduction in residue levels of all forms and is expected as a consequence (Klemm, 1989).

4.3 Lower Brunswick River

The majority of the lower Brunswick catchment, like that of the Collie, has been developed to accommodate urban expansion.

Water quality in the lower Brunswick River, as with the lower Collie, is problematic with high nutrient levels and chronic hypoxia at depth, a feature common in most seasons except for winter and early spring when well-mixed freshwater flow flushes out remnant tidal estuarine-saline waters and accumulations of organic material (Rose, 2004).

During 2000-06, the Brunswick River was considered the most problematic area within the Leschenault estuarine system in terms of excessive nutrients, algae and bacteria adversely affecting water quality. A ‘Moderate’ to ‘High’ Total Nitrogen (TN) and a ‘High’ Total Phosphorous (TP) status was maintained with over 95 per cent of TN and 98 per cent of TP samples recorded exceeding the recommended maximum ANZECC/ARMCANZ (2000) TN value of 0.75 mg/L and 0.03 mg/L TP indicating increased risk of problems associated with nutrient enrichment. Over 65 per cent of the TN and TP load that passes through the lower Brunswick River comes from the Wellesley catchment, which contains an extensive irrigation and drainage network from mainly dairy farming land use. Nutrient enrichment is a permanent feature of the lower Brunswick River resulting in problematic algal blooms arising most years.

The seasonal freshwater flushing assists in ‘re-setting’ the system and reduces conditions that predispose the lower Collie and Brunswick Rivers from having poor water quality year round, eg organic-matter nutrient rich benthic flocculations in stratified bottom saline waters. Flows within the lower Brunswick River in summer are also maintained by contributions from the Wellesley River, whose flows are supported largely by irrigation runoff over the summer period.

Organochlorine pesticide residue concentrations were reported for the length of the Brunswick River between 1974 and 1981 by Atkins (1982) and 1974 and 1979 by Shewchuk (1981). The organochlorine pesticide (Dieldrin) reported in both studies exceeded the criteria for maintenance and preservation of aquatic ecosystems (<0.03 ug/L) in only five per cent of samples over this period. As with the Collie River, the location at which these samples were taken was not identified. It could reasonably be expected that those samples exceeding the criteria would be taken in areas in proximity to intensive agricultural practices which are beyond the lower Brunswick River areas designated in this report. As noted with regard to the lower Collie River, all organochlorine pesticides were de-registered for agricultural use in July 1987 with a transition towards the use of organophosphorous pesticides as a consequence of increased awareness of working practices and reduced soil storage. This transition was likely to realise a reduction in residue levels of all forms as a consequence (Klemm, 1989).

The Brunswick River has been identified as a potential drinking water resource for inclusion within Water Corporation’s Integrated Water Supply System under the *State Sustainability Strategy 2003*, and is subject to growing demands for water extractions and diversions for private and commercial uses.

4.4 Lower Preston River

Water quality in the lower Preston River is not as problematic as that of the lower Collie and Brunswick Rivers, but as with these rivers, exhibits hypoxia at depth for most of the year. Nutrient concentrations are regarded as being comparatively low, although there are periodic influxes of organic matter from the upper catchment. The Preston River currently exhibits a 'Low' Total Nitrogen (TN) and 'Moderate' Total Phosphorous (TP) status with median concentrations showing no significant trend for TN, with only a few random samples returning a value in excess of the ANZECC/ARMCANZ guideline. While the lower Preston River has a slightly decreasing trend over the last six years in TP median concentrations, approximately 51 per cent of all samples taken between 2000 and 2006 exceeded the ANZECC/ARMCANZ guideline, decreasing to 20 per cent exceedence in the 2006 summer period (Ramsay, 2006). This may also reflect reduced rainfall and runoff volumes during recent years. Although levels of suspended solids are generally low, there have been some very high measurements taken from upstream of the lower reaches (Paice, 2001).

The lower Preston River has changed considerably from that which pre-existed the development of the Bunbury Port Authority Inner Harbour. The reclamation of the channel connecting the Leschenault Estuary and Inlet and the associated development of the harbour commenced in 1967 and continued through to 1976. However, the re-direction of the lower Preston River to discharge directly into the estuary was undertaken between 1969 and 1970 and resulted in the deposition of sediment in the southern end of the estuary, the fan delta of which has become vegetated and provides habitat for waterbirds (Figure 2). This lower area of the Preston is also subject to leveeing along the banks in order to control flooding.

The Bunbury Port Authority is currently undertaking structure planning development to reflect the proposed expansion of port activities. As part of this planning, the lower Preston River has been identified for re-alignment to accommodate the expansion of the inner harbour excavation. A number of options have been identified and will be subject to studies to be undertaken to identify potential impacts of the alignment on the environment.

Irrespective of the option undertaken, during the construction phase, the complex stratigraphy underlying the areas adjacent to the south-east end of the Leschenault Estuary will be disturbed and remobilised. The excavation of the diversion channel will remobilise water saturated sediment and mud which is both estuarine and fluvial in nature. Therein will reside iron sulphides, which upon dredging and remobilisation will be come oxidised, generating 'acid sulphate soils', as well as suspended sediments and associated turbidity (Semeniuk, 2005a).

During the operational phase, the Preston River will continue to deliver sediment to the estuary, as did the river in its present diverted alignment. If the riverine design and rate of accumulation of sediment delivered to the fan delta is equivalent to the present Preston River diversion, over several decades into the future it can be expected that the volume of sediment to be delivered to the southern end of the estuary will amount to at least one million cubic meters. This will have the effect of markedly reducing the water depth in the southern end of the estuary, essentially filling the southern end of the Leschenault Estuary with sediment (Semeniuk, 2005a).

Organochlorine pesticide residue concentrations were measured for the length of the Preston River between 1974 and 1981 by Atkins (1982). The Preston River was identified as being particularly susceptible to organochlorine residue due to the historical application on intensive agricultural pursuits such as orchards, potatoes and other vegetables which predominate in the upper reaches. While all organochlorine pesticide reported exceeded the criteria for maintenance and preservation of aquatic ecosystems (<0.03 ug/L) in 60 per cent of samples over this period, there was no measurable accumulation of pesticide in fish flesh or sediments in Leschenault Estuary as the sink for these residues. As all organochlorine pesticides were de-registered for agricultural use in July 1987 with a transition towards the use of organophosphorous pesticides as a consequence of increased awareness of working practices and reduced soil storage, a reduction in residue levels of all forms is expected as a consequence (Klemm, 1989).

Subsequent comparative sampling between 1985 and 1986 by Klemm (1989) indicated neither a further decrease in organochlorine residues along the length of the Preston River, nor bioaccumulation or concentration above available health criteria in the freshwater mussel Hyridella carteri. No pesticide residue levels exceeded limits for human consumption and, therefore, were not considered as cause for concern.

While the vast majority of agricultural practice occurs in the upper Preston River catchment, the cumulative impacts of residue accumulation could potentially be exhibited in the lower river system.

4.5 Recommendations for further investigation

Many of the environmental management issues exhibited within the lower Collie, Brunswick and Preston rivers are often an accumulation of contributions from the whole of the river catchment area. As such, the recommendations for further investigation should reflect a more holistic, catchment-based approach, where the benefits of proactive management will be most dramatically realised in the lower reaches.

The re-diversion of the predominant area of the lower Preston River will preclude this area from some recommendations for further investigation as these will be addressed through the planning and management requirements associated with that development and associated structure planning.

Undertake sediment modelling to define sediment sources movement, longevity of slugs and impacts upon the lower Collie and Brunswick river systems to provide management direction and focus of activities.

Undertake a mass balance water study (groundwater vs surface water) to better define the importance of groundwater to base-flow particularly on the coastal plain. Groundwater extraction may be determined as the appropriate and preferred water use in summer if this study identifies a link between groundwater contribution to poor water quality in the lower Collie and Brunswick river systems.

Determine Ecological Water Requirements (EWRs) for the Brunswick and Collie rivers as unregulated river systems, and review the sustainable draw limits for the Preston River to reflect EWR determinations. These studies should include the conduct of river morphology surveys to identify river form and areas of erosion and critical habitat areas. Flow regimes to maintain river form and habitats can be established as well as extraction volumes and regimes.

Undertake snapshot sediment and water sampling for organochlorine and organophosphorous pesticide residue in the Preston River to determine existing levels compared with current ANZECC guidelines. This work will assess the success of the deregistration of organochlorine pesticides in 1987, their persistency in the environment, and any accumulation of organophosphorous residue. Fish and crab flesh sampling should be undertaken to identify bioaccumulation and potential risk to humans.

Determine priority areas for river restoration and water quality recovery activities in the lower reaches such as replanting the riparian zone, stabilising exposed banks, weed control and retrofitting stormwater outlets to meet Water Sensitive Design guidelines (Water and Rivers Commission, 2002; Department of Environment, 2004).

4.6 Environmental conditions of concern

The lower river systems represent and reflect the accumulated impacts imparted by the catchment they support. Contributions of sediment and nutrient inputs from the catchment may not be readily identified locally as conditions of concern in the upper catchment but may impact on the lower river systems as a cumulative impact – the lower river systems display the symptoms that often reflect a catchment or sub-catchment problem. Locally, the lower Brunswick and Collie rivers have come under increasing pressure from urbanisation and associated recreation pressure as the localities of Eaton, Clifton Park and Australind have expanded to meet population growth. The lower Preston River is proposed to be affected by a re-diversion associated with the structure planning of the Bunbury Port Authority as it expands operations.

Table 16. Environmental conditions of concern for the lower Collie, Brunswick and Preston rivers as of June 2006.

Region	Condition	Example
Lower Collie River	**Phytoplankton** blooms in summer and autumn, presenting typically as variations in water colouration and appearance of surface scum. In addition, the potentially fish-killing species *Karlodinium micrum* has been detected in high densities (>20,000 cells/mL) and *Heterosigma* has been detected in medium densities (2,000-20,000 cells/mL).	 ***Karlodinium micrum* algal bloom (photo taken by Christine Webb, May 2004)**
	Fish Kills have been reported in: June 2002 – approx 10 fish dead; deaths likely due to minor sewerage spill and substantial rain event flushing the system. 30-40 fish seen gasping at surface. High organic material, low salinity, low oxygen, increased bacteria numbers. June 2003 – approx 50 fish dead; deaths likely due to *Karlodinium micrum* bloom in response to organic loading after storm event. May 2004 – approx 450-500 fish dead in lower Collie and Brunswick Rivers; deaths likely to be due to a combination of *Listonella anguillarium* bacterial infections, *Karlodinium micrum* bloom, potential acid sulphate pulse and organic inputs in response to storm event.	 **Deceased mulloway and black bream collected as part of two tonnes of dead fish found in the lower Collie River, May 2004 (photo by Christine Webb)**
	Ongoing reduced flows from the catchment as a consequence of damming, and licensed and unregulated surface and groundwater abstraction reduces the systems capacity to dilute and flush nutrient and sediment accumulations in the lower river reaches.	 **Scour releases from Wellington Dam continued as the dam overflowed in October 2005 (photo by Judith Carter)**
Lower Brunswick River	**Phytoplankton** blooms in summer and autumn, presenting typically as variations in water colouration and appearance of surface scum. In addition, the potentially fish-killing species *Karlodinium micrum* has been detected in high densities (>20,000 cells/mL).	 ***Carlodinium micrum* algal bloom (photo taken by Christine Webb, May 2004)**

	Fish Kills have been reported in: May 2002 – approx 90 fish dead; deaths likely due to first flush causing high organic matter, sediment loads and low oxygen after storm event. May 2004 - approx 2 tonne fish dead in lower Collie and Brunswick Rivers; deaths likely to be due to a combination of *Listonella anguillarium* bacterial infections, *Karlodinium micrum* bloom, potential acid sulphate pulse and organic inputs in response to storm event.	 **Dead black bream collected from the lower Brunswick River (photo taken by Christine Webb, May 2004)**
	Sedimentation as a consequence of catchment erosion has resulted in the in-filling of river pools which provide summer refuges and habitats for aquatic fauna. Historical maps indicate that the Brunswick had river pools of 2-5 m deep with interconnecting shallows. The shallowing of these pools increases water temperature, turbidity and reduces depth and biodiversity.	 **Sediment bars identified downstream of Paris Road (photo taken by Department of Environment, January 2005)**
Lower Preston River	**Phytoplankton** blooms in summer and autumn, presenting typically as variations in water colouration from common blooms of *Chryophyta* species. In addition, the potentially fish-killing species *Karlodinium micrum* has been detected in high densities (>20,000 cells/mL) and *Heterosigma* has been detected in medium densities (2,000-20,000 cells/mL). However, no fish kills have yet to be recorded.	
	The proposed **re-diversion** associated with the Bunbury Port Authority expansion has potential impacts with regard to sedimentation, acid sulphate soils, turbidity and water quality within the new channel and the deltaic habitat as the receiving environment.	 **Existing option for re-diversion of the lower Preston River and expansion of the Bunbury Port Inner Harbour.**

4.7 Interim Report Cards

The ‘report cards’ (pp 84-86) provide a broad assessment of the lower Leschenault river waterways and indicates the overall management response currently undertaken and identify areas which may require further investigation or research.

4.8 Summary

A summary of the biological and hydrological influences relating to the lower Collie, Brunswick and Preston rivers is described in Figures 46-48.

The state of the lower reaches of the Collie, Brunswick and Preston Rivers are influenced by a number of factors. Tidal movements and saltwater intrusion in summer are replaced by freshwater surface flows in winter. Therefore, the hydrology of these areas is strongly linked to climatic and seasonal patterns. High rainfall does not necessarily mean a healthier environment as the lower reaches act as the ‘sinks’ for sediment and nutrients transported off the surface and soil profiles of the catchment. How much of these nutrients and sediments are retained in the river systems, in conjunction with seasonal patterns will determine their susceptibility to algal blooms and fish kill events.

The catchments which source these areas are subject to increasing pressure; urban and industry expansion in the immediate adjacent areas, increasing water requirements in a drying climate, and intensification and changes in land use all impose pressure on the lower riverine reaches. Sufficient flows need to be maintained in these reaches to keep these areas sustainable, and are therefore subject to water storage and extraction decisions in the upstream catchment areas.

These riverine areas exhibit symptoms which reflect the state of the catchment environment. Therefore, the health of the lower river reaches requires management which not only needs to reflect the immediate environment, but have outcomes that are catchment-based.

Interim Report Card 2006

Subject : Ecosystem Health in lower Collie River

Environmental Quality Indicators		Management Response*	Comments
Physical and Chemical Measures	Turbidity/Light Attenuation Dissolved Oxygen pH Salinity Temperature		1996-99: Monthly sampling of 2 sites 2000-06: Fortnightly sampling of 1 site between November and May. Salinity based on freshwater inputs from catchment.
Indirect Biological Measures	Algal Growth Potential Total Nitrogen (TN) Total Phosphorous (TP) Nitrate Nitrite Ammonium Filtered Reactive Phos.		Sampling regime as above. Mean Total Nitrogen – 0.75 mg/L Mean Total Phosphorous – 0.07 mg/L (based on 2004-2006 moving median) Nutrients considered to be 'Moderate' in concentration.
Direct Biological Measures	Phytoplankton Blooms Identify Phytoplankton Chlorophyll a, b and c Seagrass	N/A (Seagrass)	Fortnightly sampling of 2 sites in lower river system between November and April. Frequent summer and autumn blooms including potentially fish-killing species.
Fish Kills	Response and Investigation		Fish kills observed in 2002, 2003 and 2004 associated with algal blooms. Management response as required.
Toxicants in Water	Metals and Metalloids Organics Pesticides Herbicides and Fungicides Hydrocarbons		Absence of previous studies.
Toxicants in Sediment	Metals and Metalloids Organics Pesticides Herbicides and Fungicides Hydrocarbons Algal Spores		Absence of previous studies.

LEGEND
* Management Response (Note: All management responses are subject to funding)

Monitor – Below guideline; continue monitoring
Investigate – Investigate and where necessary, take precautionary action
Action Required – above standard; initiate response
Research – Additional information required to establish environmental state and/or criteria

Interim Report Card 2006

Subject : Ecosystem Health in lower Brunswick River

Environmental Quality Indicators		Management Response*	Comments
Physical and Chemical Measures	Turbidity/Light Attenuation	[green]	1996-99: Monthly sampling of 3 sites 2000-06: Fortnightly sampling of 2 sites between November and May. Salinity based on freshwater inputs from catchment.
	Dissolved Oxygen	[green]	
	pH	[green]	
	Salinity	[green]	
	Temperature	[green]	
Indirect Biological Measures	Algal Growth Potential	[white]	Sampling regime as above. Mean Total Nitrogen – 1.07 mg/L Mean Total Phosphorous – 0.10 mg/L (based on 2004-06 moving median of the 2 sites) Nutrients considered to be 'High' in concentration.
	Total Nitrogen (TN)	[yellow]	
	Total Phosphorous (TP)	[yellow]	
	Nitrate	[green]	
	Nitrite	[green]	
	Ammonium	[green]	
	Filtered Reactive Phos.	[green]	
Direct Biological Measures	Phytoplankton Blooms	[white]	Fortnightly sampling of 2 sites in lower river system between November and April. Frequent summer and autumn blooms including potentially fish-killing species.
	Identify Phytoplankton	[yellow]	
	Chlorophyll a, b and c	[green]	
	Seagrass	N/A	
Fish Kills	Response and Investigation	[green]	Fish kills occurred in 2002 and 2004 associated with algal blooms. Management response as required.
Toxicants in Water	Metals and Metalloids	[grey]	Absence of previous studies.
	Organics	[grey]	
	Pesticides	[grey]	
	Herbicides and Fungicides	[grey]	
	Hydrocarbons	[grey]	
Toxicants in Sediment	Metals and Metalloids	[grey]	Absence of previous studies.
	Organics	[grey]	
	Pesticides	[grey]	
	Herbicides and Fungicides	[grey]	
	Hydrocarbons	[grey]	
	Algal Spores	[grey]	

LEGEND
* Management Response (Note: All management responses are subject to funding)

[green]	Monitor – Below guideline; continue monitoring
[yellow]	Investigate – Investigate and where necessary, take precautionary action
[red]	Action Required – above standard; initiate response
[grey]	Research – Additional information required to establish environmental state and/or criteria

Interim Report Card 2006

Subject : Ecosystem Health in lower Preston River

Environmental Quality Indicators		Management Response*	Comments
Physical and Chemical Measures	Turbidity/Light Attenuation Dissolved Oxygen pH Salinity Temperature		1996-99: Monthly sampling of 1 site 2000-06: Fortnightly sampling of 1 site between November and May. Salinity based on freshwater inputs from catchment.
Indirect Biological Measures	Algal Growth Potential Total Nitrogen (TN) Total Phosphorous (TP) Nitrate Nitrite Ammonium Filtered Reactive Phos.		Sampling regime as above. Mean Total Nitrogen – 0.44 mg/L Mean Total Phosphorous – 0.04 mg/L (based on 2004-06 moving median) Nitrogen considered to be 'Low' and phosphorous 'Moderate' in concentration.
Direct Biological Measures	Phytoplankton Blooms Identify Phytoplankton Chlorophyll a, b and c Seagrass	 N/A	Fortnightly sampling of 1 site in lower river system between November and April. Frequent summer and autumn blooms including potentially fish-killing species.
Fish Kills	Response and Investigation		Management response as required. No fish kills recorded in this region to date.
Toxicants in Water	Metals and Metalloids Organics Pesticides Herbicides and Fungicides Hydrocarbons		Previous studies 1974-81 and 1985-86 for organochlorine indicated that while contamination existed, residue levels for human consumption were not exceeded. No sampling since 1986. (see Recommendation for further investigation # 14 Section 4.5)
Toxicants in Sediment	Metals and Metalloids Organics Pesticides Herbicides and Fungicides Hydrocarbons Algal Spores		Previous studies in 1974-81 and 1985-96 for organochlorine indicated that while contamination existed, residue levels in sediments showed no measured accumulation. No sampling since 1986. (see Recommendation for further investigation # 14 Section 4.5)

LEGEND
* Management Response (Note: All management responses are subject to funding)

Monitor – Below guideline; continue monitoring
Investigate – Investigate and where necessary, take precautionary action
Action Required – above standard; initiate response
Research – Additional information required to establish environmental state and/or criteria

5 Environmental condition of the Leschenault Inlet

5.1 Background

The Leschenault Inlet, about 1,900 m in length and up to 200 m in width, represents a distinctive remnant of the former Leschenault estuarine system that connected the catchment river systems to the narrow, elongated body (now referred to as the Leschenault Estuary) and the ocean at Point MacLeod. With the construction of “the Cut” in 1951 and the subsequent development of the Bunbury Inner Harbour between 1967 and 1976, the Leschenault Inlet became isolated from the balance of the system as the connecting tidal channel was infilled through land reclamation and the Preston River was redirected to discharge into the estuary. These changes are described previously in Figure 2.

With the absence of riverine freshwater inputs, the Leschenault Inlet became a marine embayment. Variations in orientation, configuration and water depth affected the penetration of waves. The constricted entrance to the inlet at ‘the Plug’, uncharacteristic of most embayments, ensures the water body is still protected from ocean wave action and its fetch is such that it limits the ability to generate significant wind waves internally. Friction causes wave and tide influence to reduce with distance from the entrance of the inlet. Strongly indented embayments support more sheltered environments and tidal processes tend to dominate (Roy *et al*., 1980). The tidally orientated shoals are regarded as mainly relict, but tidal currents imparting large exchange of water during the tidal cycle is still the dominant hydrodynamic feature. Hence, the Leschenault Inlet can be classified as a tide-dominated narrow marine embayment.

The inlet has an urban catchment area of approximately 500 hectares consisting of residential, holiday accommodation and the Bunbury central business district; and supports a number of recreational pursuits including motorised boating, rowing, dragon boat racing, sea scouts and recreational fishing.

The Leschenault Inlet supports a significant colony of the white mangrove, Avicennia marina, as the most southern population in Western Australia. The colony is thought to have established approximately 2,500 years ago through the delivery of seeds in the Leeuwin current from the nearest mangrove colonies over 500 km to the north at the Abrolhos Islands.

The Leschenault Inlet has not been subject to any previous specific physical or biological studies. Much of the current information pertains to the regular water quality sampling undertaken by the then Water and Rivers Commission during the summer-autumn period which concluded in 2001. To begin to understand some of the physical and biological attributes of the inlet, ‘snapshot’ studies were undertaken in May 2005 to provide comparative data to the nearby Leschenault Estuary.

5.2 Current conditions

The Leschenault Inlet has not been subject to the same scrutiny and research as that of the neighbouring Leschenault Estuary. This is likely to reflect the fact that since the dramatic anthropogenic changes associated with the construction of the Bunbury Port and the creation of 'the Plug', the inlet has exhibited no discernable dramatic development events to the water body itself or the small catchment which it supports.

5.2.1 Water quality

Routine water quality monitoring and assessment was undertaken by the former Water and Rivers Commission on a bi-weekly basis between October and April from 1995 to 2001, at which time it was determined that on-going monitoring was not required as a consequence of consistency in physical and biological criteria at levels that did not present a significant risk to the Leschenault Inlet environment.

The water quality in the Leschenault Inlet is regarded as being good, with total nitrogen and total phosphorous concentrations being relatively low. These nutrient levels are slightly elevated to those from natural levels but could reasonably be expected as a consequence of the developed nature of the catchment.

5.2.2 Biological aspects

The status of the inlet is described and discussed below in terms of: 1) the presence of seagrass, 2) the invertebrate fauna; and 3) the mangrove Avicennia marina and associated halophytic vegetation, as identified through a 'snapshot' survey undertaken in May 2005.

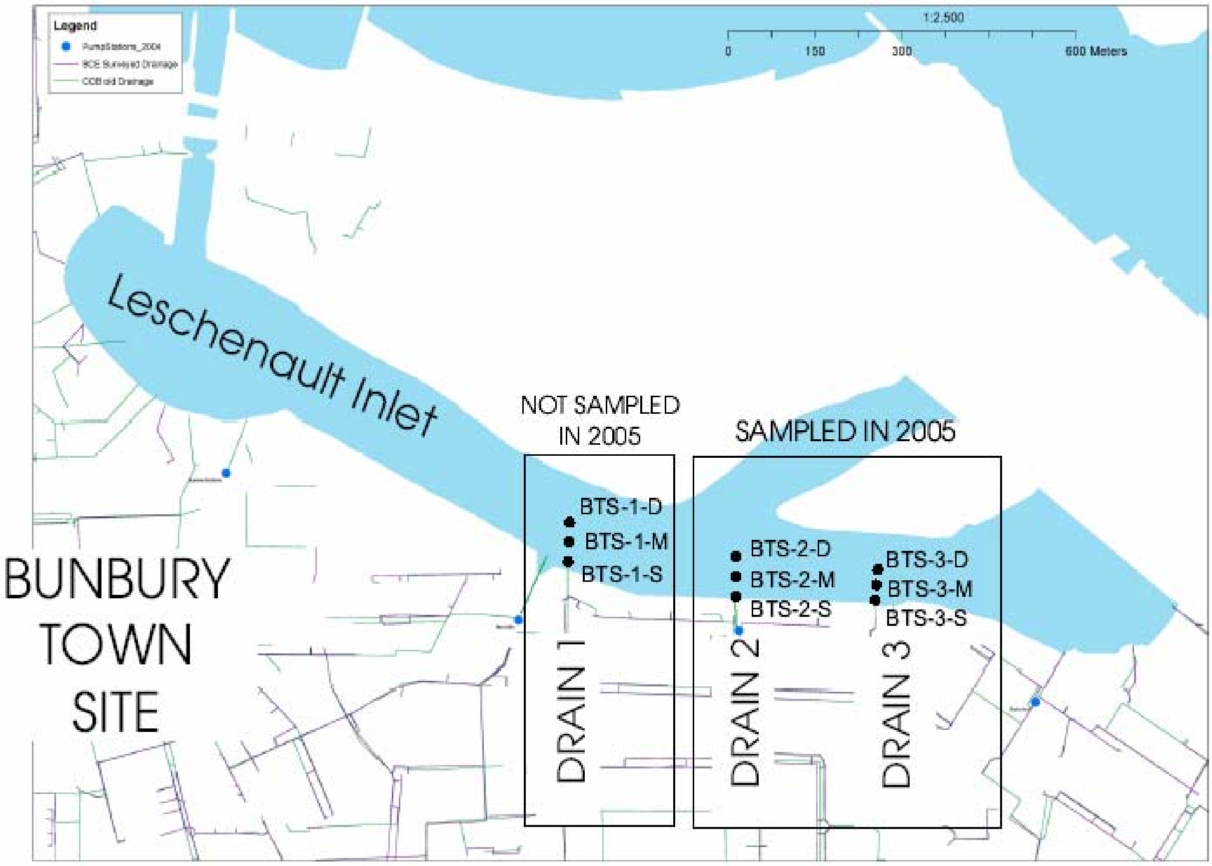


Figure 50. Location of sampling sites for the Leschenault Inlet in May 2005. Sites are located in proximity to stormwater drain outlets. D = Deep, M = Mid-depth, S = Shallow.

There was no seagrass identified in the deep water mud environments at the sample sites in Leschenault Inlet. It is likely that seagrass is absent in this environment as a consequence of low concentrations of soluble nutrients and short residence times due to the high flushing capability of the Leschenault Inlet from high tidal exchange and relatively small catchment. The absence of these nutrients restricts the same proliferation of seagrasses observed in the Leschenault Estuary as a consequence of nutrients borne in freshwater catchment inflows. The high tidal movement in the inlet is also likely to result in high suspended sediment loads and turbidity, which would restrict light penetration required for growth. As discussed in Section 3.5, seagrasses have a high minimum light requirement due to a high respiratory demand and lack of certain pigments which restricts the spectral range which can be utilised for growth (Geosciences Australia, Ozestuaries website).

Overall, faunal diversity and abundance is low within the Leschenault Inlet when compared with the equivalent site (CD3) in the Leschenault Estuary, a deep water mud site with oceanic salinities. During the period 1982 to 1987, the greatest diversity of fauna was encountered at this site in the estuary. During the ‘snapshot’ survey of May 2005 in the Leschenault Estuary (VCSRG 2005), CD3 (Figure 11) showed greater faunal diversity and faunal abundance than the BTS sites of the Leschenault Inlet (Table 17).

Table 17. Comparative abundance of fauna (numbers/m^2): BTS-2, BTS-3, and CD3.

SITE	*Nassarius burchardi*	*Tellina deltoidalis*	*Caprella*	*Ceratonereis aequisetis*	*Diapatra dentata*	*Lumbreineris cf latreilli*
CD3	16.0 ± 16.0	3.2 ± 7.2	25.6 ± 57.2	76.8 ± 171.7	128.0 ± 221.7	128.0 ± 221.7
BTS-2 D	0	6.4 ± 8.8	0	0	0	1177.6 ± 1139.1
BTS-3 D	0	0	0	0	0	998.4 ± 331.3
BTS-3 M	0	0	0	0	0	682.7 ± 195.5

The invertebrate fauna of the deep water mud habitat is regarded as being depauperate. While polychaete numbers are moderately high when compared with the equivalent estuary site, the polychaete assemblage (*Lumbreineris cf latreilli*) is monospecific. The mollusc *Tellina deltoidalis* occurred in low numbers, and the decapod Alpheus occurred in moderate numbers. The depauperate nature of invertebrate fauna observed in the inlet when compared with the equivalent site in the estuary (CD3) is reflective of a number of factors. The main reason why the benthic faunal composition of Leschenault Inlet is so different from the apparently equivalent depth-and-substrate sites in Leschenault Estuary is that the former is now a marine embayment, and the sampling sites are located in relatively deep water marine mud habitat, while the latter are in estuarine environments that receive freshwater annually. In this context, the area of Leschenault Inlet is an artificial environment, ie anthropogenically created by the alteration of the original hydrodynamics and hydrochemical factors. In this system, there is a general absence of freshwater inputs, unlike the estuary where site CD3 is subject to significant freshwater inputs from the catchment. Freshwater inputs to the inlet are only from urban stormwater discharge and some expected limited groundwater seepage. As described for the estuary, nutrients provided through these inputs stimulate macrophyte growth, which subsequently provide for greater invertebrate faunal abundance and diversity through habitat and food web complexes.

The extent of the white mangrove *Avicennia marina* and the halophytic vegetation across the Leschenault Inlet showed little change in the ‘snapshot’ survey of the Leschenault Inlet of May 2005 when compared against an equivalent study conducted in 1997, but it has been recognised that the mangrove population of the inlet has increased in density and distribution over the last 60 years (Semeniuk *et al*, 2000). While it is recognised that a number of anthropological hindrances to mangrove expansion exist within the inlet such as Koombana Drive, retaining walls and urban development – substrate and salinity are regarded to be the major determining factors in mangrove growth. *Avicennia* inhabits the mid- to high-tide substrates which reflect the muddy shoals, and is limited to its upper occurrence by salinity. *Avicennia* will typically not inhabit areas of salinity in excess of 100 ppt. In the Leschenault Inlet, mangroves generally inhabit areas with groundwater salinity of 19-36 ppt and soil water salinity of 31-72 ppt. Other halophytes, such as samphire, inhabit the area above this mid- to high-tide zone with the upper extent limited by circa 120-150 ppt salinity. Therefore, in the Leschenault Inlet, the current extent of *Avicennia* and associated samphire is expected to be delineated by salinity and tidal stratification in which *Avicennia* will generally not expand into samphire areas in areas and samphire will not compete with *Avicennia* towards the mid-tide level.

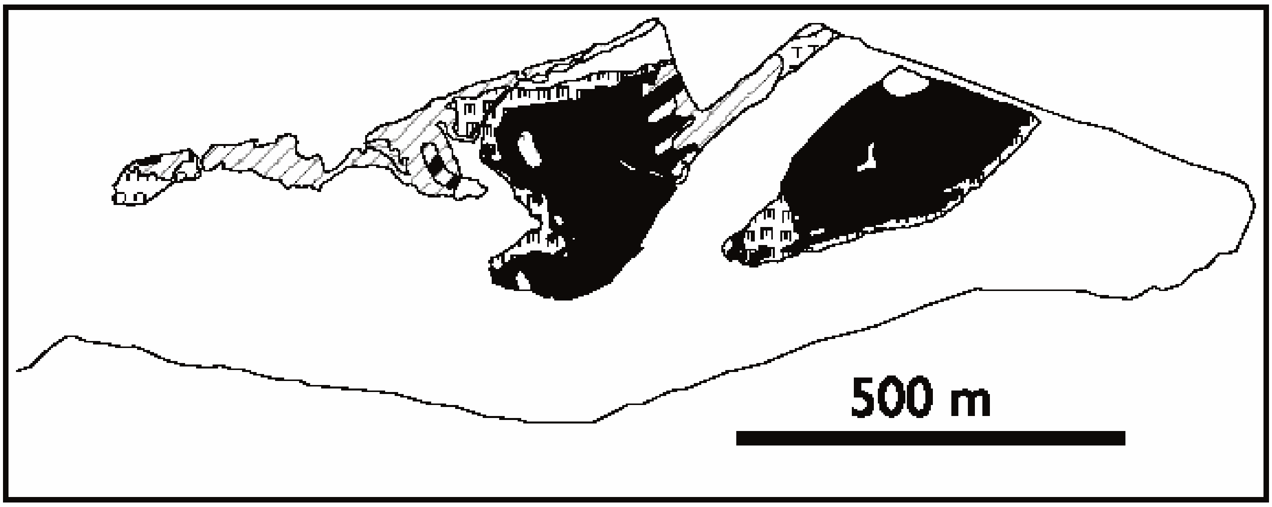


Figure 51. Remnant peripheral vegetation complexes of the Leschenault Inlet, identified in 1989 (Pen *et al*, 2000), and found to be consistent in 2005 (Semeniuk, 2005) Note: This figure is to be read in conjunction with the vegetation complexes described in Figure 15.

5.2.3 Heavy metals

Sediment analysis of the Leschenault Inlet was undertaken as part of the May 2005 ‘snapshot’ survey to identify potential heavy metal and nutrient accumulation from urban drainage within the inlet and whether this would likely impact upon other biological and physical aspects of the environment.

The results of the metal/metalloid and nutrient content of the sediments and vegetation showed several interesting patterns. The results for the sediments, reduced to means and standard deviations for the replicate samples, and related to sediment type, are presented in Tables 18 and 19 in relation to the transects BTS-2 and BTS-3. Comparative information on guidelines/criteria on contamination levels is also provided. While there are numerous guidelines in the literature to assess the level of environmental acceptability of metal and metalloid contamination, only a selection is presented in Tables 18 and 19 to provide comparative measure of different approaches and different systems to assessment. These guidelines are drawn from: ANZEEC/ARMCANZ (2000), ANZEEC/ARMCANZ (2005) in Simpson *et al* (2005), and McCombe *et al* (2000).

The comparative guidelines for metal contamination presented in Tables 18 and 19 identify a range in values. The reasons for the variations are as follows:

1 The ultimate criterion for acceptable levels of metal contamination is toxicity of the metals to humans and benthic fauna, and different regions and sediment types, have varying uptake potential for metals, and conversely, varying ability to release metals back into the environment; site specific criteria thus are developed that relate to the relationship of sediment type, and bio-availability of the metals for the particular sediment types and biota at hand.

2 Guidelines may be based on different underlying assumptions of what it is important to measure, eg some guidelines are based on measured toxicity data, others on bio-accumulation data.

3 Some guidelines are based on suspended sediment while others deal with bottom sediments.

4 Some guidelines highlight the lowest level of concentration wherein toxic effects become apparent, while others emphasise the levels that could effectively eliminate most of the benthic biota, resulting in identification of two levels, viz a low threshold, and a severe threshold.

5 The tolerability of the biota will vary, determined by species, climate setting, and residency time of metals as soluble forms, and hence, threshold levels will vary regionally (Semeniuk, 2005b)

Table 18. Metal and nutrient content of sediments for BTS-2 sites expressed as x + σ.

	As	**Cd**	**Cu**	**Hg**	**N**	**P**	**Pb**
	σ ± x	σ ± x	σ ± x	σ ± x	σ ± x	σ ± x	σ ± x
	ppm	ppm	ppm	ppb	ppm	ppm	ppm
SITE							
BTS2 D mud	28.7 ± 1.2	< 0.5	66.7 ± 2.9	210.0 ± 43.6	3186.7 ± 650.3	900.0 ± 40.0	124.7 ± 3.1
BTS2 M mud	26.3 ± 2.5	< 0.5	64.3 ± 2.5	260.0 ± 26.5	3256.7 ± 107.9	866.7 ± 50.3	114.7 ± 5.1
BTS2 S sand	5.0 ± 1.0	< 0.5	10.7 ± 0.6	26.7 ± 5.8	343.3 ± 123.4	173.3 ± 41.6	32.3 ± 9.5
ANZEEC/ ARMCANZ	20-70	1.5-10	65-270	150-1000			50-220
McComb 2000						330 (389)	

McCombe *et al* (2000) data on total: 330 ppm = average for the estuary; (389) ppm = total P at site 1 of McCombe *et al* (2000) which is sedimentologically and bathymetrically equivalent to Leschenault Inlet (*sensu stricto*).

Table 19. Metal and nutrient content of sediments for BTS-3 sites expressed as x + σ.

	As	**Cd**	**Cu**	**Hg**	**N**	**P**	**Pb**
	σ ± x	σ ± x	σ ± x	σ ± x	σ ± x	σ ± x	σ ± x
	ppm	ppm	ppm	ppb	ppm	ppm	ppm
SITE							
BTS3 M mud and muddy sand	8.0 ± 1.0	< 0.5	11.3 ± 2.5	20.0 ± 0.0	433.3 ± 148.4	266.7 ± 23.1	24.3 ± 2.9
BTS3 S sand	8.0 ± 1.0	< 0.5	11.7 ± 3.1	23.3 ± 5.8	496.7 ± 149.8	273.3 ± 46.2	23.7 ± 2.5
BTS-3 M1 -tin: v (leaves)	23.6	< 1.0	16	20	0.740	1120	80
BTS-3 M1 -tin: v (leaves)	8.2	< 1.0	7	30	0.820	4200	9
ANZEEC/ ARMCANZ	20-70	1.5-10	65-270	150-1000			50-220
McComb 2000						330 (389)	

McCombe *et al* (2000) data on total: 330 ppm = average for the estuary; (389) ppm = total P at site 1 of McCombe *et al* (2000) which is sedimentologically and bathymetrically equivalent to Leschenault Inlet (*sensu stricto*).

In the first instance, the information in Tables 18 and 19 shows that substrate plays a large role in the uptake and retention of contaminants and nutrients. For transect BTS-2, the mud sites, even though they are most distal from the drain outfalls, have the highest content of contaminants: the content of Hg and N in the muds is an order of magnitude more than in the sand, and the content of As, Cu, P and Pb are factors more concentrated in the mud than the sand. The same pattern is evident in the BTS-3 transect. Thus, for the two transects sampled, rather than showing a gradient effect of concentration of contaminants away from the drain outfall (the source of the pollutants), the sampling showed that muds were the preferred repository for the pollutants. Thus, sampling for this project did not show a clear gradient of contamination in relation to the assumed source, being the drains. While the drains may in fact be the source of contamination, the sampling to date suggests that sediment type, particularly clay content, is a major factor in determining the uptake, residency and hence distribution of contaminants (Semeniuk, 2005b).

The level of contamination of metals or metalloids within the sediments of the Leschenault Inlet varies from low to high depending on metal species, which guidelines are used, and whether the lower range or upper range in the guidelines are used.

The metal or metalloid content of the rotted leaves showed that terrestrial vegetation, brought down the drains in floods, absorb and retain contaminants. The content of As, Cu, Hg, and Pb was at values between the low and moderate levels of contamination.

For nutrients, using the data presented by McCombe *et al* (2000), for total phosphorous in sediments of the Leschenault Estuary, P in Leschenault Inlet is above average levels. There are no data for nitrogen levels in Leschenault Estuary, but the data from the 2005 'Snapshot' indicate that total N in the sediments of Leschenault Inlet are elevated (Semeniuk, 2005b).

The sediment samples collected were part of a preliminary reconnaissance survey of heavy metals and nutrient contaminants in the Inlet, and therefore the sampling protocol did not involve sampling in detail in relation to depth (eg on a cm basis down the sediment profile). Sampling in this type of detail down depth would determine whether there was a vertically differentiated contamination distribution, and such information would be a key to understanding the chemical dynamics. The results of the present sampling strategy thus provide only bulk results for the upper five cm of sediment. However, while it is intimated that future sampling should test for vertical differentiation by contaminants, bioturbation by infauna is prevalent in this environment, and probably is blurring any such vertical partitioning, and this would imply that the bulk results of the upper five cm of sediment reflect homogenisation of the shallow stratigraphic profile. The potential effects of bioturbation could be subject to further investigation.

At present, the results show that there is contamination of the sediments in Leschenault Inlet by heavy metals and nutrients; though the exact process and pathways by which the metals are delivered and accumulate are largely speculative and require quantification. Management action would be targeted best at the presumed source, being the stormwater drainage from the adjacent catchment, and by management of any hydrocarbon spillage from recreational boats penned or launched from within the inlet.

Table 20. A history of dredging in the Leschenault Inlet (Department for Planning and Infrastructure, 2005).

Date	Location	Volume (m3)	Disposal Area
1975	Rowing course and Anglesea Island	20,000	Land north of the Inlet
1987	Rowing course extension	6,000	Turkey Point

The rate of sedimentation in the Leschenault Inlet is dependent upon the amount of material (organic and mineral) deposited as a consequence of the hydrological influences imparted over the inlet over a given interval of time. As with the Leschenault Estuary, a bathymetric survey was undertaken within the Leschenault Inlet in June 2005 to determine the vertical accumulation of sediment. The survey was conducted to reflect the previous survey completed in 1984 by the then Department of Transport. Vertical accumulation is a determination of changes in the rate at which the water body has been vertically filling up with sediment, and can provide a useful insight into the functionality and health of an inlet. The colour differential plot for the southern portion of the Leschenault Inlet, indicating the relative changes in depth between the two surveys, is presented in Figure 52.

Changes in sediment level in the inlet are generally within +/- 20 cm which is acceptably within the margin of practical and statistical error of the sampling process, reflecting the re-working of sediments internally within the inlet as a consequence of high tidal movements and prevailing wind movements. However, sediment accretion was evident during this period and is most pronounced in areas adjacent to the western, southern and eastern periphery of the inlet. These areas reflect nominated stormwater discharge points from the surrounding catchment and the deposition of sediments in proximity to the outlet where energy lows dissipate as they enter the inlet allowing sediments to settle out of suspension.

One significant area of deepening is identified at the eastern end of the inlet. Given the hydrodynamic nature of the inlet, this deepening is considered to have occurred only as a consequence of dredging or other form of mechanical excavation. This may directly relate to that identified in Table 20 as an extension to the existing rowing course, but given this deep area is not likely to be inclusive of the rowing course (due to inability to contribute to a straight line course), this dredging is considered as being done by an authority other than the Department for Planning and Infrastructure or is an oversight in that department's records.

5.3 Environmental conditions of concern

The isolation of the Leschenault Inlet from freshwater river inputs, as stated, transformed the water body from an estuarine system to that more representative of a tide-dominated marine embayment. As a consequence, the localised environment changed dramatically in terms of water quality as it became more reflective of that of adjacent Koombana Bay. Similarly, land use continued to intensify within the surrounding catchment and increased recreational pressures were imposed upon the inlet as a consequence of a rapidly increasing population.

A summary of the present environmental conditions of concern in the Leschenault Inlet has been summarised in Table 20.

5.4 Interim report card

The ‘report card’ provides a broad assessment of the Leschenault Inlet waterway, indicates the overall management response currently undertaken and identifies areas which may require further investigation or research.

5.5 Summary

The transition of the Leschenault Inlet from an estuarine system to a marine embayment and the associated anthropological changes has altered the biological and physical dynamics considerably. However, historical water quality data from the inlet suggests that while a proportion of nutrients are bound in sediment, those in the water column are readily diluted/ dissipated through high tidal exchange. The absence of macrophytes, and hence depauparate faunal diversity and abundance, does suggest a perception of an ecosystem in decline. However, this should be viewed under consideration of the capacity of the substrate to support seagrasses in the absence of sand and freshwater nutrient inputs. Considering these factors, the Leschenault Inlet can be considered relatively healthy in its current state, but will require careful management of stormwater and recreational pressures, particularly those likely to result in the pollution or accumulation of heavy metals.

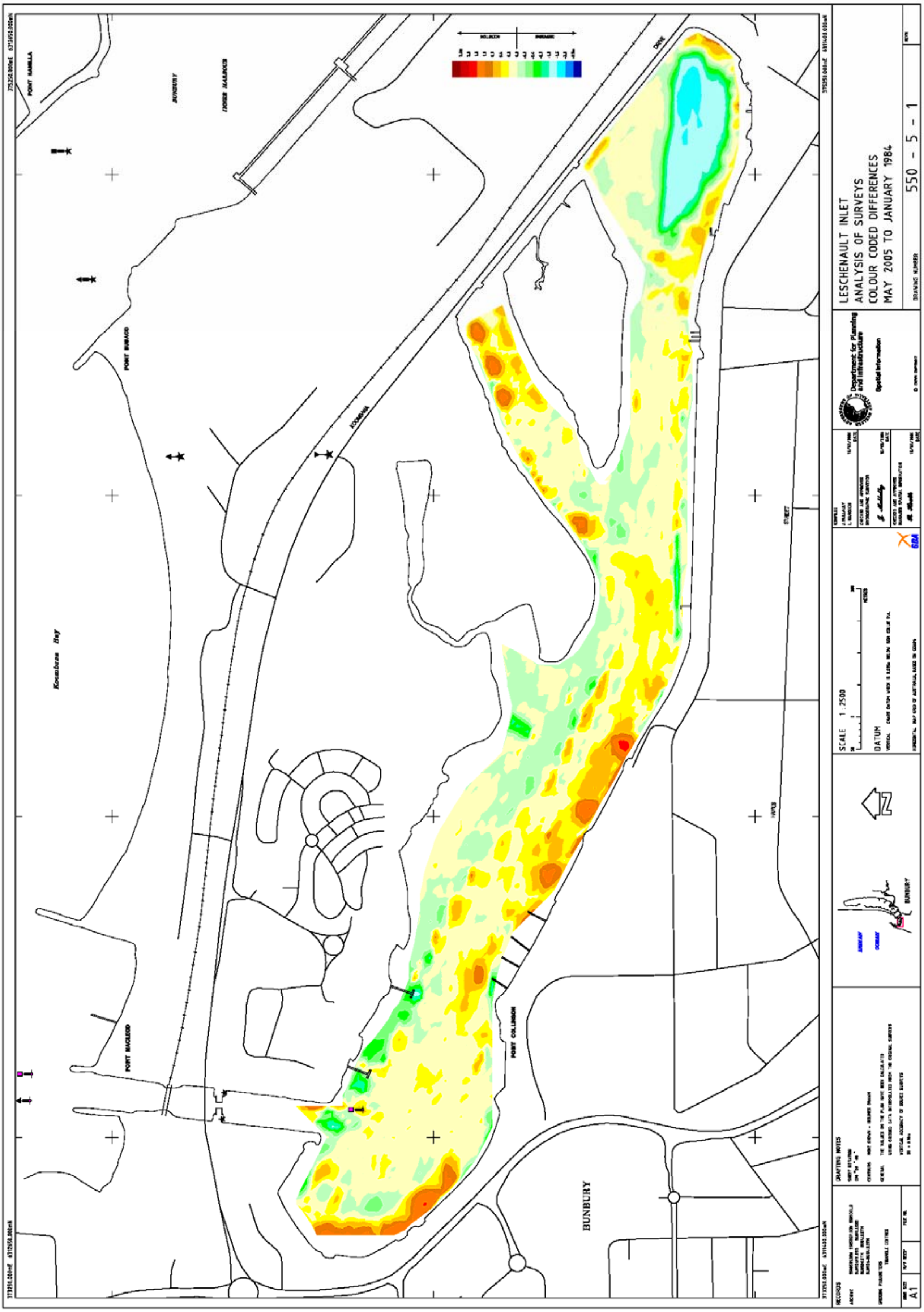
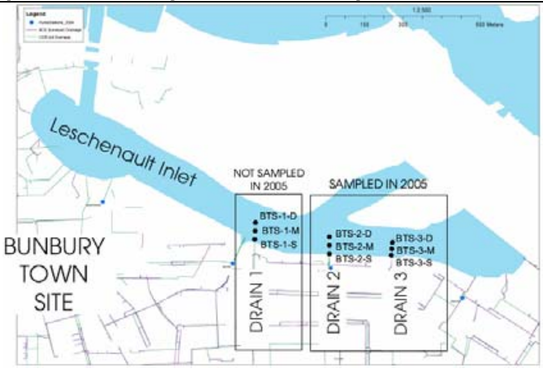


Figure 52. Colour differential plot identifying changes in bathymetric depth in the Leschenault Inlet between surveys undertaken in 1984 and 2005.

Table 21. Environmental conditions of concern in the Leschenault Inlet as of June 2006.

Region	Condition	Example
Leschenault Inlet	Protection of the significant white mangrove, ***Avicennia marina***, population.	 **Mangrove population of Leschenault Inlet 2005 (Photo taken by Mike McKenna)**
	Heavy Metal deposition in sediments from stormwater discharges.	 **Indicative stormwater drainage into Leschenault Inlet (Semeniuk, 2005)**
	High levels of general **litter** from high public usage.	 **Department of Environment staff during annual collection of rubbish from the Leschenault Inlet October 2004 (Photo taken by Bree Skennar)**
	Potential **pollution risk** from motorised boating	 **Private motorised boats penned in the Leschenault Inlet (photo by Mike McKenna)**

Interim Report Card 2006

Subject : Ecosystem Health in Leschenault Inlet

Environmental Quality Indicators		Management Response*	Comments
Physical and Chemical Measures	Turbidity/Light Attenuation		Sporadic monitoring undertaken on an 'as required' basis, due to consistency of conditions over 1995-2001 period.
	Dissolved Oxygen		
	pH		
	Salinity		
	Temperature		
Indirect Biological Measures	Algal Growth Potential		Mean Total Nitrogen – 0.38 mg/L Mean Total Phosphorous – 0.03 mg/L Nutrients considered to be 'Low' in concentration.
	Total Nitrogen (TN)		
	Total Phosphorous (TP)		
	Nitrate		
	Nitrite		
	Ammonium		
	Filtered Reactive Phos.		
Direct Biological Measures	Phytoplankton Blooms		Management response as required. No phytoplankton blooms recorded in the Leschenault Inlet since sampling commenced in 1995.
	Identify Phytoplankton		
	Chlorophyll a, b and c		
	Seagrass		
Fish Kills	Response and Investigation		No fish kills recorded to date. Management response as required.
Toxicants in Water	Metals and Metalloids		Absence of previous studies. Considered 'low risk' due to relatively small catchment and high tidal flushing/ water exchange.
	Organics		
	Pesticides		
	Herbicides and Fungicides		
	Hydrocarbons		
Toxicants in Sediment	Metals and Metalloids		May 2005 'snapshot' survey identified heavy metal and nutrient accumulation in sediments – precautionary management action required. Absence of previous studies for other attributes.
	Organics		
	Pesticides		
	Herbicides and Fungicides		
	Hydrocarbons		
	Algal Spores		

LEGEND
* Management Response (Note: All management responses are subject to funding)

Monitor – Below guideline; continue monitoring
Investigate – Investigate and where necessary, take precautionary action
Action Required – above standard; initiate response
Research – Additional information required to establish environmental state and/or criteria

6 Strategic directions — Leschenault catchment

The most significant issue that will affect waterways and catchment management over the next five years is the new regional Natural Resource Management (NRM) governance structure for the delivery of NRM objectives. This involves a three-way partnership between the Commonwealth and State Governments and, for the Leschenault catchment, the South West Catchments Council (SWCC) as the incorporated community-based regional NRM group. The arrangement facilitates the channelling of hundreds of millions of dollars of Commonwealth and State NRM funding from the Natural Heritage Trust (NHT) and National Action Plan for Salinity and Water Quality (NAP) programs through the regional NRM groups to achieve NRM outcomes.

In 2005, the SWCC released the South West Regional Strategy for NRM which "is a statement by community, industry and government stakeholders within the South West Region of the value of our natural resource assets. It acknowledges the threatening processes affecting these assets and presents our vision for delivering integrated natural resource management outcomes with a view to measurable improvements in resource condition on a regional scale." (SWCC, 2005)

The Department of Water has been actively involved in the development of the SWCC Strategy, and supporting the Leschenault Catchment Council (LCC) as a sub-regional delivery group identified under this strategy. There is a need for alignment between regional NRM strategy priorities and the Department of Water and LCC business to influence the formation of regional strategies and investment plans, in order to use this new funding most efficiently.

The Department has a vision of "highest and best use of West Australian water resources", and purpose that "the Department of Water ensures that the State's water resources are planned, managed and developed to meet community requirements, now and into the future". The LCC has a vision of "environmental values within the Leschenault Catchment restored, enhanced and protected, while creating social, cultural and economic opportunities for present and future generations". These statements, and the integrated, triple bottom line approach of both the Department and LCC, identify strong synergies with the guiding principles on water identified by SWCC through the Regional NRM Strategy.

The key asset classes used to progress the strategic direction for the Department and the LCC in the catchment are:

- Waterways, Wetlands and Estuaries
- Water Resources
- Biodiversity
- Remnant Vegetation
- Agricultural Land
- Urban Landscapes
- Community.

These asset classes have been described in Table 22 to recognise the management issues existing within the catchment, objectives for management and strategic actions which can be potentially undertaken and/or influenced by the Department of Water and the LCC in meeting those objectives.

Table 23 goes on to further establish priorities for these strategic actions, recognising existing programs and information gaps. The progression of key programs related to the strategic action undertaken in 2005-06 is noted. It should be noted that where no specific notation is made against a strategic action, it can be considered than no specific project towards meeting that action was initiated in 2005-06. However, many of the strategic actions identified represent a continuation or enhancement of work undertaken as part of day-to-day Departmental business and does not recognise completed projects undertaken by the LCC in previous years.

Table 22. Assets, issues, objectives and strategic actions for management of the Leschenault catchment.

ASSETS	MANAGEMENT ISSUES	OBJECTIVES	STRATEGIC ACTIONS
Waterways, Wetland and Estuaries	▪ Increasing salinisation ▪ Eutrophication ▪ Sedimentation ▪ Acidification ▪ Aquatic habitat loss (fringing vegetation, pest/ weed invasion, fragmentation) ▪ Drainage modification/ manipulation ▪ Reduced water flows	▪ Waterways, wetlands and estuaries do not become further degraded. ▪ Priority waterways, wetlands and estuarine habitats are rehabilitated to restore ecological and community value. ▪ Reduced incidence of algal blooms and fish kills. ▪ Increase community awareness of issues and impacts ▪ Extent, distribution and magnitude of point and diffuse sources of nutrient and sediment identified. ▪ Integrated catchment planning	1. Undertake assessment of hydrological processes to support decision-making and planning in the Leschenault Estuary. 2. Support local governments to update/extend planning mechanisms (TPSs, strategies and policies) to reduce land and water degradation and protect waterways, wetlands and estuaries. 3. Undertake EWR and EWP determination in un-regulated areas to reflect resource demands and pressures, and climate change, and integrate this information into sustainable decision-making processes for waterways. 4. Undertake holistic water cycle monitoring and assessment to improve understanding of ground/surface water interactions. 5. Undertake nutrient and sediment modelling to identify priority sub-catchments, waterways and wetlands for targeted management action. 6. Support and implement the State-wide Algal Management Strategy. 7. Undertake river action planning to engage landholders in waterway restoration. 8. Work in partnership with the community and stakeholders to undertake rehabilitation projects in identified priority waterways and wetlands. 9. Support community, industry and government stakeholders in implementing strategies to reduce nutrient and sediment inputs to waterways and wetlands. 10. Communicate clarification of roles and responsibilities for waterway, wetland and estuary management.
Water Resources	▪ Lack of EWR understanding for ground and surface water areas ▪ Lack of understanding and consideration of GDEs ▪ High allocation of groundwater resources ▪ Poor regulatory compliance ▪ Increasing demand for surface water in un-regulated areas ▪ Salinity recovery of the	▪ Sustainable use and allocation of groundwater and surface water resources, recognising environmental, social and economic influences. ▪ Protection of water quality and quantity.	11. Undertake EWR and EWP determination in un-regulated areas to reflect population growth, demand, and climate change, and integrate this information into sustainable allocation decision-making processes 12. Complete a review of groundwater monitoring program requirements for highly allocated water resources. 13. Undertake holistic water cycle monitoring and assessment to improve understanding of ground/surface water interactions to drive allocation of water resources. 14. Promote water efficiency BMPs as part of Tradeable Water Entitlements 15. Develop and implement policy to meter all non-domestic draws

ASSETS	MANAGEMENT ISSUES	OBJECTIVES	STRATEGIC ACTIONS
	Collie drainage catchment		to determine accurate assessment of water use and availability 16. Establishment of a Water Resources Management Committee for Leschenault Catchment with a view to progressing proclamation of un-regulated areas 17. Support and assess management options identified under the Collie Water Resource Management Plan.
Biodiversity	▪ Increasing salinity and rising water tables ▪ Eutrophication ▪ Sedimentation ▪ Toxin accumulation ▪ Habitat fragmentation ▪ Weed/Pest Invasion	▪ Biodiversity assets and values protected through improved management of the dependant environment. ▪ Surface and groundwater quality is not further degraded ▪ Ecological corridors are identified, protected and restored to provide linkages between habitats	18. Work in partnership with the community and stakeholders to undertake rehabilitation projects in identified priority areas to enhance biodiversity outcomes. 19. Influence land-use planning, in partnership with other key agencies, to identify areas and maintain areas of biodiversity significance and linkages through the application of appropriate planning mechanisms. 20. Support the directives of the State Weed Plan 2001. 21. Influence community and stakeholders land use and practices through education and awareness of impacts affecting biodiversity 22. Identify biodiversity protection incentives for landholders.
Remnant Vegetation	▪ Increasing salinity and water tables ▪ Loss of habitat ▪ Fragmentation of remnants ▪ Loss of fringing vegetation ▪ Land Clearing Regulations assessment and compliance	▪ Remnant vegetation protected and managed to maintain or improve the extent and condition of remnant vegetation. ▪ Landholders with priority remnants supported for their management and restoration to facilitate linkages with other remnants.	23. Identify incentives for landholders in protecting and managing remnant vegetation 24. Influence land-use planning at the strategic level to promote the National Biodiversity targets 25. Identify important landform and vegetation elements of the natural environment and ensure adequate representation of these elements in reserves or other protected land. 26. Support the EPA in undertaking TPS/TPS Amendment assessment of land use planning 27. Support the Leschenault Community Nursery in rehabilitation projects by use of local provenance seed banks. 28. Define a strategy for monitoring the status of remnant vegetation across the catchment. 29. Improved monitoring and compliance.
Agricultural Land	▪ Land salinisation ▪ Erosion from land clearing and cultivation ▪ Acidic soils ▪ Inundation/ Waterlogging ▪ Drainage management ▪ Eutrophic discharges	▪ Appropriate responses to the hydrological cycle are determined and applied to reduce the impacts of salinity on agricultural land. ▪ Holistic on-farm plans developed to mitigate the impacts of excessive nutrient and sediment discharges. ▪ Identification of nutrient and sediment export 'hotspots' to define priority areas for management.	30. Undertake assessment of hydrological processes to support decision-making and agricultural planning. 31. Support local governments to update/extend planning mechanisms (TPSs, strategies and policies) which seek to implement BMPs to reduce land and water degradation and protect high value agricultural and natural resource assets. 32. Promote the expansion and application of the cost-sharing 'Dairycatch' and 'NutrientSmart' programs to develop an integrated approach to land use and environmental management.

ASSETS	MANAGEMENT ISSUES	OBJECTIVES	STRATEGIC ACTIONS
			33. Support relevant agencies and community groups to assist in the dissemination and implementation of BMPs in whole-farm planning for sustainable agriculture. 34. Undertake catchment drainage planning to identify initiatives for agricultural drainage management. 35. Undertake nutrient and sediment modelling to identify point and diffuse discharges from agricultural land for targeted management action.
Urban Landscape	▪ Land clearing ▪ Stormwater management ▪ Garden 'escapees' (exotic flora and fauna)	▪ Urban development undertaken recognising environmental, social and economic restrictions. ▪ Identification of nutrient and sediment export 'hotspots' to define priority areas for management.	36. Provide land use planning and development advice using a strategic focus to ensure land use and development is undertaken in a manner that achieves good environmental outcomes. 37. Prepare and implement Leschenault Water Sensitive Urban Design Local Planning Policy through negotiation with local government. 38. Influence and support local government in retro-fitting urban drainage systems to meet WSUD guidelines and principles. 39. Undertake nutrient and sediment modelling to identify 'hotspots' for nutrient and sediment in urban stormwater discharges.
Community	▪ Lack of understanding of catchment based issues ▪ Increasing outrage at perceived inaction	▪ Community empowerment in understanding integrated catchment management. ▪ Work in partnership with the community to identify and undertake natural resource management projects. ▪ Community capacity to be involved and undertake proactive management	40. Encourage and support community groups involved in the management of natural areas to realise environmental goals. 41. Educate and empower the community to undertake rehabilitation and restoration works. 42. Support the Leschenault Catchment Council in developing a revised catchment management strategy and project development. 43. Work with the Leschenault Catchment Council to develop a communication strategy for general awareness activities. 44. Review, assess and negotiate future support arrangements to the Leschenault Catchment Council. 45. Continue to support programs, such as Ribbons of Blue, which offer a strategic approach to informing the community of catchment management activities. 46. Support and contribute to the implementation of the South West Catchment's Council's Strategic and Investment planning and investment process.

Table 23. Priority ranking of strategic actions and progression towards meeting those actions as of June 2006.

Issue/Strategic Action	Priority for Action			Specific Project Progression undertaken in 2005-06
	High	Medium	Low	
Waterways, Wetlands and Estuaries				
1. Undertake assessment of hydrological processes to support decision-making and planning in the Leschenault Estuary.		X		Water-borne nutrient and sediment modelling being undertaken for the catchment. Due for completion in 2008.
2. Support local governments to update/extend planning mechanisms (TPSs, strategies and policies) to reduce land and water degradation and protect waterways, wetlands and estuaries.	X			
3. Undertake EWR and EWP determination in un-regulated areas to reflect resource demands and pressures, and climate change, and integrate this information into sustainable decision-making processes for waterways.		X		EWR determination for Brunswick River due for completion 2007-08.
4. Undertake holistic water cycle monitoring and assessment to improve understanding of ground/surface water interactions.		X		
5. Undertake nutrient and sediment modelling to identify priority sub-catchments, waterways and wetlands for targeted management action.	X			Data gathering to support modelling initiated in July 2005. Due for completion in 2008.
6. Support and implement the State-wide Algal Management Strategy.			X	Awaiting State Government Endorsement.
7. Undertake river action planning to engage landholders in waterway restoration.		X		Brunswick RAP and Upper Preston RAP due for release early 2007. Lower Collie RAP to be undertaken in 2007.
8. Work in partnership with the community and stakeholders to undertake rehabilitation projects in identified priority waterways and wetlands.		X		Project proposal to SWCC to make small landholder rehabilitation grants available from LCC in 2007-08.
9. Support community, industry and government stakeholders in implementing strategies to reduce nutrient and sediment inputs to waterways and wetlands.	X			
10. Communicate clarification of roles and responsibilities for waterway, wetland and estuary management.		X		

Issue/Strategic Action	Priority for Action			Specific Project Progression undertaken in 2005-06
	High	Medium	Low	
Water Resources				
11. Undertake EWR and EWP determination in un-regulated areas to reflect population growth, demand, and climate change, and integrate this information into sustainable allocation decision-making processes	X			EWR determination for Brunswick River due for completion 2007-08.
12. Complete a review of groundwater monitoring program requirements for highly allocated water resources.		X		
13. Undertake holistic water cycle monitoring and assessment to improve understanding of ground/surface water interactions to drive allocation of water resources		X		
14. Promote water efficiency BMPs as part of Tradeable Water Entitlements			X	
15. Develop and implement policy to meter all non-domestic draws to determine accurate assessment of water use and availability	X	X		
16. Establishment of a Water Resources Management Committee for Leschenault Catchment with a view to progressing proclamation of un-regulated areas				Awaiting outcomes from the Whicher WRMC prior to considering establishment of Leschenault WRMC.
17. Support and assess management options identified under the Collie Water Resource Management Plan		X		Collie Recovery Plan ongoing. Stage 1 Collie River East branch diversion and groundwater pumping investigations progressing.
Biodiversity				
18. Work in partnership with the community and stakeholders to undertake rehabilitation projects in identified priority areas to enhance biodiversity outcomes.		X		Grants program for biodiversity protection initiated in 2005 continues through LCC in 2007-08
19. Influence land-use planning, in partnership with other key agencies, to identify areas and maintain areas of biodiversity significance and linkages through the application of appropriate planning mechanisms.	X			
20. Support the directives of the State Weed Plan 2001.		X		
21. Influence community and stakeholders land use and practices through education and awareness of impacts affecting biodiversity		X		
22. Identify biodiversity protection incentives for landholders.		X		

Issue/Strategic Action	Priority for Action			Specific Project Progression undertaken in 2005-06
	High	Medium	Low	
Remnant Vegetation				
23. Identify incentives for landholders in protecting and managing remnant vegetation		X		
24. Influence land-use planning at the strategic level to promote the National Biodiversity targets	X			Negotiating with EPA to ensure recognition and consistency of response.
25. Identify important landform and vegetation elements of the natural environment and ensure adequate representation of these elements in reserves or other protected land.	X			
26. Support the EPA in undertaking TPS/TPS Amendment assessment of land use planning		X		
27. Support the Leschenault Community Nursery in rehabilitation projects by use of local provenance seed banks.		X		
28. Define a strategy for monitoring the status of remnant vegetation across the catchment.		X		
29. Improved monitoring and compliance.		X		
Agricultural Land				
30. Undertake assessment of hydrological processes to support decision-making and agricultural planning.		X		
31. Support local governments to update/extend planning mechanisms (TPSs, strategies and policies) which seek to implement BMPs to reduce land and water degradation and protect high value agricultural and natural resource assets.	X			
32. Promote the expansion and application of the cost-sharing ‘Dairycatch’ and ‘NutrientSmart’ programs to develop an integrated approach to land use and environmental management.		X		Both programs promoted and implemented in catchment during 2005-2006.
33. Support relevant agencies and community groups to assist in the dissemination and implementation of BMPs in whole-farm planning for sustainable agriculture.			X	
34. Undertake catchment drainage planning to identify initiatives for agricultural drainage management.		X		Leschenault Landscape Water management Plan completed in mid - 2006.
35. Undertake nutrient and sediment modelling to identify point and diffuse discharges from agricultural land for targeted management action.	X			Data gathering to support modelling initiated in July 2005. Models due for completion in 2008.

Issue/Strategic Action	Priority for Action			Specific Project Progression undertaken in 2005-06
	High	Medium	Low	
Urban Landscape				
36. Provide land use planning and development advice using a strategic focus to ensure land use and development is undertaken in a manner that achieves good environmental outcomes.	X			
37. Prepare and implement Leschenault Water Sensitive Urban Design Local Planning Policy through negotiation with local government.		X		Proposed project to SWCC to undertake Local Planning Policy preparation over 2006-08 period.
38. Influence and support local government in retro-fitting urban drainage systems to meet WSUD guidelines and principles.			X	Above project includes education and information dissemination to local governments, including retrofitting demonstration sites.
39. Undertake nutrient and sediment modelling to identify 'hotspots' for nutrient and sediment in urban stormwater discharges.	X			Data gathering to support modelling initiated in July 2005. Models due for completion in 2008.
Community				
40. Encourage and support community groups involved in the management of natural areas.	X			
41. Educate and empower the community to undertake rehabilitation and restoration works.		X		Project proposal to SWCC to make small landholder grants available in 2006-08 period.
42. Support the Leschenault Catchment Council in developing a catchment management strategy and project development.	X			Management Strategy for the Leschenault Catchment Council due for release in early 200
43. Work with the Leschenault Catchment Council to develop a communication strategy for general awareness activities.		X		
44. Review, assess and negotiate future support arrangements to the Leschenault Catchment Council.	X			Formal support arrangements between the DoW and LCC due to be finalised early-mid 2007.
45. Continue to support programs, such as Ribbons of Blue, which offer a strategic approach to informing the community of catchment management activities.		X		
46. Support and contribute to the implementation of the South West Catchment Council's Strategic and Investment planning and investment process.	X			Projects for the Leschenault catchment submitted to SWCC as part of the Investment Plan 2 process for 2006-08 period.

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Glossary

Aeolian Relating to, caused by, or carried by the wind.

Allocation The quantity of groundwater or surface water permitted to be abstracted by licence, usually specified in kilolitres/year (kl/a)

Amphipod Any of numerous small, flat-bodied crustaceans of the group *Amphipoda*, including the beach fleas, sand hoppers, etc.

Anthropology The scientific study of the origin, the behaviour, and the physical, social, and cultural development of humans.

mAHD Australian Height Datum. Height in metres above Mean Sea Level +0.026 m at Fremantle

Assemblage A collection of people or things; a gathering.

Bathymetric The measurement of the depth of bodies of water.

Benthic The collection of organisms living on or in sea or lake bottoms.

Biodiversity Collective term for all the taxa of plants, animals and micro-organisms in an area.

Bioturbation The disturbance of sediment layers by biological activity

Crustacean Any chiefly aquatic arthropod of the class *Crustacea*, typically having the body covered with a hard shell or crust, including the lobsters, shrimps, crabs, barnacles, and wood lice.

Cryptophyte Common in fresh and salt water appearing along the shore as algal blooms

Cyanophyte Relating to or caused by photosynthetic bacteria of the class *Cyanobacteria*

Depauperate Severely diminished; impoverished

Detritus Disintegrated or eroded matter

Diatom Any of various microscopic one-celled or colonial algae of the class *Bacillariophyceae*, having cell walls of silica consisting of two interlocking symmetrical valves.

Dinoflagellate Any of numerous minute, chiefly marine protozoans of the order *Dinoflagellata*, characteristically having two flagella and a cellulose

Dissolved Oxygen (DO) The concentration of oxygen dissolved in water or effluent, measured in milligrams per litre (mg/L) or per cent (%).

Ecological Water Provisions Actual level (allocation) made after consideration of the economic and social requirements for the water. It may be equal to or less than the Environmental Water Requirements.

Environmental Water Requirements Water level that will maintain current ecological values.

Estuarine Of, relating to, or found in an estuary

Euryhaline Capable of tolerating a wide range of salt water concentrations. Used of an aquatic organism.

Eutrophication A natural process of accumulation of nutrients leading to increased aquatic plant growth. Human activities contributing fertilisers and other high nutrient wastes can speed up the process, leading to algal blooms and deterioration in water quality.

Fluvial Produced by the action of a river or stream

Gastropod Any of various molluscs of the class *Gastropoda*, such as the snail, slug, cowrie, or limpet, characteristically having a single, usually coiled shell or no shell at all, a ventral muscular foot for locomotion, and eyes and feelers located on a distinct head.

Halophyte A plant adapted to living in a saline environment

Hectare 10,000 square metres or 2.47 acres

Holocene Time, rock series, or sedimentary deposits of the more recent of the two epochs of the Quaternary Period, beginning at the end of the last Ice Age about 11,000 years ago and characterized by the development of human civilizations.

Hydrodynamics The dynamics of fluids in motion

Hypersaline Of or belonging to the geologic saline concentration above that of seawater (ie >35ppt)
Alkalinity in water in which pH 7 is neutral, values above 7 are alkaline and values below 7 are acidic.

Hypoxia Deficiency in the amount of oxygen reaching body tissues

Invertebrate Lacking a backbone or spinal column; not vertebrate

Isopod Any freshwater, marine, or terrestrial crustacean of the order or suborder *Isopoda*, having seven pairs of legs typically adapted for crawling, and a dorsoventrally flattened body, and including wood lice, several aquatic parasites of crabs and shrimps, and numerous swimming or bottom-dwelling species.

Macrophyte A macroscopic plant

Metalloid A non-metal that in combination with a metal forms an alloy or an element that has both metallic and non-metallic properties, as arsenic, silicon, or boron.

Mollusc Any of numerous chiefly marine invertebrates of the phylum *Mollusca*, typically having a soft unsegmented body, a mantle, and a protective calcareous shell and including the edible shellfish and the snails.

Morphology The branch of biology that deals with the form and structure of organisms without consideration of function.

Nitrification The process by which micro-organisms convert ammonia compounds to nitrate. It takes place only under oxygenated conditions.
$NH_4 \rightarrow NO_2 \rightarrow NO_3$

Nitrogen In the environment, inorganic nitrogen occurs in a range of oxidation states as nitrate (NO_3) and nitrite (NO_2), the ammonium ion (NH_4^+) and molecular nitrogen (N_2).

Nutrients Minerals dissolved in water, particularly inorganic compounds of nitrogen (nitrate and ammonia) and phosphorus (phosphate) which provide nutrition (food) for plant growth. Total nutrient levels include the inorganic forms of an element plus any bound in organic molecules.

Parabolic Of or having the form of a parabola or paraboloid

pH A symbol denoting the concentration of hydrogen (H) ions in solution. A measure of acidity or covering and forming one of the chief constituents of plankton.

Phosphorous The total phosphorus is the organically combined phosphorus and all phosphates. The dissolved form of phosphorus is measured after filtering the sample through a 0.45um membrane filter, this is known as filtered reactive phosphorus (frp).

Phytoplankton Minute, free-floating aquatic plants

Polychaetes Any of various annelid worms of the class *Polychaeta*, including mostly marine worms such as the lugworm, and characterized by fleshy paired appendages tipped with bristles on each body segment.

ppt Parts per thousand

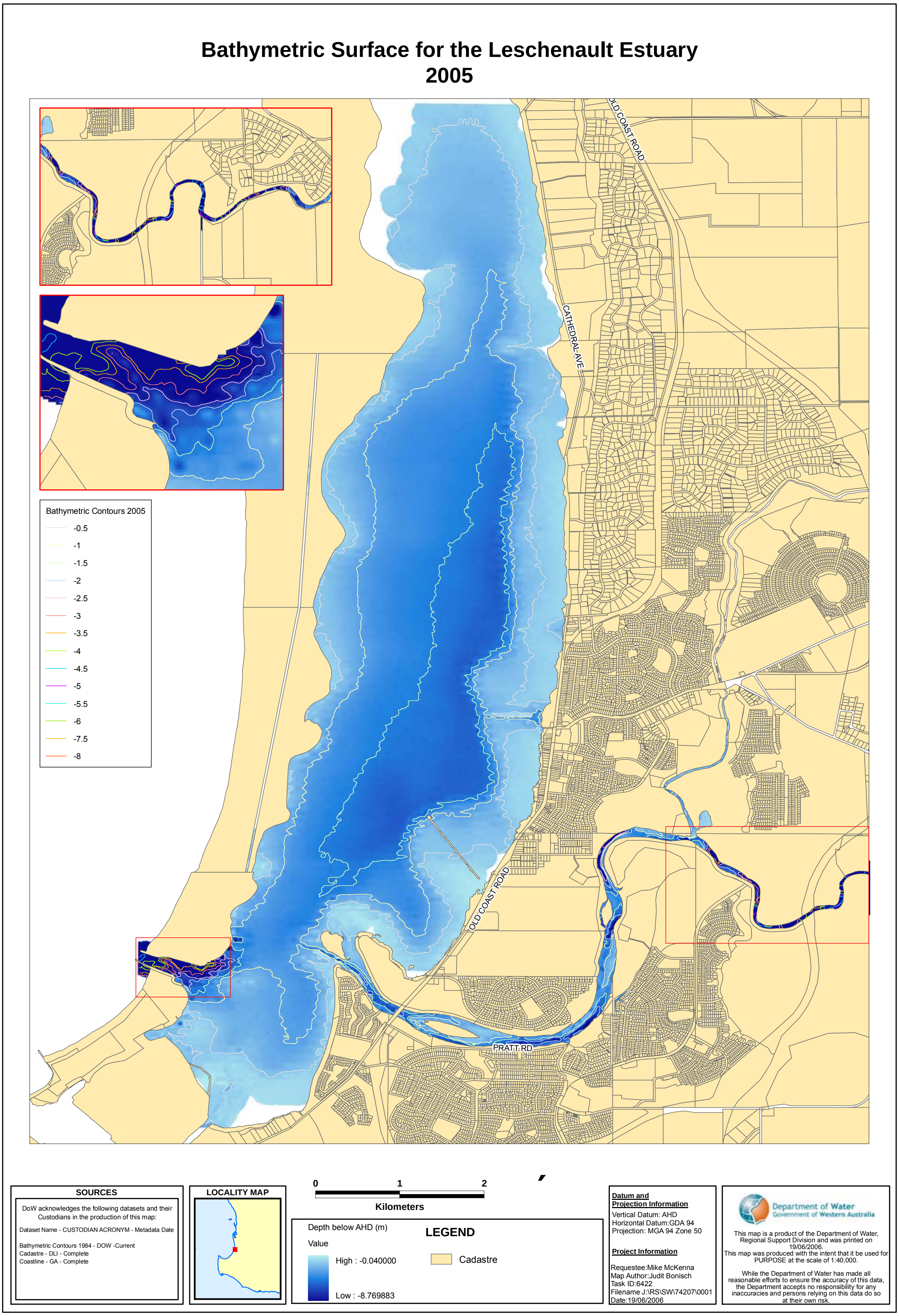
Salinity The measure of total soluble (or dissolved) salt i.e. mineral constituents in water. Measurements are usually in milligrams per litre (mg/L) or parts per thousand (ppt).

Sedimentation The act or process of depositing sediment

Turbidity Having sediment or foreign particles stirred up or suspended; muddy

Water quality A general term describing the suitability of water for a given use.

Appendix 1. List of Bathymetric Figures — Leschenault Estuary and Inlet


Bathymetric Surface for the Leschenault Estuary
2005
OLD COAST ROAD
CATHEDRAL AVE
OLD COAST ROAD
PRATT RD
Bathymetric Contours 2005
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
-6
-7.5
-8
SOURCES
DoW acknowledges the following datasets and their Custodians in the production of this map:
Dataset Name - CUSTODIAN ACRONYM - Metadata Date
Bathymetric Contours 1984 - DOW -Current
Cadastre - DLI - Complete
Coastline - GA - Complete
LOCALITY MAP
0 1 2
Kilometers
Depth below AHD (m)
Value
High : -0.040000
Low : -8.769883
LEGEND
Cadastre
Datum and Projection Information
Vertical Datum: AHD
Horizontal Datum:GDA 94
Projection: MGA 94 Zone 50
Project Information
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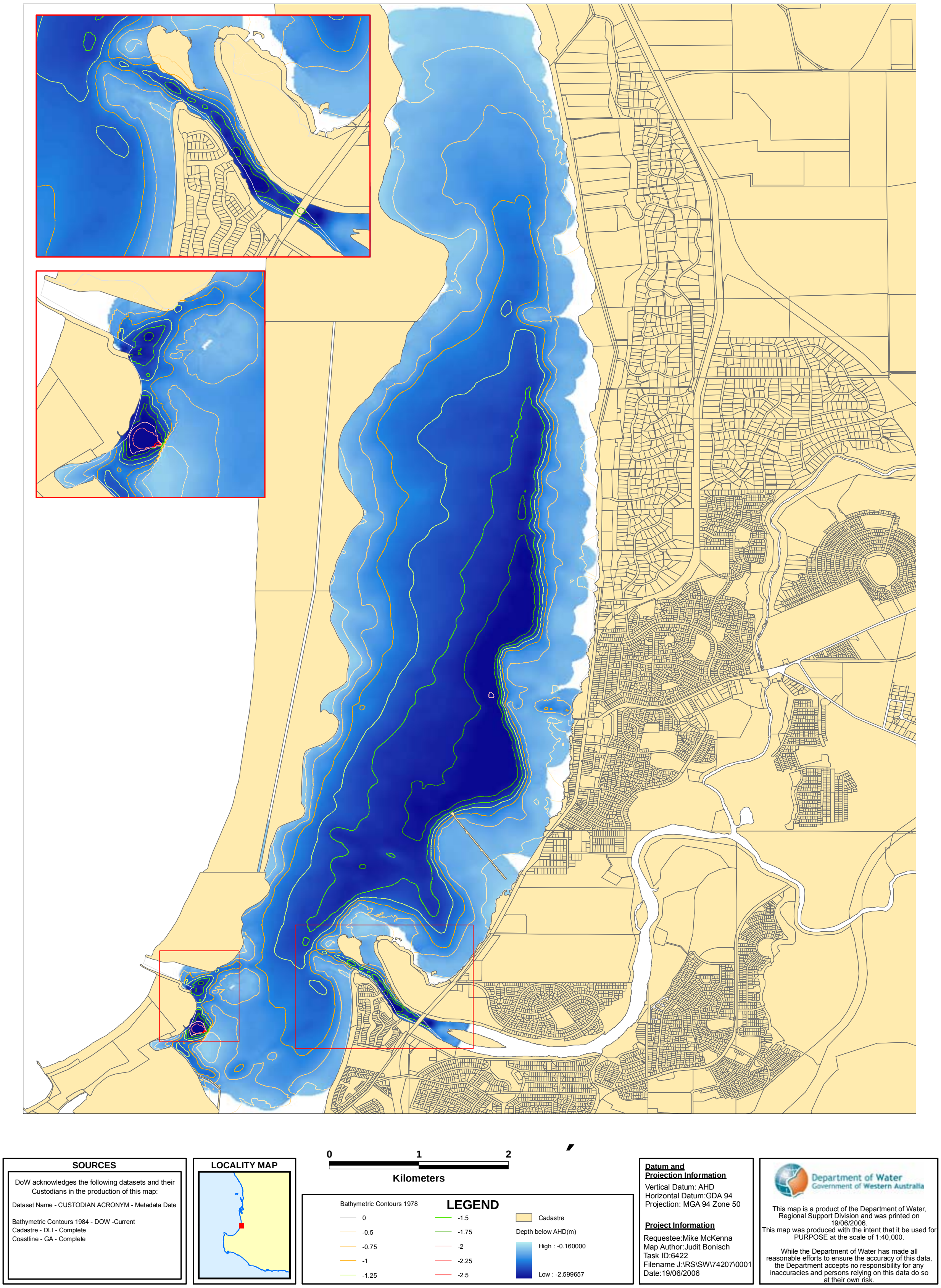
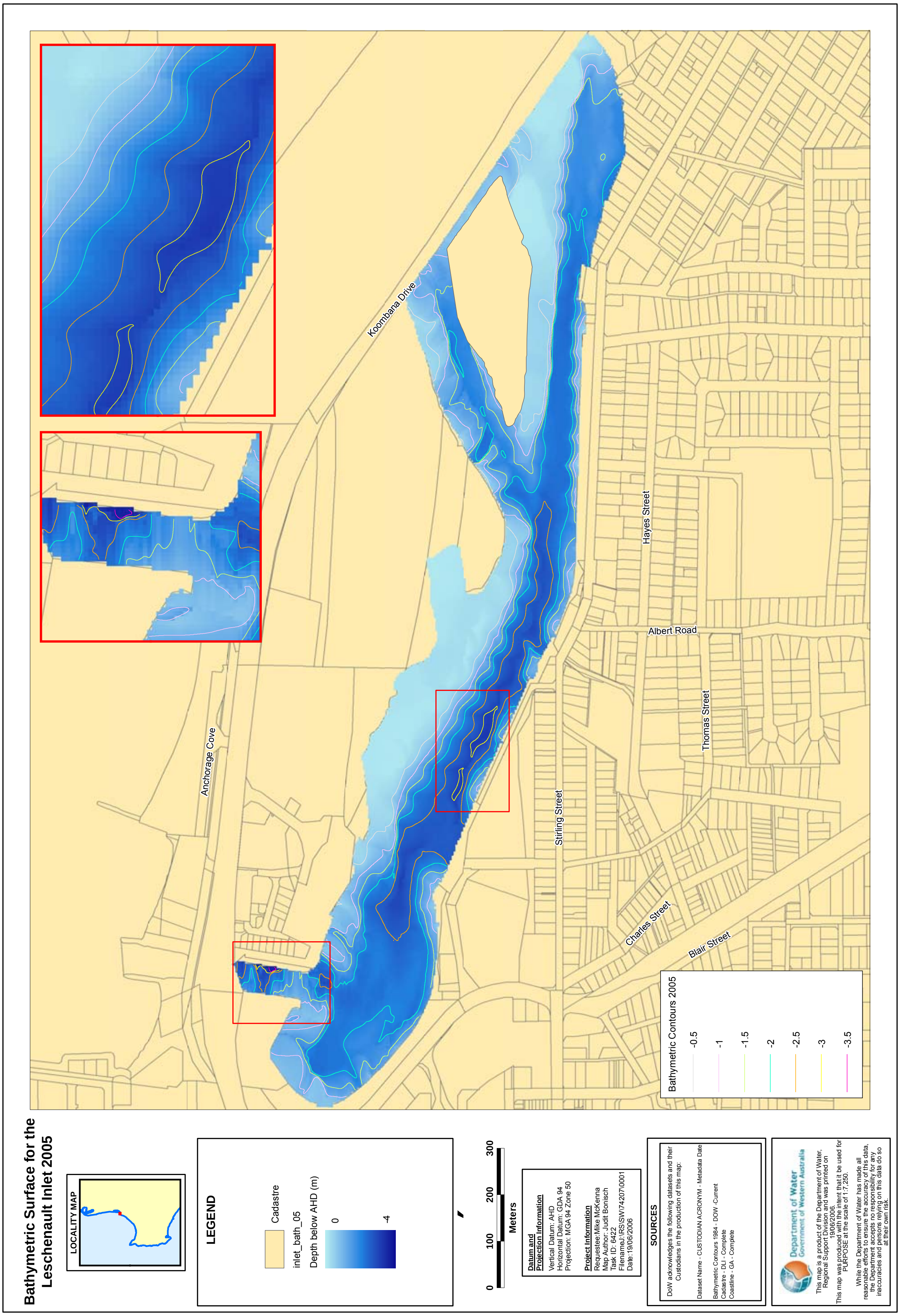
Map Author:Judit Bonisch
Task ID:6422
Filename J:\RS\SW\74207\0001
Date:19/06/2006
Department of Water
Government of Western Australia
This map is a product of the Department of Water, Regional Support Division and was printed on 19/06/2006.
This map was produced with the intent that it be used for PURPOSE at the scale of 1:40,000.
While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the Department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

Bathymetric Surface for the Leschenault Estuary 1978




Bathymetric Surface for the Leschenault Inlet 2005
LOCALITY MAP
LEGEND
Cadastre
inlet_bath_05
Depth below AHD (m)
0
-4
0
100
200
300
Meters
Datum and Projection Information
Vertical Datum: AHD
Horizontal Datum: GDA 94
Projection: MGA 94 Zone 50
Project Information
Requestee:Mike McKenna
Map Author: Judit Bonisch
Task ID: 6422
FilenameJ:\RS\SW7420\0001
Date:19/06/2006
SOURCES
DoW acknowledges the following datasets and their Custodians in the production of this map:
Dataset Name - CUSTODIAN ACRONYM - Metadata Date
Bathymetric Contours 1984 - DOW -Current
Cadastre - DLI - Complete
Coastline - GA - Complete
Department of Water
Government of Western Australia
This map is a product of the Department of Water, Regional Support Division and was printed on 19/06/2006.
This map was produced with the intent that it be used for PURPOSE at the scale of 1:7,250.
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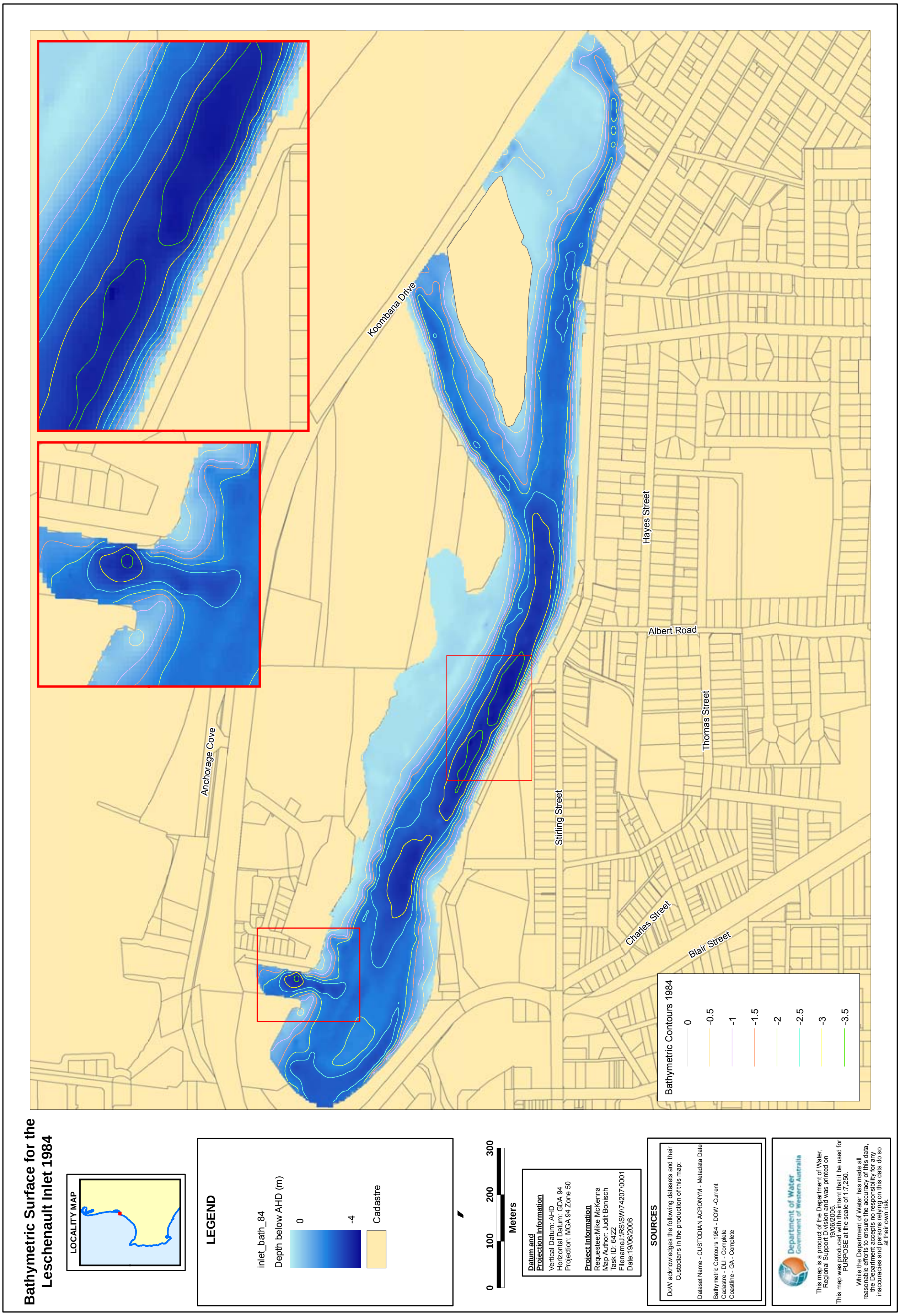
Koombana Drive
Hayes Street
Albert Road
Thomas Street
Stirling Street
Anchorage Cove
Charles Street
Blair Street
Bathymetric Contours 2005
-0.5
-1
-1.5
-2
-2.5
-3
-3.5



Bathymetric Surface for the Leschenault Inlet 1984
LOCALITY MAP
LEGEND
inlet_bath_84
Depth below AHD (m)
0
-4
Cadastre
0
100
200
300
Meters
Datum and Projection Information
Vertical Datum: AHD
Horizontal Datum: GDA 94
Projection: MGA 94 Zone 50
Project Information
Requestee: Mike McKenna
Map Author: Judit Bonisch
Date:19/06/2006
SOURCES
Department of Water
Government of Western Australia
Bathymetric Contours 1984
0
-0.5
-1
-1.5
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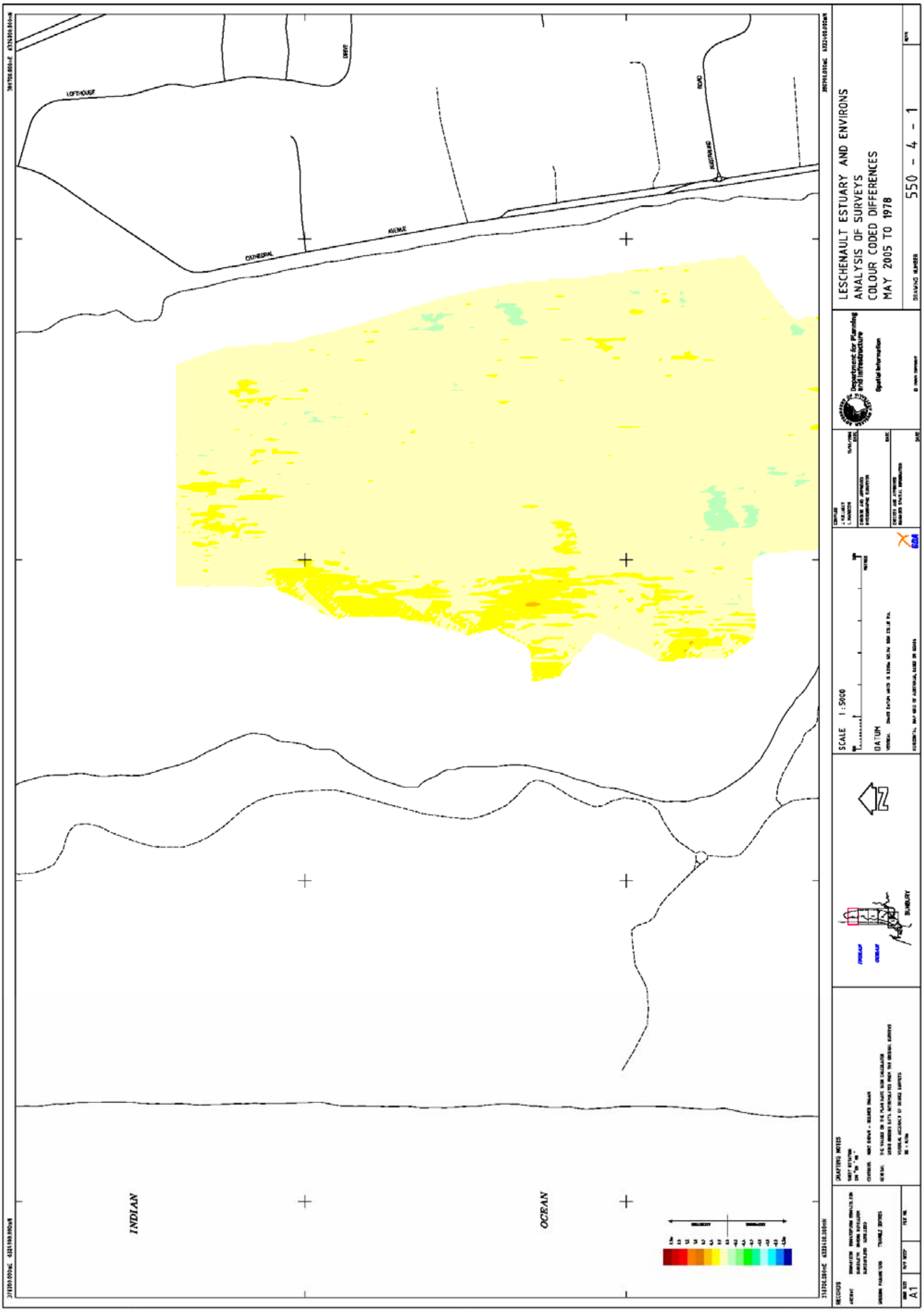
Hayes Street
Albert Road
Thomas Street
Stirling Street
Charles Street
Blair Street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COLOUR CODED DIFFERENCES
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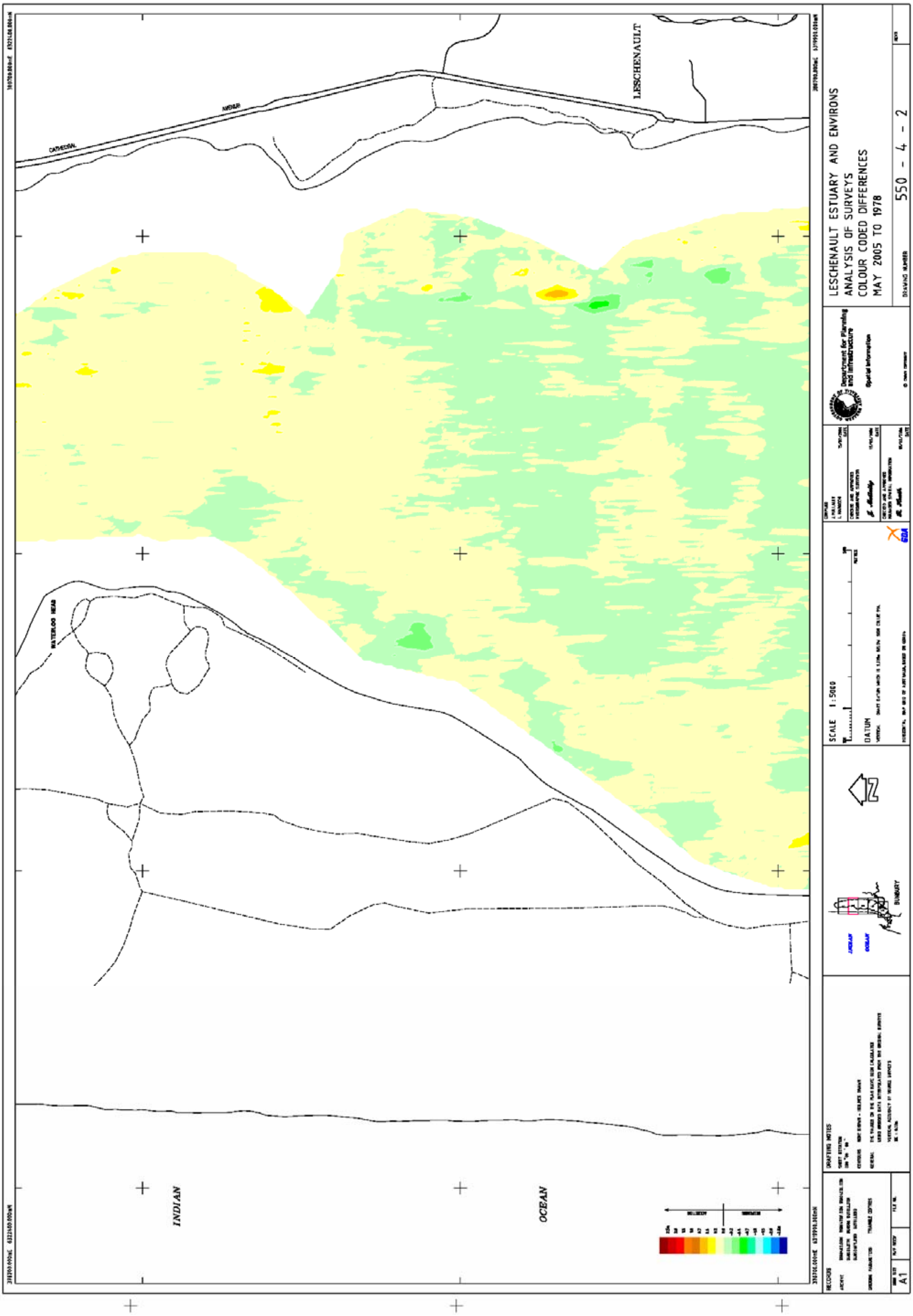
CATHEDRAL
AVENUE
LOFTHOUSE
INDIAN
OCEAN
A1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OCEAN
SCALE 1:5000
DATUM
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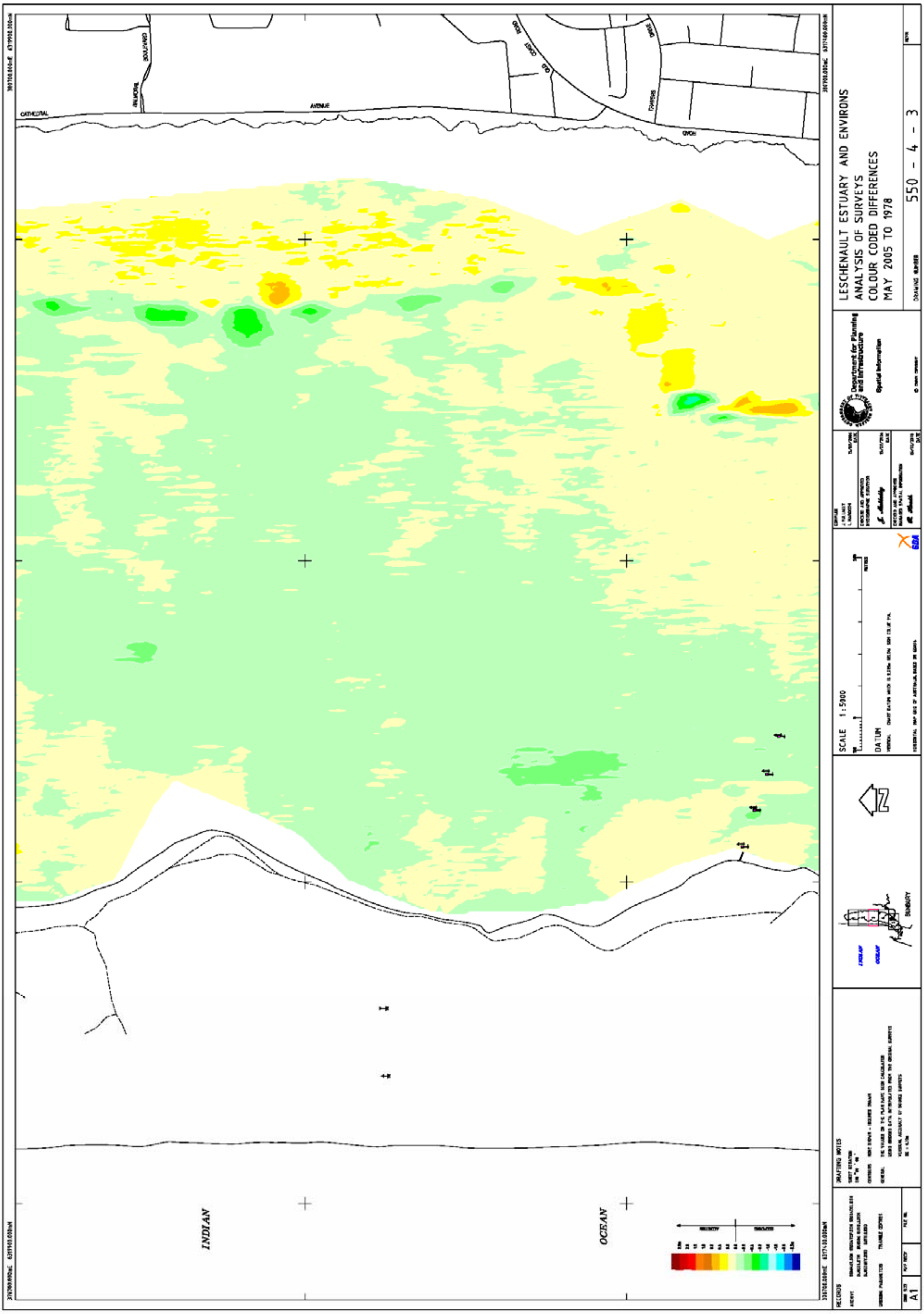
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ANALYSIS OF SURVEYS
COLOUR CODED DIFFERENCES
MAY 2005 TO 1978
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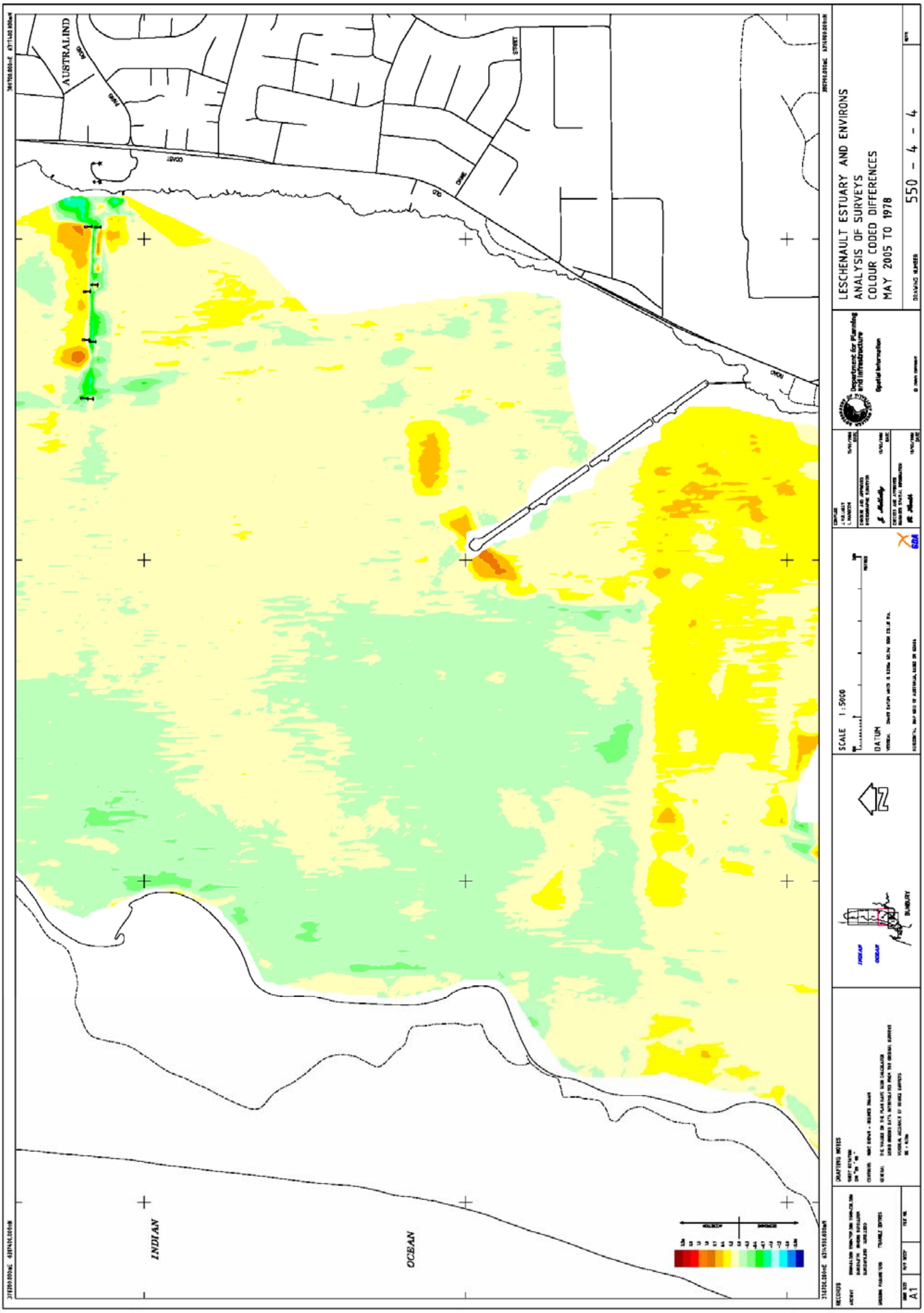
DATUM
INDIAN
OCEAN
CATHEDRAL
AVENUE
A1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ANALYSIS OF SURVEYS
COLOUR CODED DIFFERENCES
MAY 2005 TO 1978
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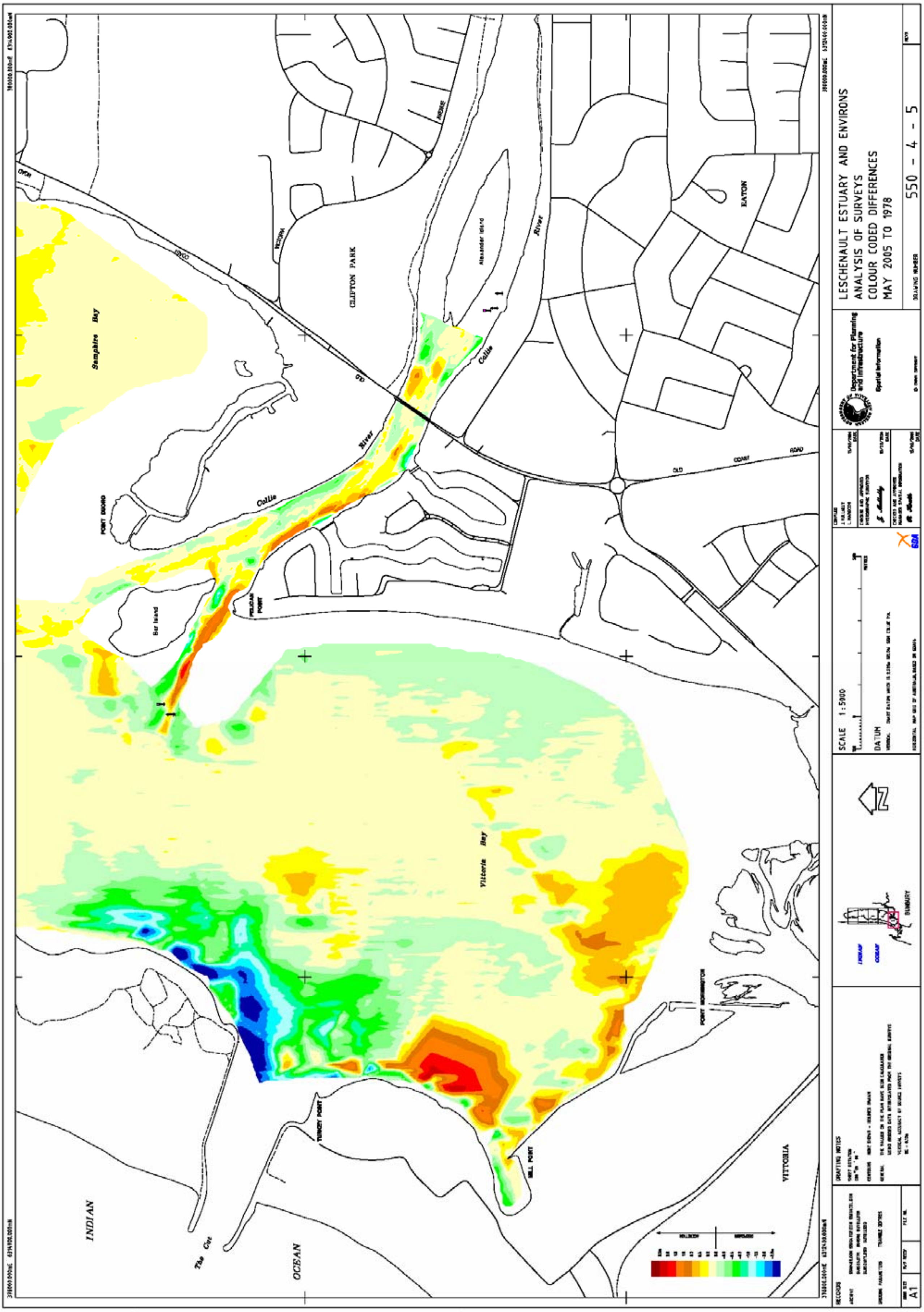
DATUM
AUSTRALIND
INDIAN
OCEAN
BUNBURY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COLOUR CODED DIFFERENCES
MAY 2005 TO 1978
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Department for Planning and Infrastructure
A1
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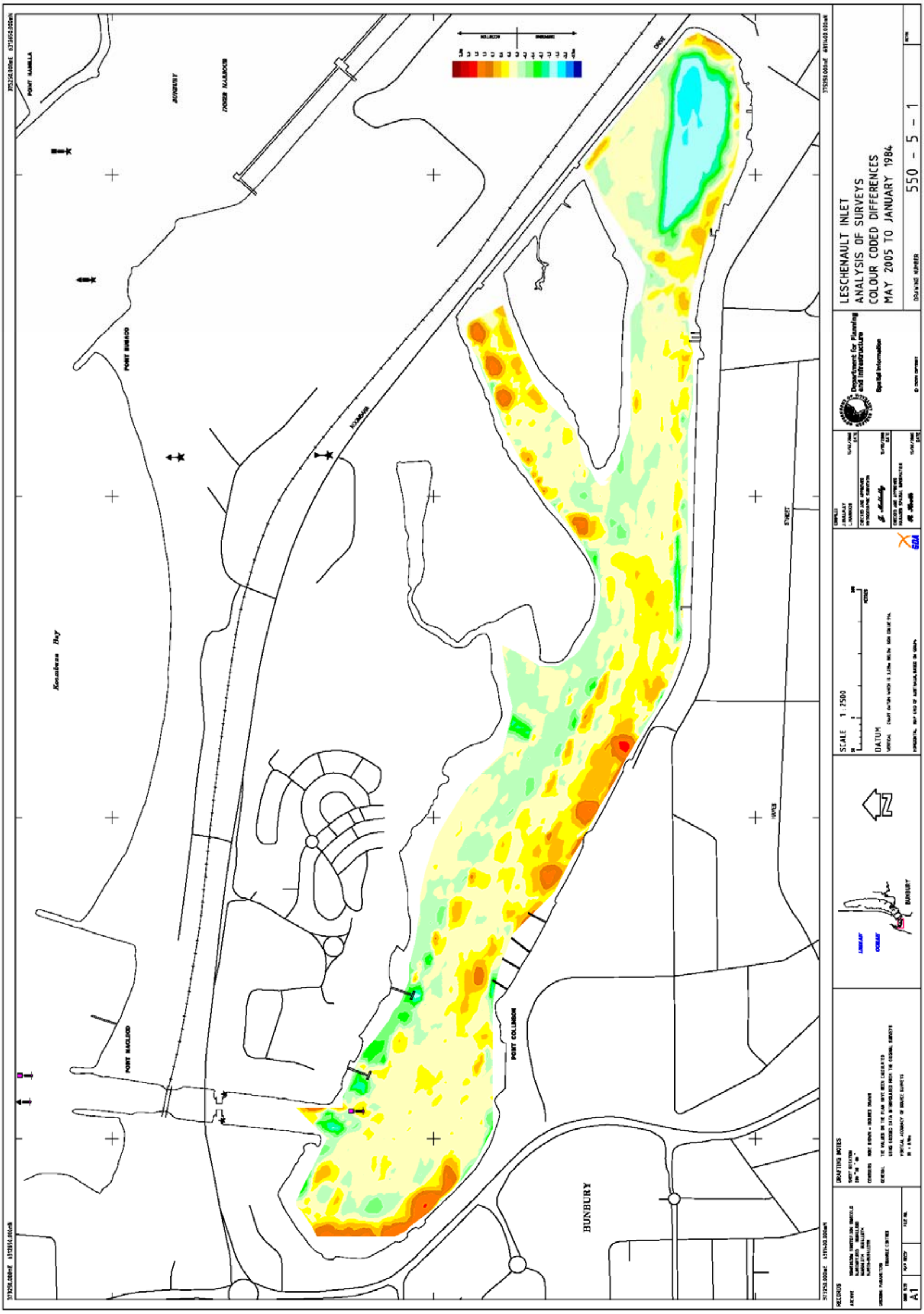
CLIFTON PARK
Collie River
EATON
OLD COAST ROAD
Bar Island
Victoria Bay
The Cut
INDIAN
OCEAN
VITTORIA


LESCHENAULT INLET
ANALYSIS OF SURVEYS
COLOUR CODED DIFFERENCES
MAY 2005 TO JANUARY 1984
550 - 5 - 1
SCALE 1:2500
DATUM
BUNBURY
POINT COLLINSON
POINT MACLEOD
Koombana Bay

Appendix 2. Water Quality of the Leschenault Estuary and Estuarine Reaches

Ashley Ramsay

Department of Water

Executive summary

The water quality of the Leschenault Estuary and its lower catchment reaches of the Brunswick, Collie and Preston Rivers, as well as the artificial Parkfield Drain, displayed variability among parameters as indicators of waterway health over the 2000-06 sampling period. Water quality indicators of salinity, dissolved oxygen, pH, total nitrogen, total phosphorous, chlorophyll *a* and phytoplankton density and composition were shown to be strongly influenced by contributing seasonal factors such as rainfall, catchment runoff, mixing influences, evaporation and marine exchange. Parameters displayed distinctive seasonality reflective of the cool, wet winters and dry, hot summers consistent with the Mediterranean climate of the southwest, combined with a reflection of catchment land use and land practices.

The estuary itself with its strong exchange of tidal marine waters is regarded as being in relatively good condition when compared to outer south-west estuarine systems, having a low nutrient status. Algal blooms were not common and it exists as a clear-water macrophyte dominated system. The four major inflows to the estuary – the Preston, Collie and Brunswick Rivers, and the Parkfield Drain all exhibit water quality conditions reflective of stressed catchments under increasing land use pressures. Of particular concern are the Collie and Brunswick rivers which succumb to annual summer phytoplankton blooms that, in combination with summer storm events, either triggered or were the catalyst for fish kill events in 2002 and 2004.

Introduction

The Leschenault estuarine system is located approximately 180 km south of Perth in south Western Australia in proximity to the town of Bunbury. The Leschenault estuarine system consists of the Leschenault Estuary, and the lower reaches of the Brunswick, Collie, and Preston rivers and the artificial drainage outfall of the Parkfield Drain. This system has significant ecological, aesthetic and social importance as habitat for migratory birds and providing a fish and crab nursery, which supports a vibrant coastal and water-based recreational community.

Water quality within the Leschenault estuarine system indicates a system in relatively good health in comparison to neighbouring Swan Coastal Plain estuarine systems such as the Vasse/Wonnerup at Busselton to the south and the Peel-Harvey to the north at Mandurah. Historically, both these systems have exhibited adverse water quality conditions, particularly eutrophication, that has led to sustained annual summer algal blooms and episodic fish kill events. While water quality conditions in the Leschenault estuarine reaches are not regarded as severe, the system has exhibited frequent algal blooms in the lower river reaches and significant fish kill events in 2002, 2003 and 2004. These events represent symptoms of a catchment under stress, generally through development pressures and inappropriate land practices.

In January 2001 the Water and Rivers Commission released the first *South West Inflo* for the Leschenault Estuary and catchment, summarising the key findings from water quality data collected between 1995 and 1999. A classification of the nutrient status for the Leschenault drainage catchment and a summary of water quality indicators were produced as an overview of system status and issues; which will complement the findings of this report.

This report represents a summary of the main findings of water quality data collected from the Leschenault Estuary Monitoring Program (SW-E-LESCH) between 2000 and 2006. This sampling program included surface water sampling for nutrients (total nitrogen and total phosphorous), salinity, dissolved oxygen, pH, chlorophyll *a*, and phytoplankton density and composition at sites within the Leschenault Estuary, the estuarine reaches of the Brunswick, Collie and Preston rivers and the estuarine outfall of the Parkfield Drain as the significant catchment outfalls of the catchment (Figure 1). There are some fundamental differences between the 2000-06 sampling program and the one reported on in the 2001 *Inflo* document. They include:

- Reduction from an annual sampling program on a monthly frequency to a summer base program predominately monitored between November to May on a fortnightly frequency;
- Reduction of the number of sample sites from 26 down to the current number of 10 sample sites; and
- Reduction in nutrient monitoring by dropping the fractional components of nitrogen and phosphorus as well as silica.

The rationale behind these amendments was in order to concentrate more frequent monitoring of nutrients and chlorophyll *a*, as an indicator of algal growth, during the problematic summer period. These fundamental changes have introduced difficulties in provision of trend analysis across the pre- and post- 2000 sampling regimes for the Leschenault Estuary program. Therefore, while the 2001 *Inflo* document complements this report, this report should be considered independent, and read in isolation as the data is not directly comparable. While the sampling regime has shown variability in approach, water quality sampling procedures and techniques utilising the Hydrolab have remained consistent across programs.

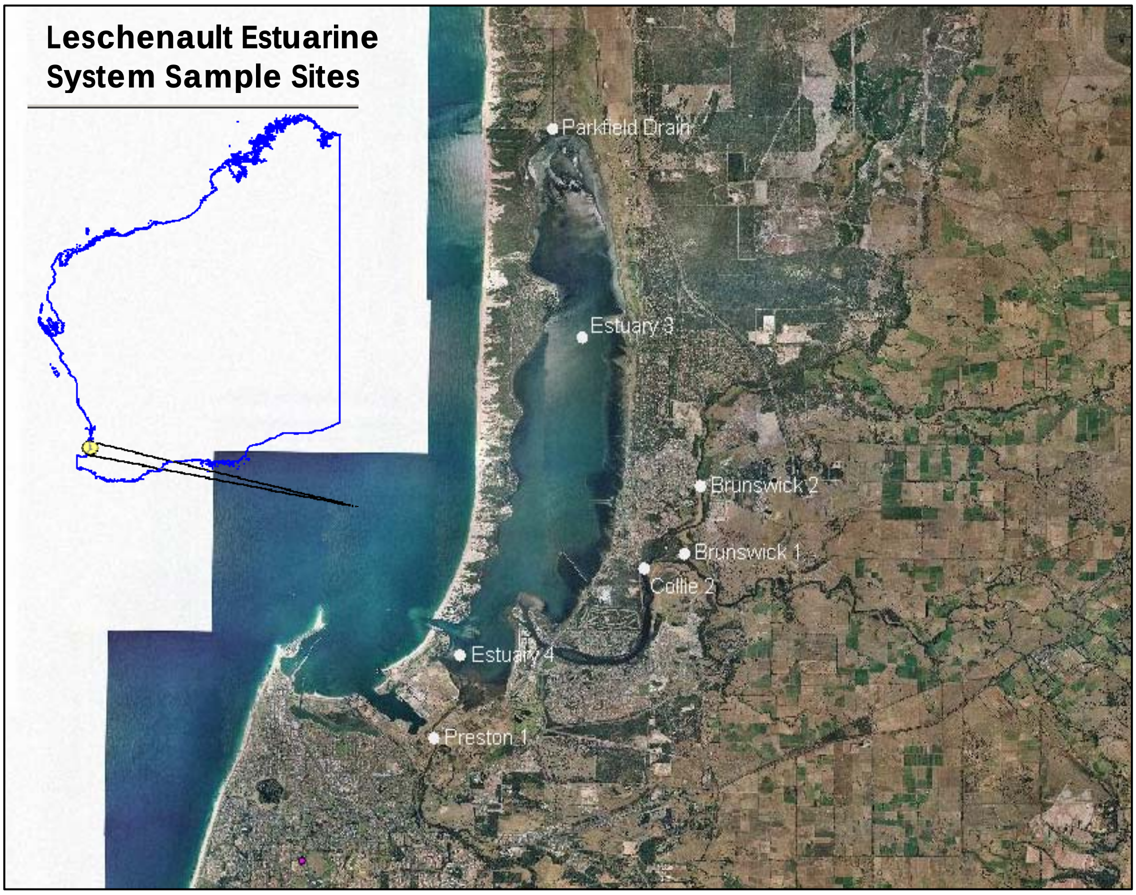


Figure 1. Sampling sites of the Leschenault Estuary Monitoring Program (SW-E-LESCH) 2000-2006.

Assessing Nutrient Status

In June 2006, the Department of Water prepared the draft report *Nutrient Status, Trends and Loads Report – Phase 1: DSS Modelling for the Leschenault Catchment* which presents the current nutrient status, trends and loads through a South West Catchment's Council (SWCC) funded project to develop nutrient, water and sediment models to support investment decision-making. This report statistically analyses data collected from sites on the significant waterways from the Darling Range down to the Swan Coastal Plain.

The assessment for classification of nutrient status for total Nitrogen (TN) and total Phosphorus (TP) at the monitored sites of the Leschenault Estuarine System for this report has been adopted from the State-wide River Water Quality Assessment website, and is consistent with the nutrient assessments detailed in the modelling report. These classifications have been adopted in the absence of estuarine specific classification assessment standards. These classifications are described below.

Table 1. Classifications used to assess the status of TN and TP concentrations in monitored (estuarine) waterways.

TN (MG/L)	STATUS	TP (MG/L)
> 2.0	Very High	> 0.2
1.2 – 2.0	High	0.08 – 0.2
0.75 – 1.2	Moderate	0.02 – 0.08
< 0.75	Low	< 0.02

The nutrient status for a waterway or estuary used in this report is assigned by using the median of nutrient concentration over a three-year period. The three-year period is used to diminish the influence of natural variation between years and the median is used rather than average to diminish extreme events.

Results

1.2 Leschenault Estuary

Site: Estuary 4 (The ‘Cut’). AWRC Code: 6121207

Parameter	Period	Status	Comment
TN	2000 - 2006	Low	Decreasing trend
TP	2000 - 2006	Low	Decreasing trend

During the study period from 2000 to 2006 there were 72 TN and TP samples taken at Estuary 4 sample site. This site is characterised by its proximity to the ‘the Cut’ just inside the estuary and its strong tidal exchange of seawater. On average, it has a depth of 0.8m.

Table 1.11. Total Nitrogen and Total Phosphorus Statistics for 6121207.

Statistic	Total Nitrogen	Total Phosphorus
Median	0.21	0.02
Average	0.224	0.0253
10th %ile	0.13	0.01
90th %ile	0.31	0.04
Lowest concentration	0.079	0.007
Highest concentration	0.75	0.08
Moving Median 2000-02	0.228	0.028
2001-03	0.223	0.0217
2002-04	0.218	0.0233
2003-05	0.197	0.0217
2004-06	0.192	0.0188

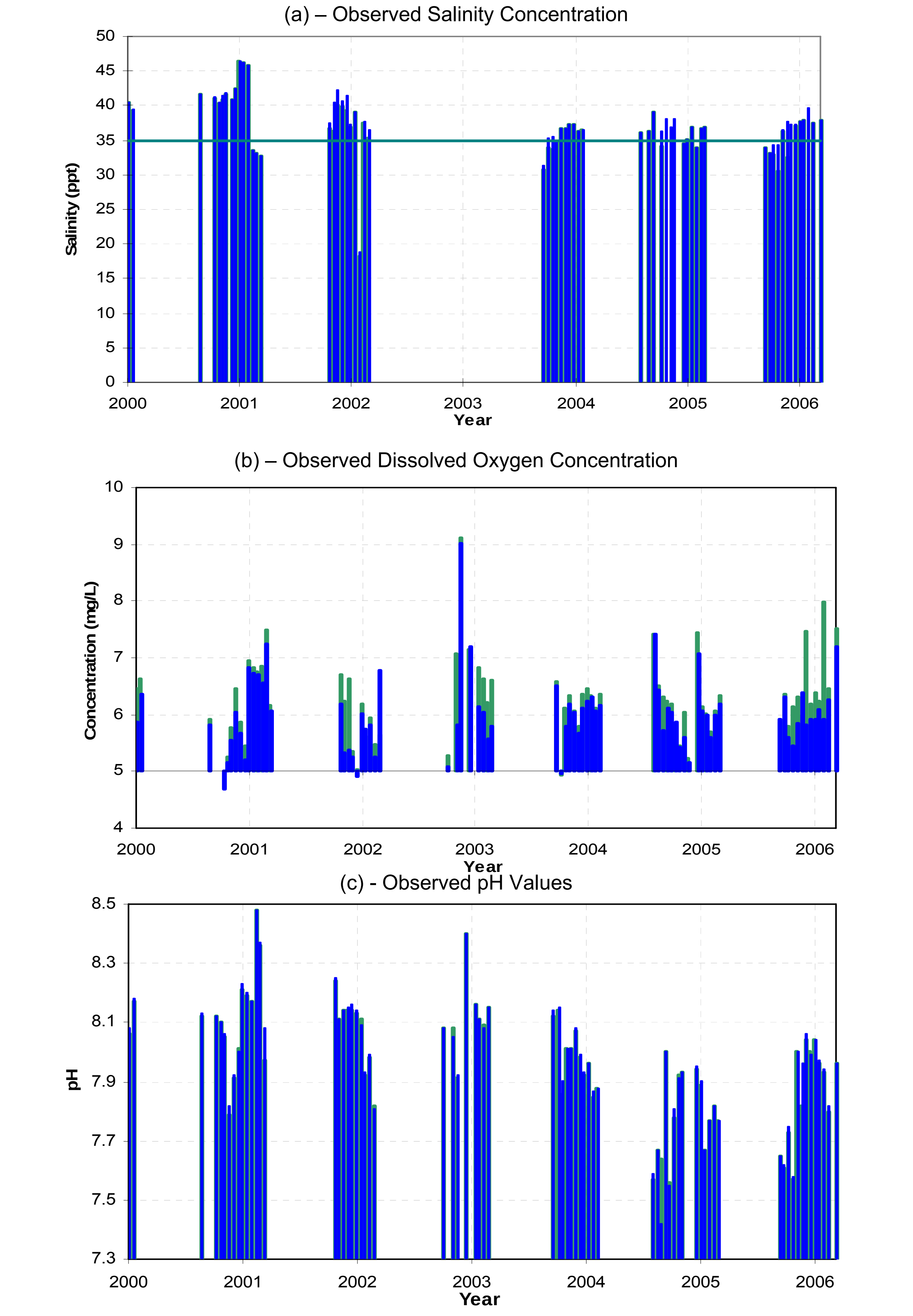


Figure 1.12. Graphical representation of the surface (green) and bottom (blue) physical data set for Estuary 4 between 2000 -2006. (a) time series plot of the salinity values in parts per thousand with standard seawater (35ppt) shown, (b) time series plot of Dissolved Oxygen concentration in milligrams per litre. Here the x-axis runs through the 5mg/L value which is the ANZECC guideline to estuarine health, above is considered healthy and below indicates reducing health and at 2mg/L or below, critical to ecology. (c) time series bar plot of observed pH values.

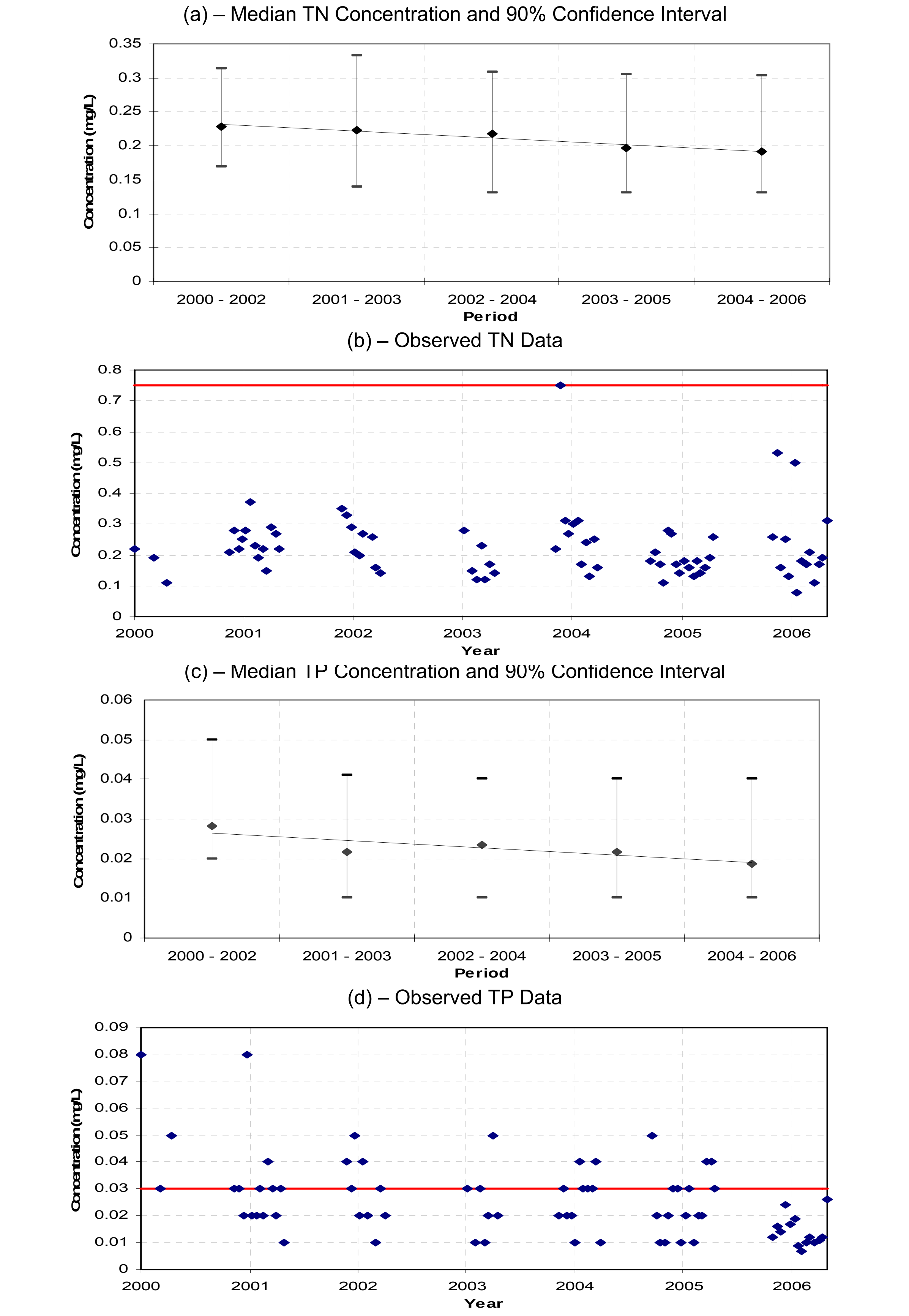


Figure 1.13. Total Nitrogen (TN) and Phosphorus (TP) analysis for Estuary 4 data set between 2000 - 2006 (a) three year moving median TN concentration with linear trend line (b) Observed TN concentrations with red line indicating ANZECC guideline for TN concentration in estuarine waters (0.75mg/L). (c) three year moving median TP concentration with linear trend line. (d) Observed TP concentrations with red line indicating ANZECC guideline for TP concentration in estuarine waters (0.03mg/L).

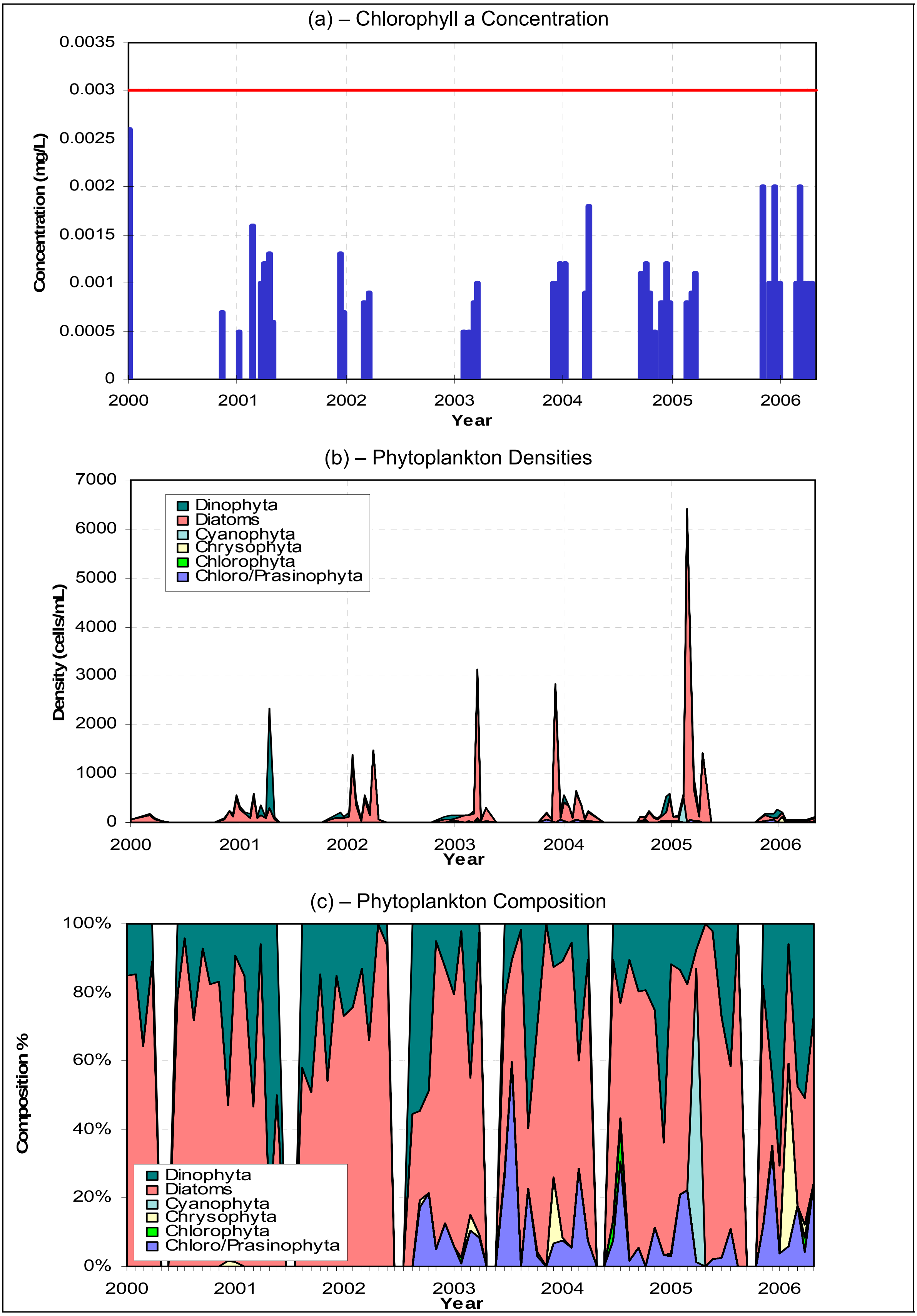


Figure 1.14. Graphical representation of biological activity in the Estuary 4 water column between 2000 – 2006. (a) Chlorophyll *a* concentrations (in mg/L) measured from a surface sample with the red line representing ANZECC guideline for chlorophyll *a* concentrations in estuarine waters (0.003mg/L). (b) Phytoplankton densities (in cells/mL) measured through integrated depth sample. (c) Phytoplankton composition (in % abundance) measured through an integrated depth sample. Please note: Density graphs are a combined total and should be assessed in conjunction with composition %.

1.2 Leschenault Estuary Cont'd

Site: Estuary 3. (North end) AWRC Code: 6121206

Parameter	Period	Status	Comment
TN	2000 – 2006	Low	No trend
TP	2000 – 2006	Low	No trend

During the study period from 2000 to 2006 there were 74 TN and TP samples taken at Estuary 3 sample site. This site is characterised by its location at the northern end of the estuary where it is very shallow and there is a lack of tidal exchange. On average, it has a depth of 0.5m.

Table 1.21. Total Nitrogen and Total Phosphorus Statistics for 6121206.

Statistic	Total Nitrogen	Total Phosphorus
Median	0.38	0.02
Average	0.38	0.0285
10^{th} %ile	0.26	0.01
90^{th} %ile	0.48	0.05
Lowest concentration	0.16	0.007
Highest concentration	0.8	0.09
Moving Median 2000-02	0.38	0.0283
2001-03	0.372	0.025
2002-04	0.387	0.0283
2003-05	0.387	0.025
2004-06	0.355	0.021

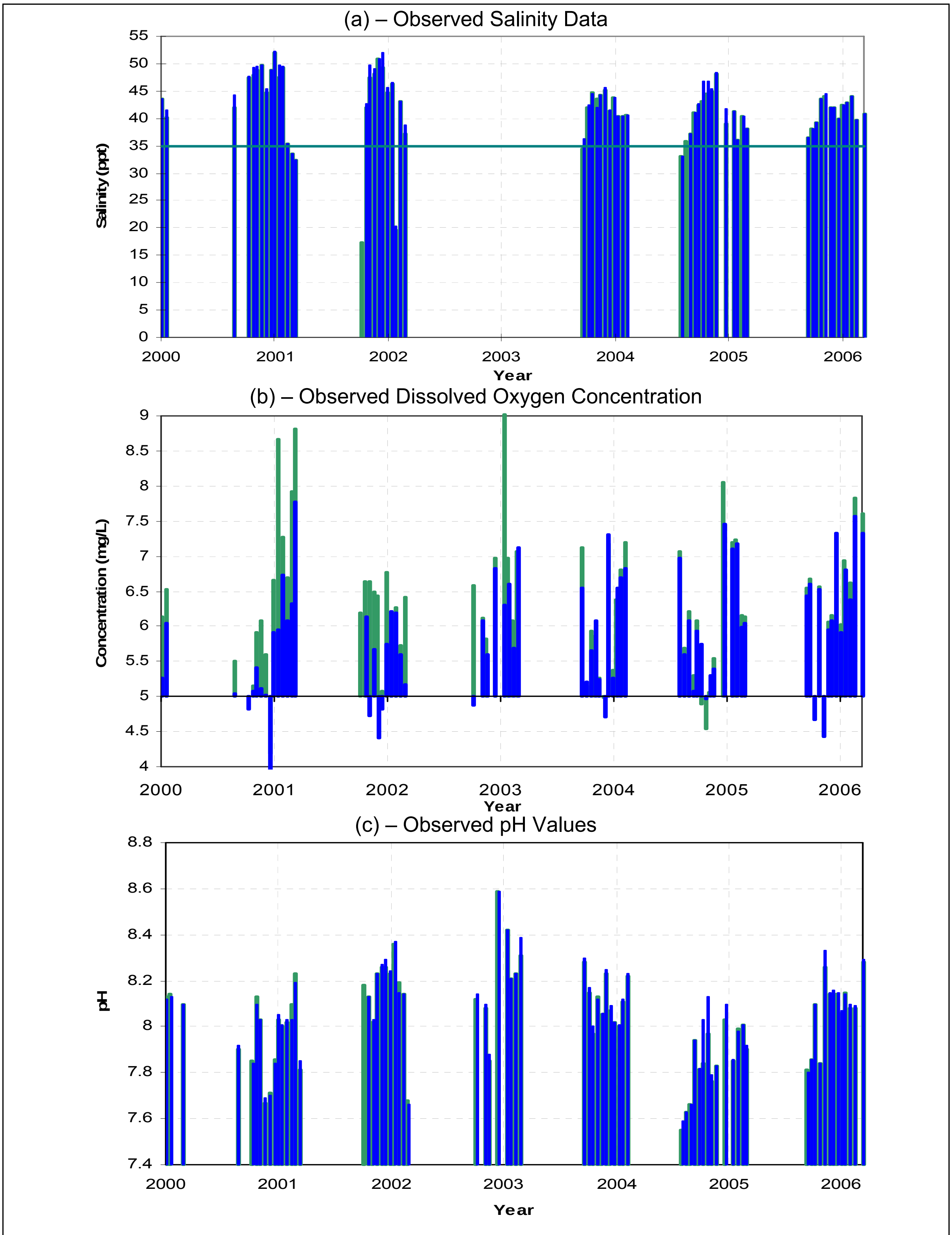


Figure 1.22 – Graphical representation of the surface (green) and bottom (blue) physical data set for Estuary 3 between 2000 -2006. (a) time series plot of the salinity values in parts per thousand with seawater standard (35ppt) shown, (b) time series plot of Dissolved Oxygen concentration in milligrams per litre. Here the x-axis runs through the 5mg/L value which is the ANZECC guideline to estuarine health, above is considered healthy and below indicates reducing health and at 2mg/L and below, critical to ecology. (c) time series bar plot of observed pH values.

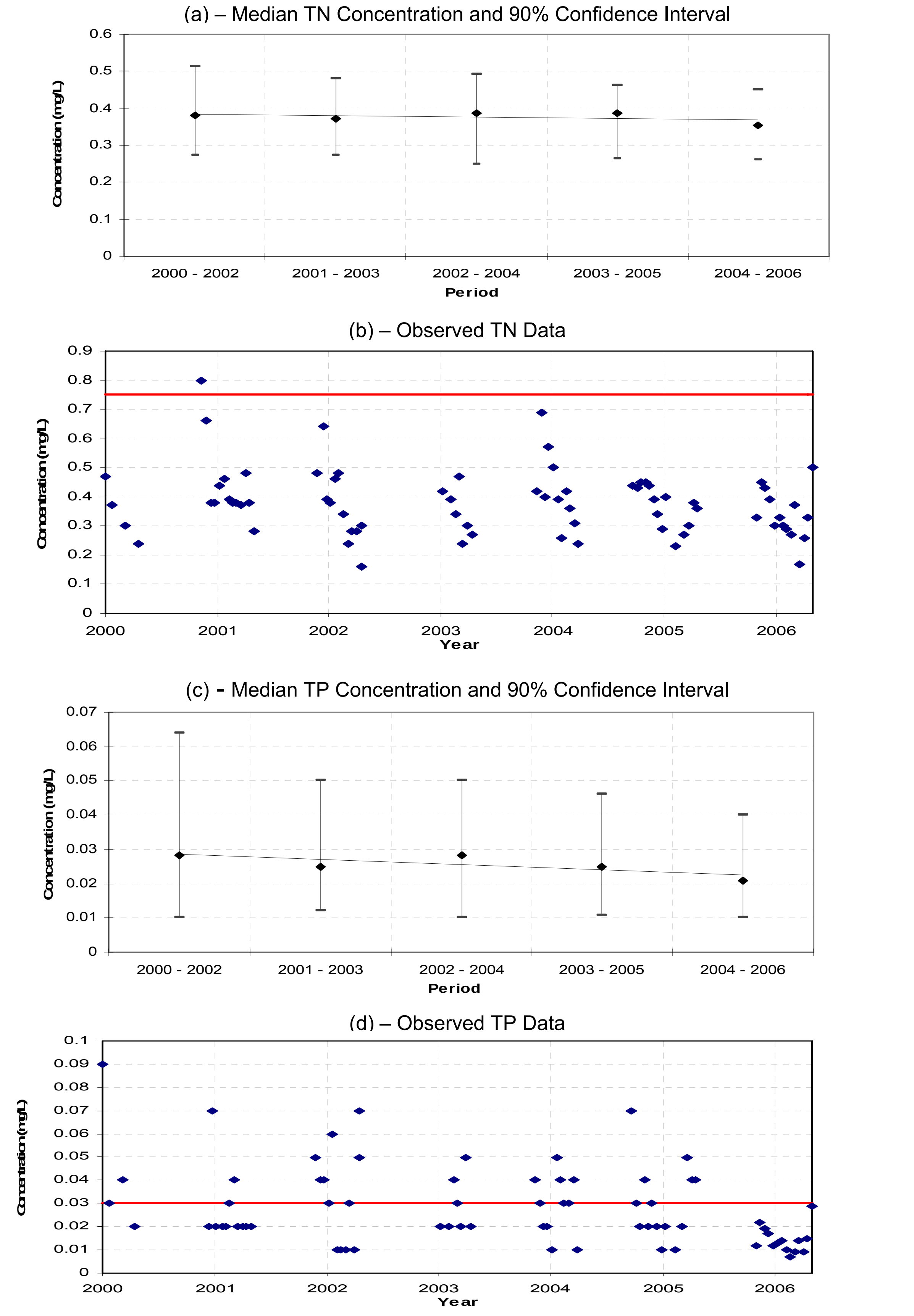


Figure 1.23 – Total Nitrogen (TN) and Phosphorus (TP) analysis for Estuary 3 data set between 2000 - 2006 (a) three year moving median TN concentration with linear trend line (b) Observed TN concentrations with red line indicating ANZECC guideline for TN concentration in estuarine waters (0.75mg/L). (c) three year moving median TP concentration with linear trend line. (d) Observed TP concentrations with red line indicating ANZECC guideline for TP concentration in estuarine waters (0.03mg/L).

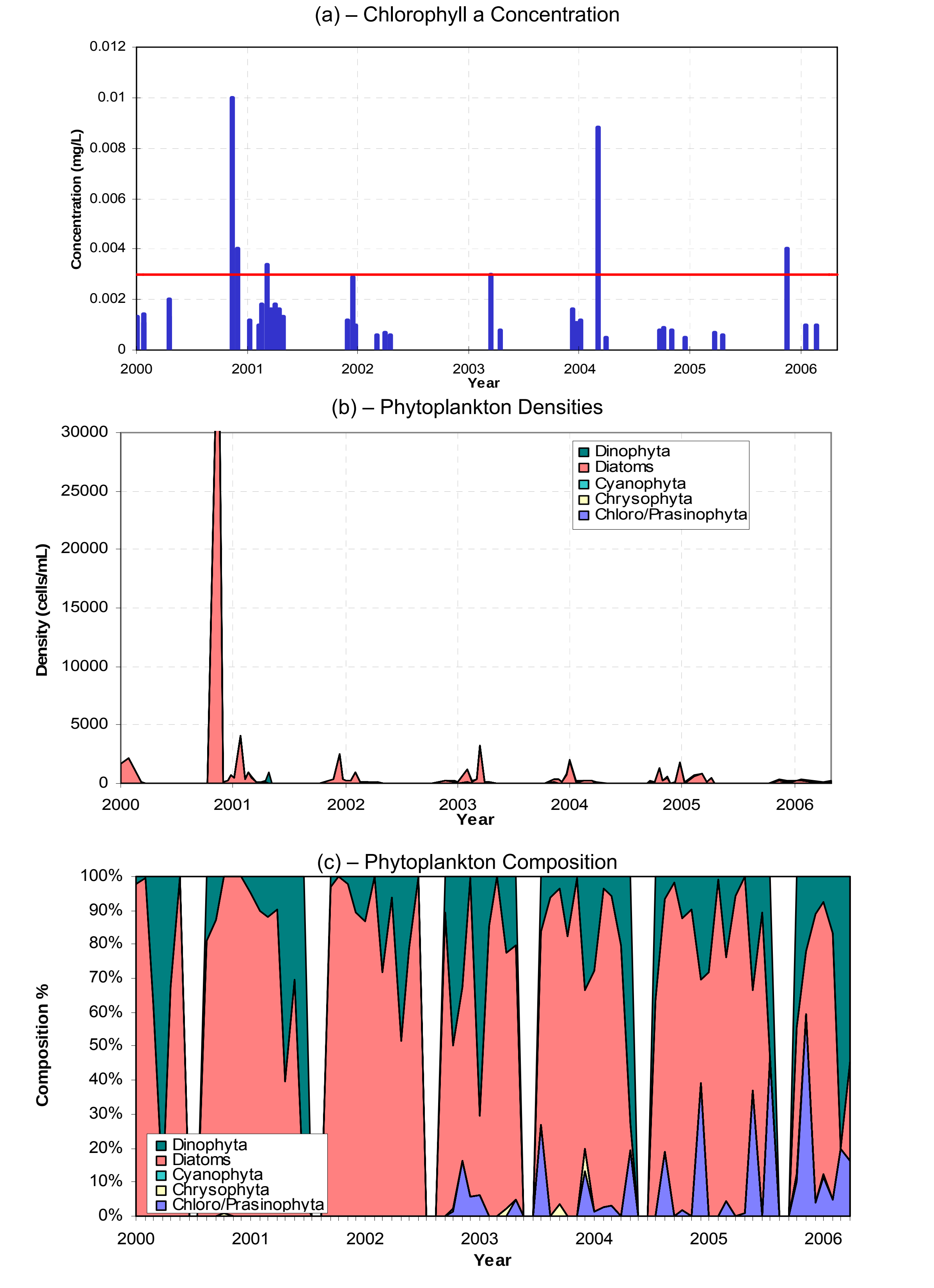


Figure 1.24. Graphical representation of biological activity in the Estuary 3 water column between 2000 – 2006.
(a) chlorophyll *a* concentrations (in mg/L) measured from a surface sample with the red line representing ANZECC guideline for chlorophyll *a* concentrations in estuarine waters (0.003mg/L). (b) Phytoplankton densities (in cells/mL) measured through integrated depth sample. (c) Phytoplankton composition (in % abundance) measured through an integrated depth sample. Please note: Density graphs are a combined total and should be used with composition %.

1.3 Preston River

Site: Preston 1 (Estuary Drive). AWRC Code: 6111043

Parameter	Period	Status	Comment
TN	2000 - 2006	Low	No trend
TP	2000 - 2006	Moderate	Decreasing trend

During the study period from 2000 to 2006 there were 77 TN and TP samples taken at Preston 1 sample site. This site is characterised by its proximity to the estuary and relatively strong tidal exchange located under the Estuary Drive Bridge. On average, it has a depth of 1.0m.

Table 1.31. Total Nitrogen and Total Phosphorus Statistics for 6111043.

Statistic	Total Nitrogen	Total Phosphorus
Median	0.45	0.04
Average	0.466	0.0403
10th %ile	0.307	0.02
90th %ile	0.65	0.06
Lowest concentration	0.2	0.019
Highest concentration	0.97	0.1
Moving Median 2000-02	0.465	0.0467
2001-03	0.463	0.045
2002-04	0.442	0.0467
2003-05	0.415	0.04
2004-06	0.443	0.0352

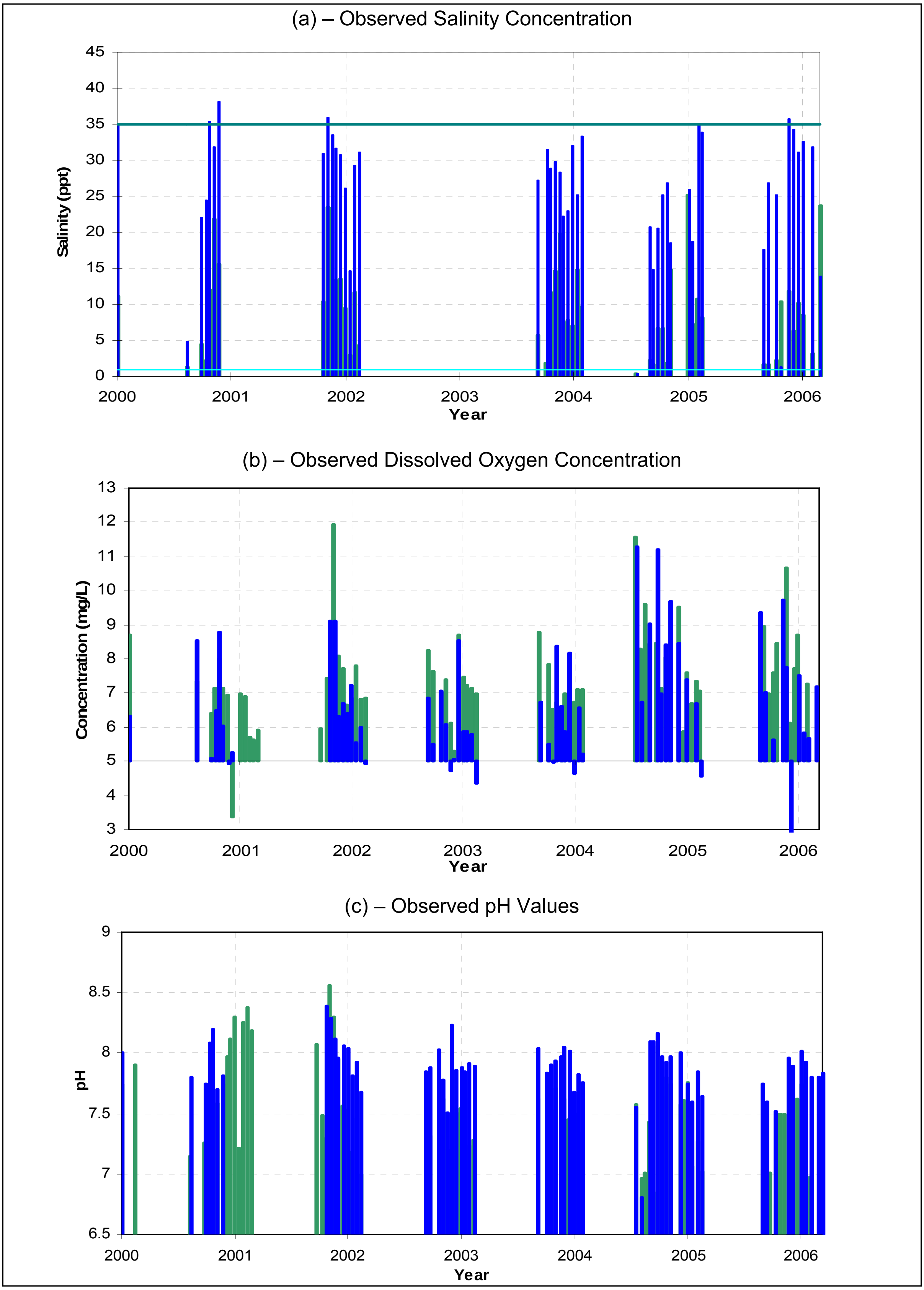


Figure 1.32. Graphical representation of the surface (green) and bottom (blue) physical data set for Preston 1 between 2000 -2006. (a) time series plot of the salinity values in parts per thousand with seawater (35ppt) and freshwater (0.8ppt) standards shown. Areas of flat line represent periods of no data. (b) time series plot of Dissolved Oxygen concentration in milligrams per litre. Here the x-axis runs through the 5mg/L value which is the ANZECC guideline to estuarine health, above is considered healthy and below indicates reducing health and at 2mg/L or below, critical to ecology. (c) time series bar plot of observed pH values.

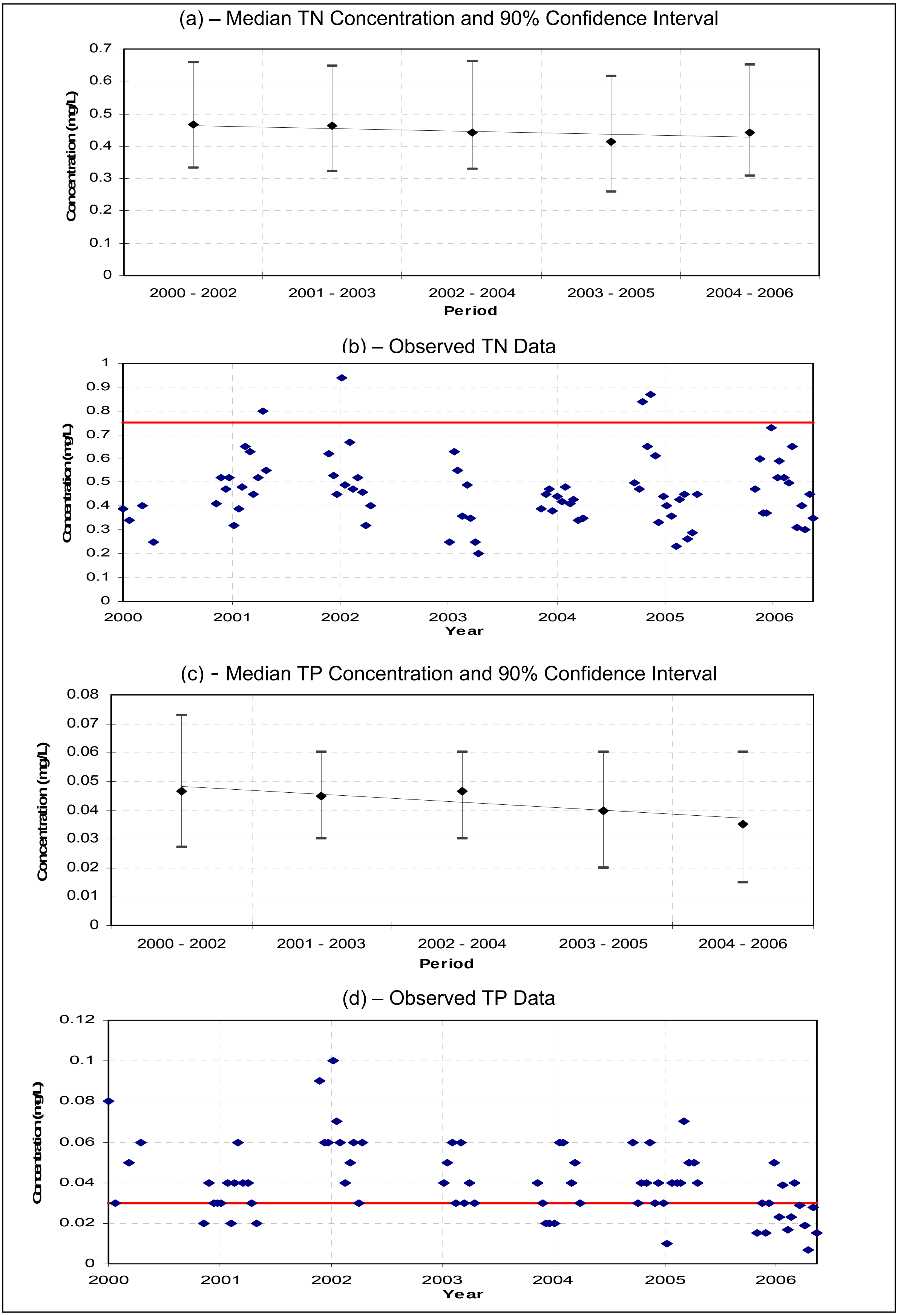


Figure 1.33. Total Nitrogen (TN) and Phosphorus (TP) analysis for Preston 1 data set between 2000 - 2006 (a) three year moving median TN concentration with linear trend line (b) Observed TN concentrations with red line indicating ANZECC guideline for TN concentration in estuarine waters (0.75mg/L). (c) three year moving median TP concentration with linear trend line. (d) Observed TP concentrations with red line indicating ANZECC guideline for TP concentration in estuarine waters (0.03mg/L).

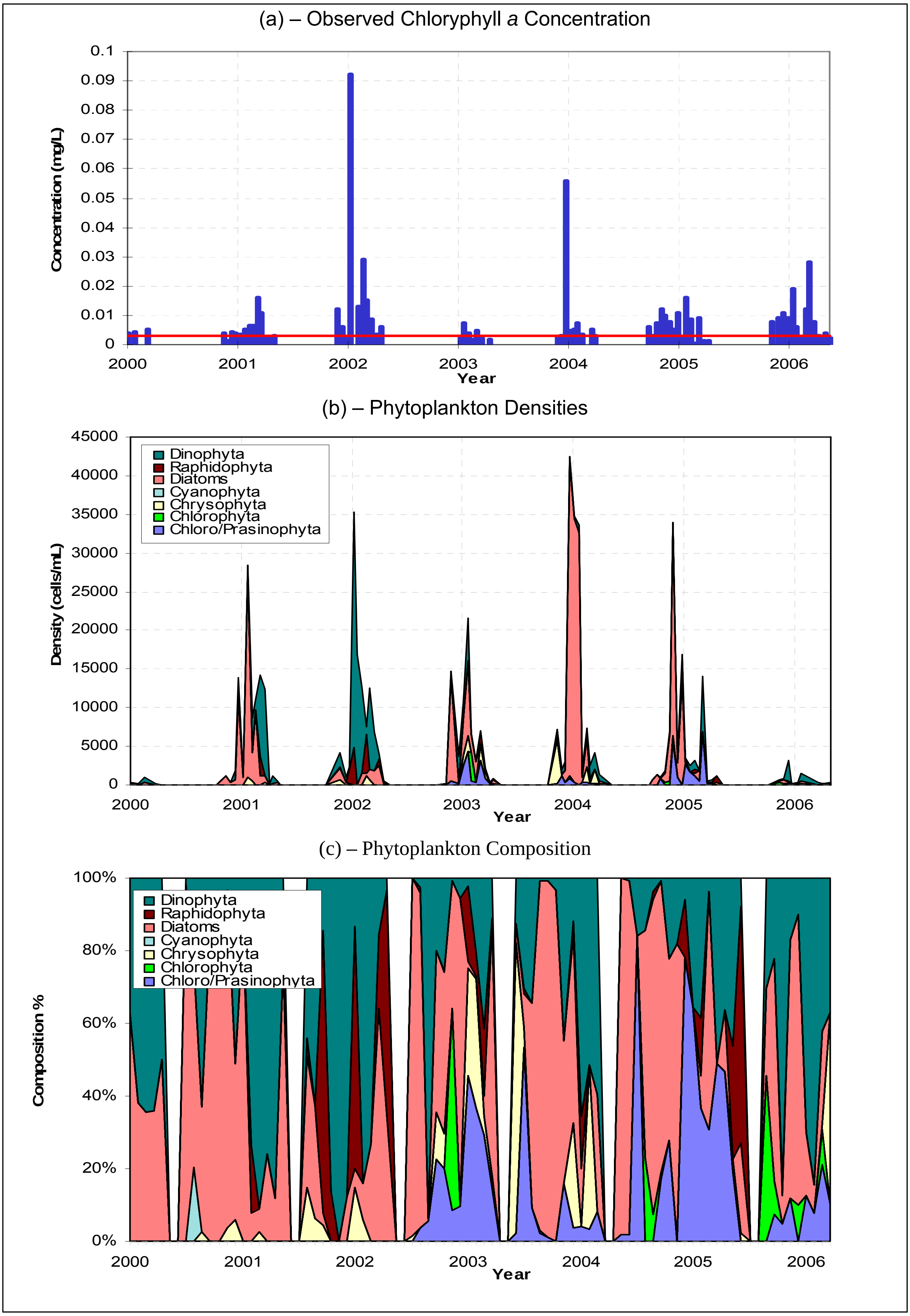


Figure 1.34. Graphical representation of biological activity in the Preston 1 water column between 2000 – 2006.
(a) chlorophyll *a* concentrations (in mg/L) measured from a surface sample with the red line representing ANZECC guideline for chlorophyll *a* concentrations in estuarine waters (0.003mg/L) (b) Phytoplankton densities (in cells/mL) measured through integrated depth sample. (c) Phytoplankton composition (in % abundance) measured through an integrated depth sample. Please note: Density graphs are a combined total and should be used with composition %.

1.4 Collie River

Site: Collie 2 (the elbow). AWRC Code: 6121166

Parameter	Period	Status	Comment
TN	2000 - 2006	Moderate	No trend
TP	2000 - 2006	High	Decreasing trend

During the study period from 2000 to 2006 there were 78 TN and TP samples taken at Collie 2 sample site. This site is characterised by its location on 'the elbow' of the Collie River just downstream of the confluence of the Brunswick River and is generally stratified with tidal marine bottom waters and fresh over laying waters at the surface. On average, it has a depth of 4.0m.

Table 1.41. Total Nitrogen and Total Phosphorus Statistics for 6121166.

Statistic	Total Nitrogen	Total Phosphorus
Median	0.878	0.0834
Average	0.82	0.08
10^{th} %ile	0.548	0.04
90^{th} %ile	1.2	0.133
Lowest concentration	0.32	0.019
Highest concentration	3.2	0.22
Moving Median 2000-02	0.862	0.095
2001-03	0.9	0.0933
2002-04	0.9	0.08
2003-05	0.68	0.063
2004-06	0.748	0.0662

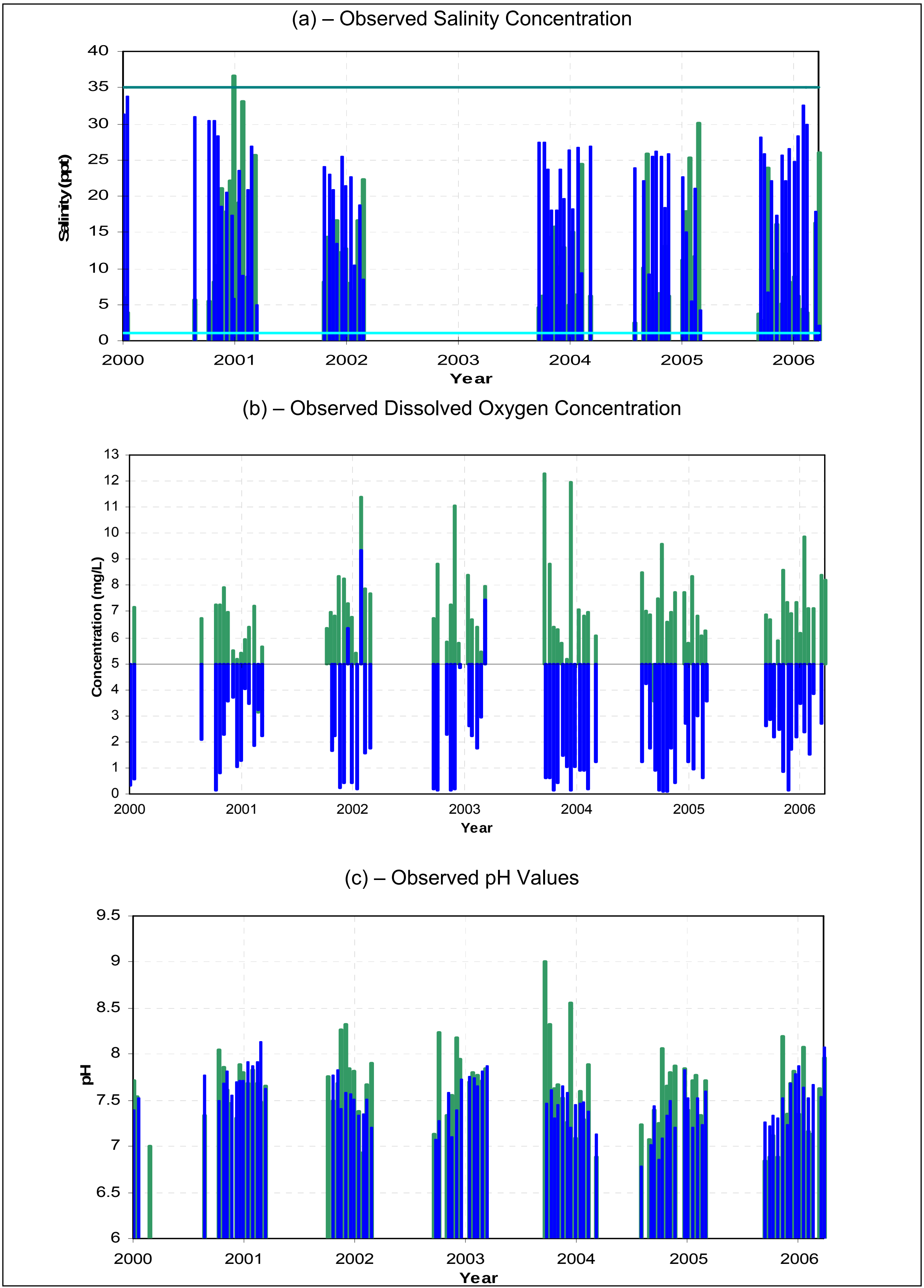


Figure 1.42. Graphical representation of the surface (green) and bottom (blue) physical data set for Collie 2 between 2000 -2006. (a) time series plot of the salinity values in parts per thousand with seawater (35ppt) and freshwater (0.8ppt) shown by aquamarine gridlines. (b) time series plot of Dissolved Oxygen concentration in milligrams per litre. Here the x-axis runs through the 5mg/L value which is the ANZECC guideline to estuarine health, above is considered healthy and below indicates reducing health and at 2mg/L critical to ecology. (c) time series bar plot of observed pH values.

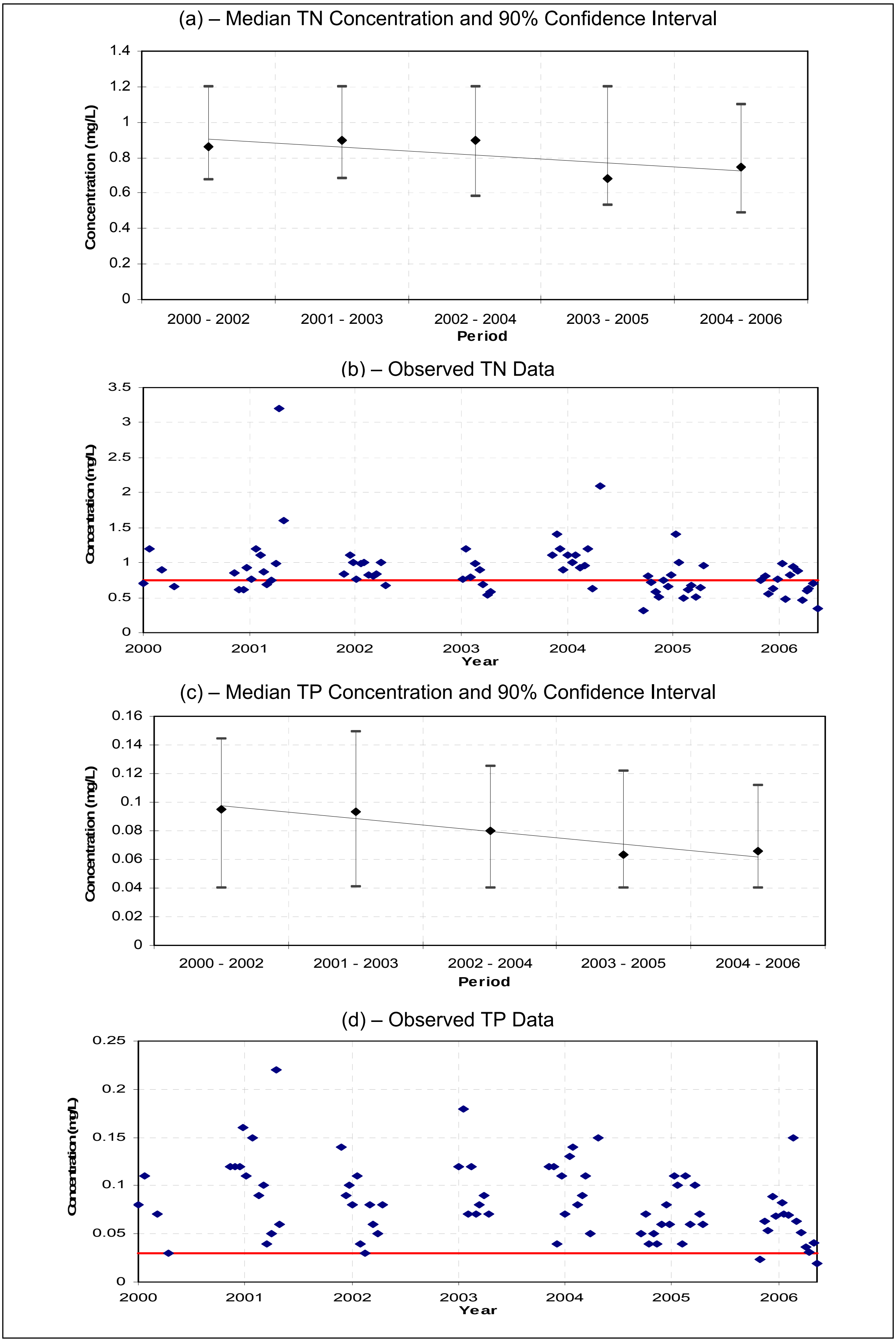


Figure 1.43. Total Nitrogen (TN) and Phosphorus (TP) analysis for Collie 2 data set between 2000 - 2006 (a) three year moving median TN concentration with linear trend line (b) Observed TN concentrations with red line indicating ANZECC guideline for TN concentration in estuarine waters (0.75mg/L). (c) three year moving median TP concentration with linear trend line. (d) Observed TP concentrations with red line indicating ANZECC guideline for TP concentration in estuarine waters (0.03mg/L).

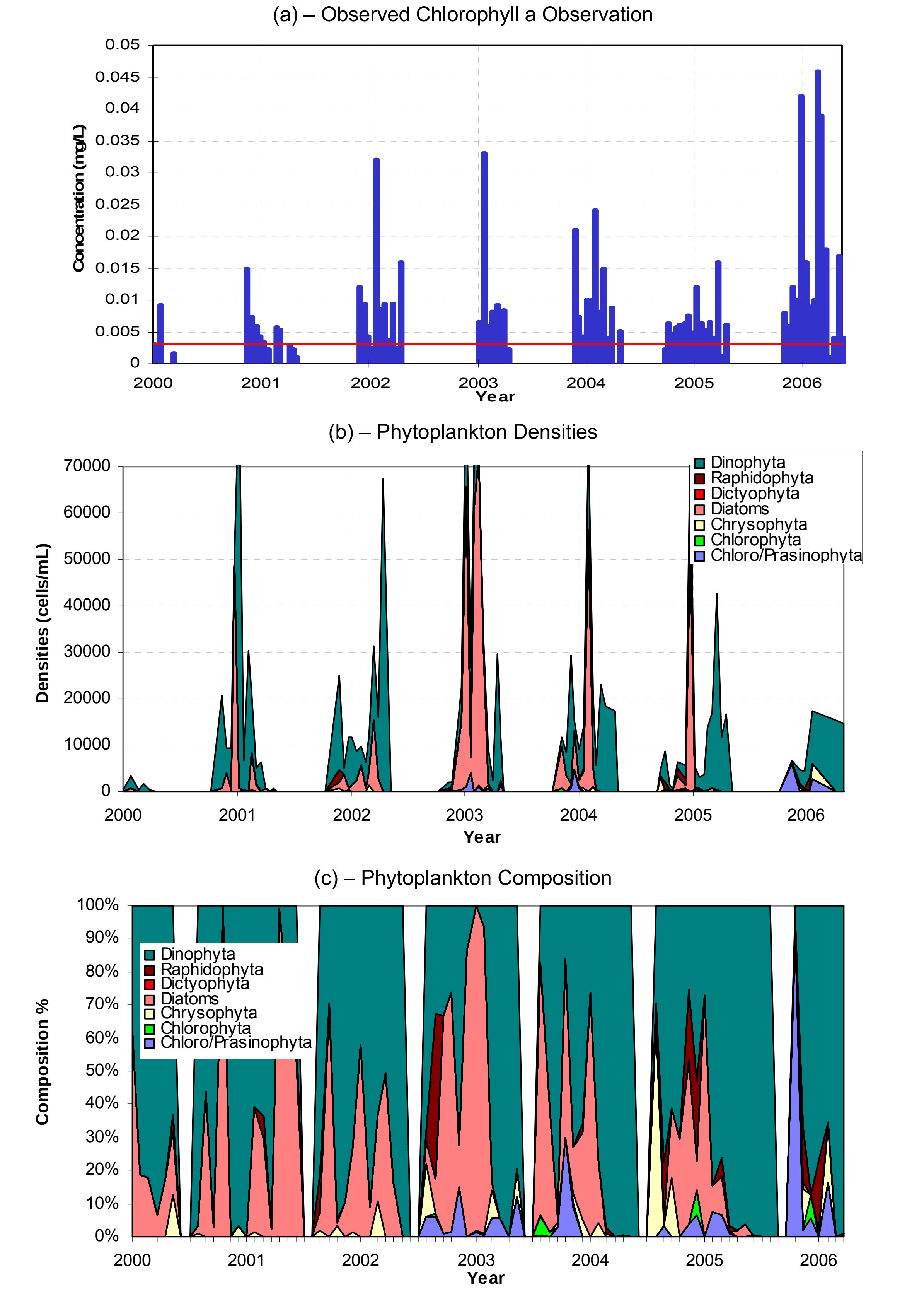


Figure 1.44. Graphical representation of biological activity in the Collie 2 water column between 2000 – 2006.
(a) chlorophyll *a* concentrations (in mg/L) measured from a surface sample with the red line representing ANZECC guideline for chlorophyll *a* concentrations in estuarine waters (0.003mg/L) (b) Phytoplankton densities (in cells/mL) measured through integrated depth sample. (c) Phytoplankton composition (in % abundance) measured through an integrated depth sample. Please note: Density graphs are a combined total and should be used with composition %.

1.5 Brunswick River

Site: Brunswick 1 (near confluence of Collie). AWRC Code: 6121161

Parameter	Period	Status	Comment
TN	2000 – 2003 2004 - 2006	**High**	No Trend
TP	2000 – 2003 2004 - 2006	**High**	No Trend

During the study period from 2000 to 2006 there were 56 TN and TP samples taken at Brunswick 1 sample site. This site is characterised by its proximity to the confluence of the Collie River and in recent years a very shallow sand bar has formed making boat access difficult. On average, it has a depth of 0.5m.

Table 1.51. Total Nitrogen and Total Phosphorus Statistics for 6121161.

Statistic		Total Nitrogen	Total Phosphorus
Median		0.99	0.1
Average		1.140	0.112
10^{th} %ile		0.778	0.055
90^{th} %ile		1.8	0.2
Lowest concentration		0.56	0.028
Highest concentration		3.1	0.33
Moving Median	2000-02	1.06	0.105
	2001-03		
	2002-04		
	2003-05		
	2004-06	0.943	0.0938

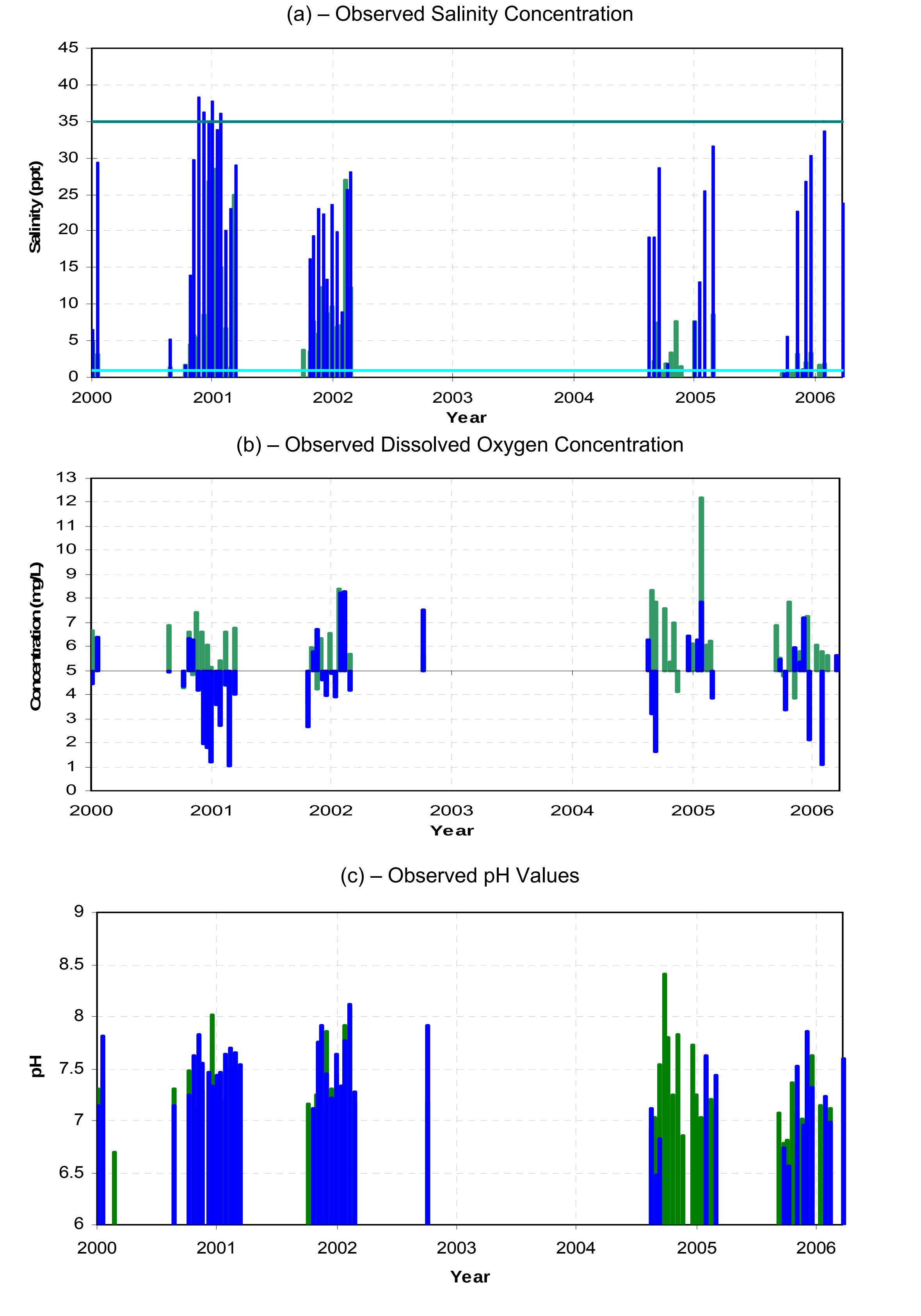


Figure 1.52. Graphical representation of the surface (green) and bottom (blue) physical data set for Brunswick 1 between 2000 -2006. (a) time series plot of the salinity values in parts per thousand with seawater (35ppt) and freshwater (0.8ppt) shown by aquamarine gridlines. (b) time series plot of Dissolved Oxygen concentration in milligrams per litre. Here the x-axis runs through the 5mg/L value which is the ANZECC guideline to estuarine health, above is considered healthy and below indicates reducing health and at 2mg/L critical to ecology. (c) time series bar plot of observed pH values.

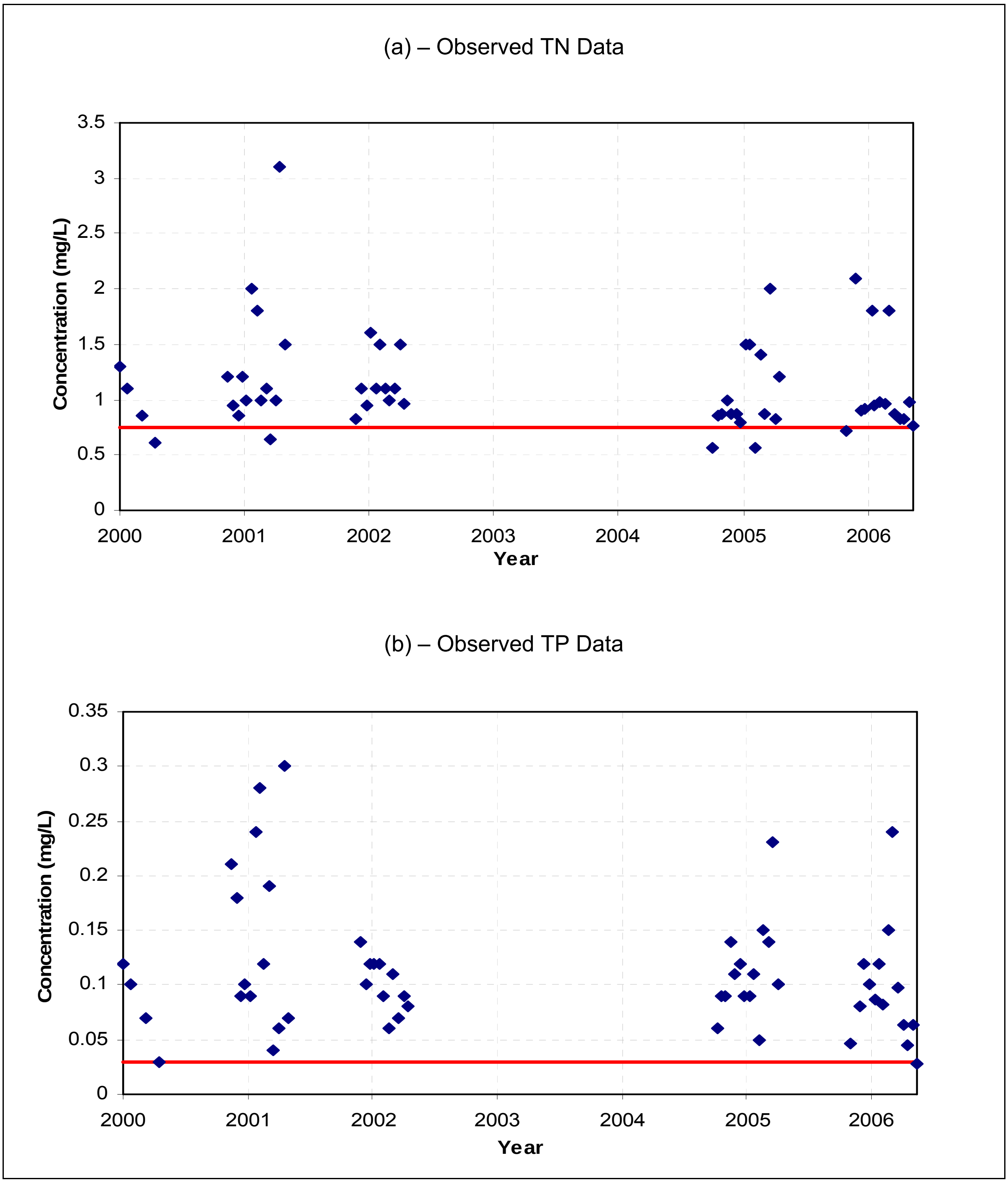


Figure 1.53. Total Nitrogen (TN) and Phosphorus (TP) analysis for Brunswick 1 data set between 2000 - 2006 (a) three year moving median TN concentration with linear trend line (b) Observed TN concentrations with red line indicating ANZECC guideline for TN concentration in estuarine waters (0.75mg/L). (c) three year moving median TP concentration with linear trend line. (d) Observed TP concentrations with red line indicating ANZECC guideline for TP concentration in estuarine waters (0.03mg/L).

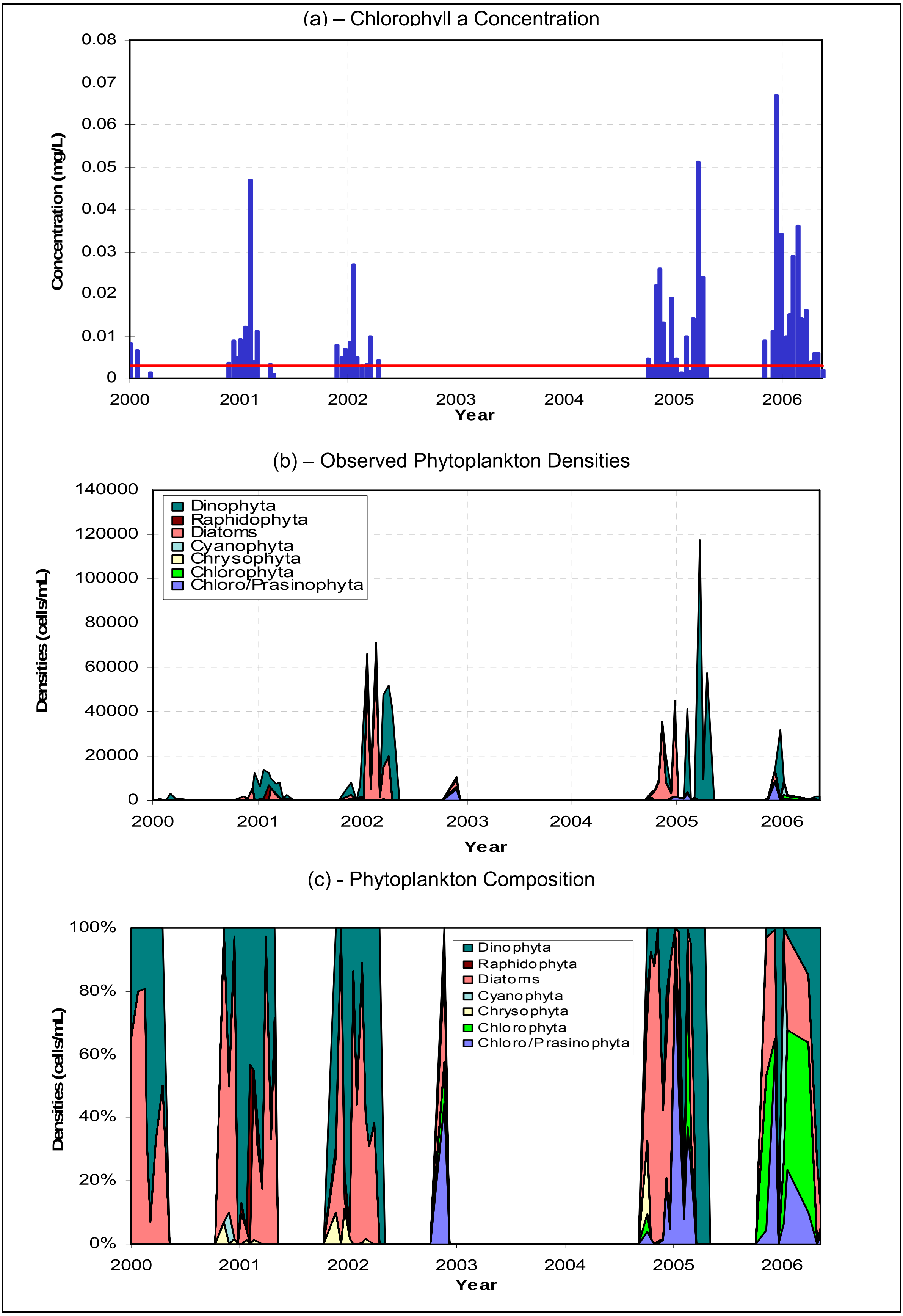


Figure 1.54. Graphical representation of biological activity in the Brunswick 1 water column between 2000 – 2006. (a) chlorophyll *a* concentrations (in mg/L) measured from a surface sample with the red line representing ANZECC guideline for chlorophyll *a* concentrations in estuarine waters. (b) Phytoplankton densities (in cells/mL) measured through integrated depth sample. (c) Phytoplankton composition (in % abundance) measured through an integrated depth sample. Please note: Density graphs are a combined total and should be used with composition %.

1.6 Brunswick River (continued)

Site: Brunswick 2 (Paris Rd Bridge). AWRC Code: 6121162

Parameter	Period	Status	Comment
TN	2000 2003 - 2006	**High**	No trend
TP	2000 2003 - 2006	**High**	No trend

During the study period from 2000 to 2006 there were 55 TN and TP samples taken at Brunswick 2 sample site. This site is characterised by its distance from the estuary itself and is located under the Paris Road Bridge in Australind. On average, it has a depth of 0.5m.

Table 1.61. Total Nitrogen and Total Phosphorus Statistics for 6121162.

Statistic		Total Nitrogen	Total Phosphorus
Median		1.33	0.124
Average		1.12	0.12
10^{th} %ile		0.775	0.0545
90^{th} %ile		2	0.18
Lowest concentration		0.53	0.02
Highest concentration		4.7	0.27
Moving Median	2000-02		
	2001-03		
	2002-04		
	2003-05	1.25	0.117
	2004-06	1.2	0.113

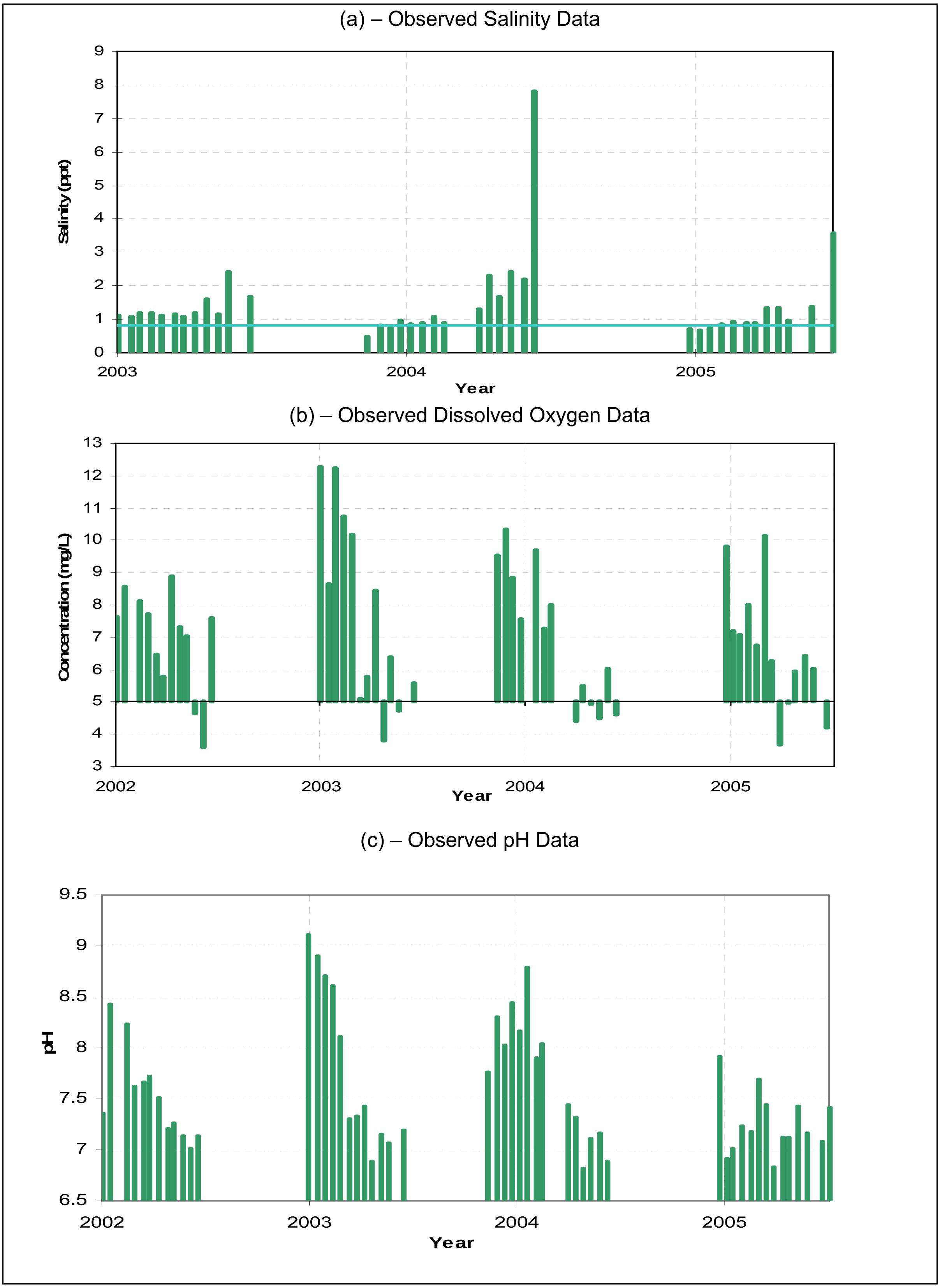


Figure 1.62. Graphical representation of the surface (green) physical data set for Brunswick 2 between 2000 -2006. (a) time series plot of the salinity values in parts per thousand with freshwater (0.8ppt) shown by aquamarine gridlines. (b) time series plot of Dissolved Oxygen concentration in milligrams per litre. Here the x-axis runs through the 5mg/L value which is the ANZECC guideline to estuarine health, above is considered healthy and below indicates reducing health and at 2mg/L or below, critical to ecology. (c) time series bar plot of observed pH values.

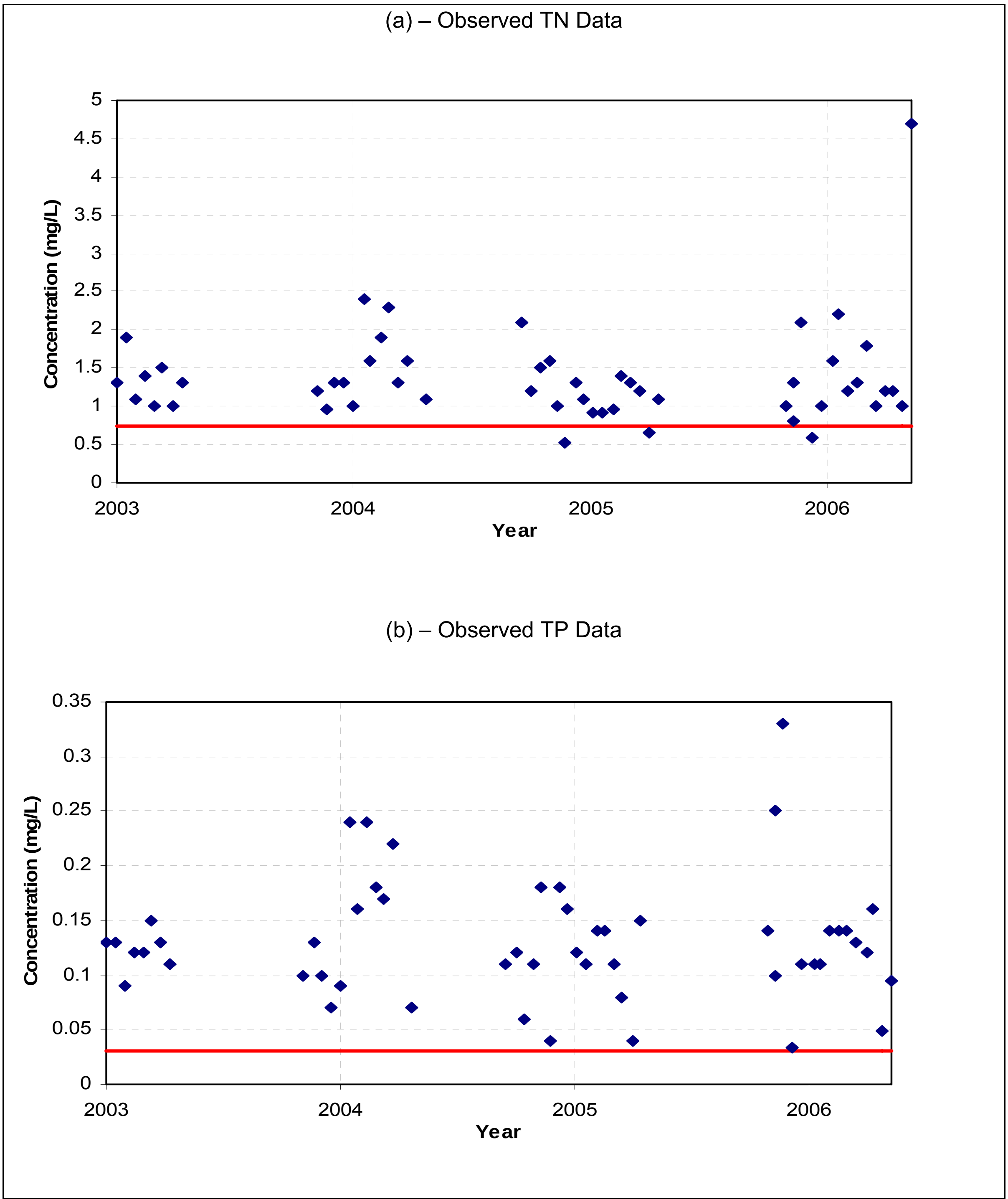


Figure 1.63. Total Nitrogen (TN) and Phosphorus (TP) analysis for Brunswick 1 data set between 2000 - 2006 (a) three year moving median TN concentration with linear trend line (b) Observed TN concentrations with red line indicating ANZECC guideline for TN concentration in estuarine waters (0.75mg/L). (c) three year moving median TP concentration with linear trend line. (d) Observed TP concentrations with red line indicating ANZECC guideline for TP concentration in estuarine waters (0.03mg/L).

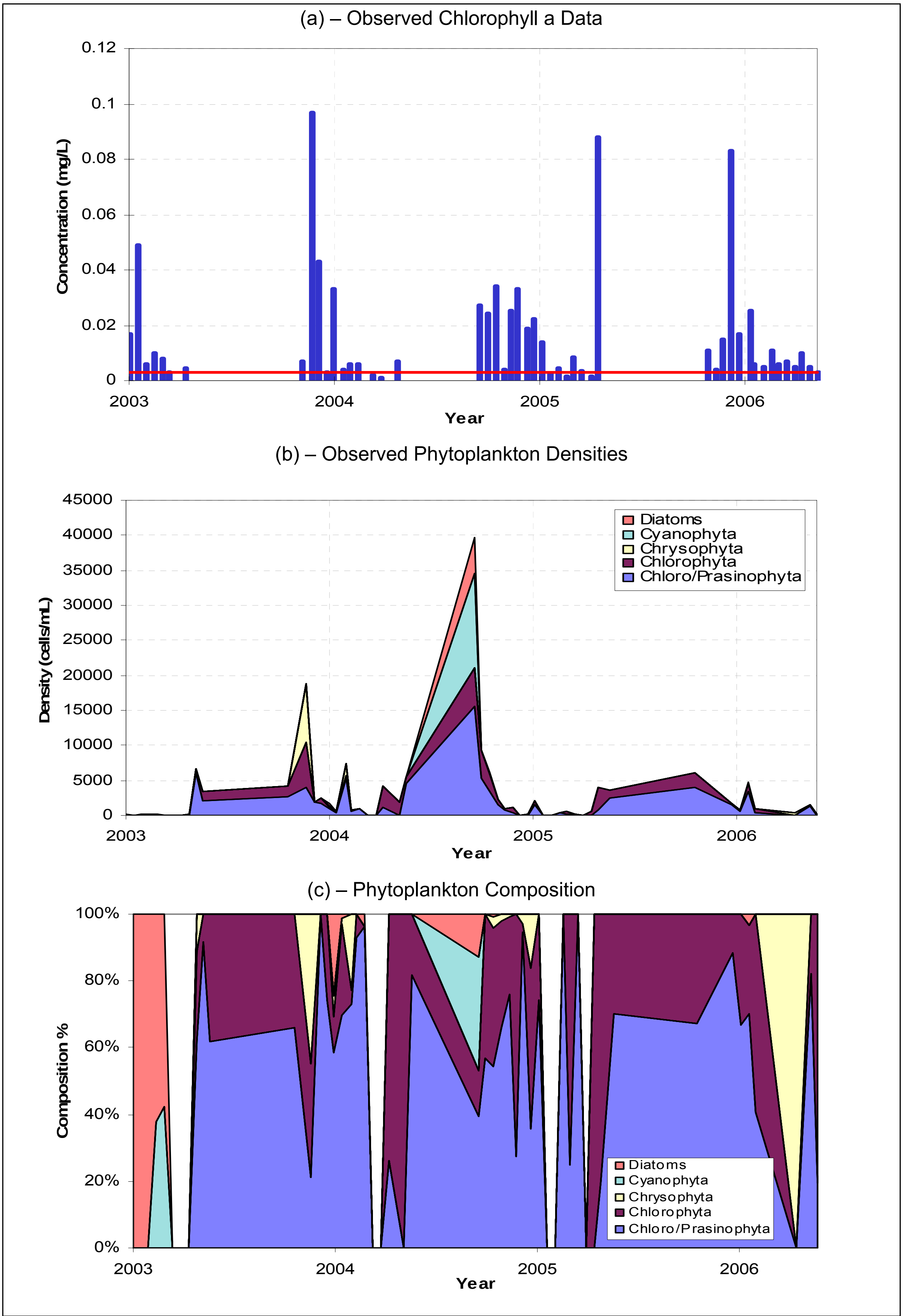


Figure 1.64. Graphical representation of biological activity in the Brunswick 1 water column between 2000 – 2006. (a) chlorophyll *a* concentrations (in mg/L) measured from a surface sample with the red line representing ANZECC guideline for chlorophyll *a* concentrations in estuarine waters. (b) Phytoplankton densities (in cells/mL) measured through integrated depth sample. (c) Phytoplankton composition (in % abundance) measured through an integrated depth sample. Please note: Density graphs are a combined total and should be used with composition %.

1.7 Parkfield Drain

Site: Parkfield 1. AWRC Code: 6121173

Parameter	Period	Status	Comment
TN	2000 - 2006	High	No significant trend
TP	2000 - 2006	Moderate	Decreasing trend

During the study period from 2000 to 2006 there were 77 TN and TP samples taken at Parkfield Drain sample site. This site is characterised by its location at the northern most end of the estuary draining the coastal plain to the north. On average, it has a depth of 0.5m and discharge is through a one-way valve.

Table 1.71. Total Nitrogen and Total Phosphorus Statistics for 6121207.

Statistic		Total Nitrogen	Total Phosphorus
Median		1.2	0.07
Average		1.2	0.0823
10^{th} %ile		0.687	0.0312
90^{th} %ile		1.93	0.144
Lowest concentration		0.47	0.02
Highest concentration		2.8	0.27
Moving Median	2000-02	1.25	0.09
	2001-03	1.22	0.075
	2002-04	1.18	0.0733
	2003-05	1.08	0.0632
	2004-06	1.16	0.0635

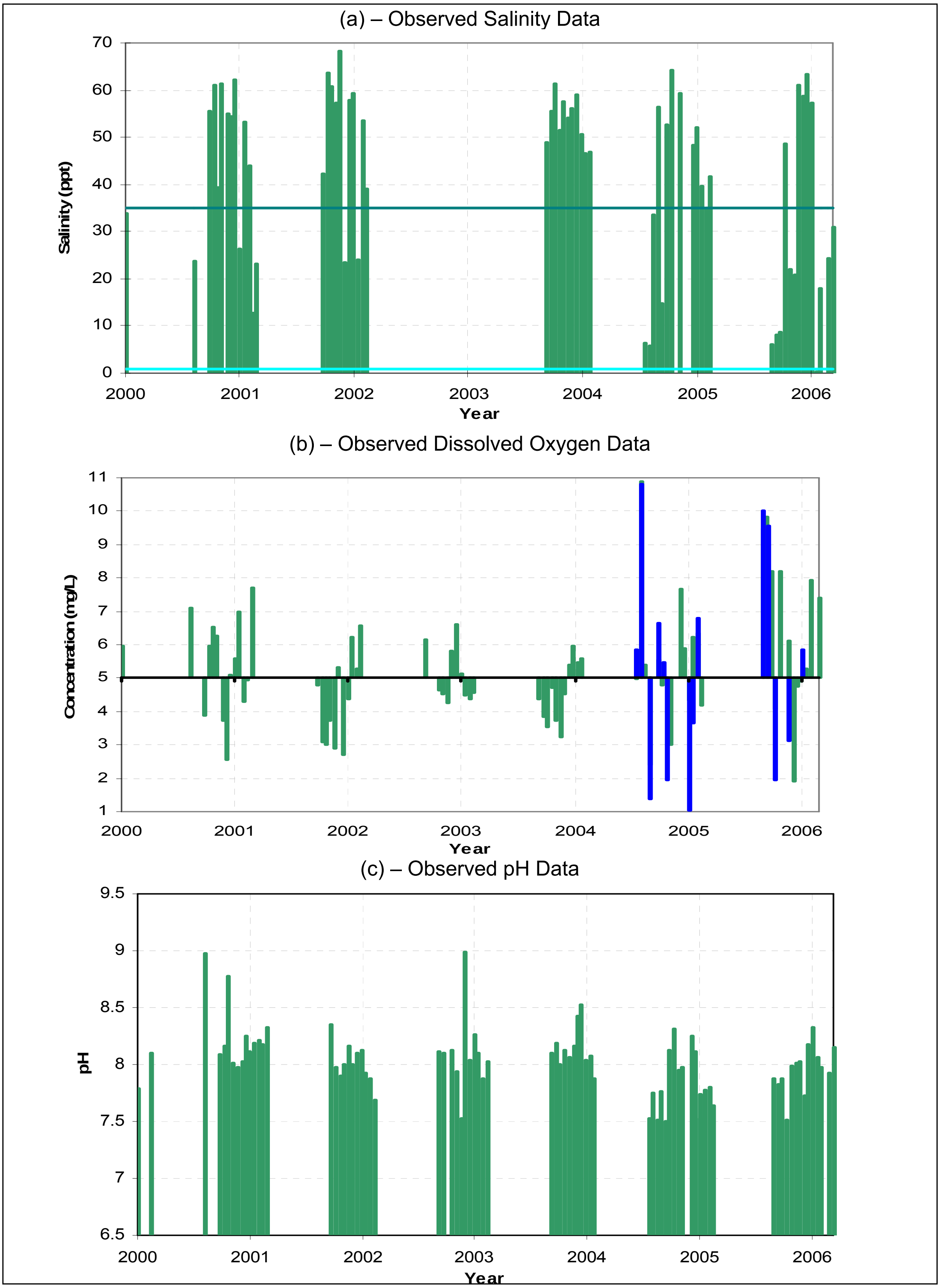


Figure 1.72. Graphical representation of the surface (green) and bottom (blue) physical data set for Parkfield 1 between 2000 -2006. (a) time series bar plot of the salinity values in parts per thousand with seawater (35ppt) shown by aquamarine gridlines (b) is a time series plot of Dissolved Oxygen concentration in milligrams per litre. Here the x-axis runs through the 5mg/L value which is the ANZECC guideline to estuarine health, above is considered healthy and below indicates reducing health and at 2mg/L critical to ecology. (c) time series bar plot of observed pH values.

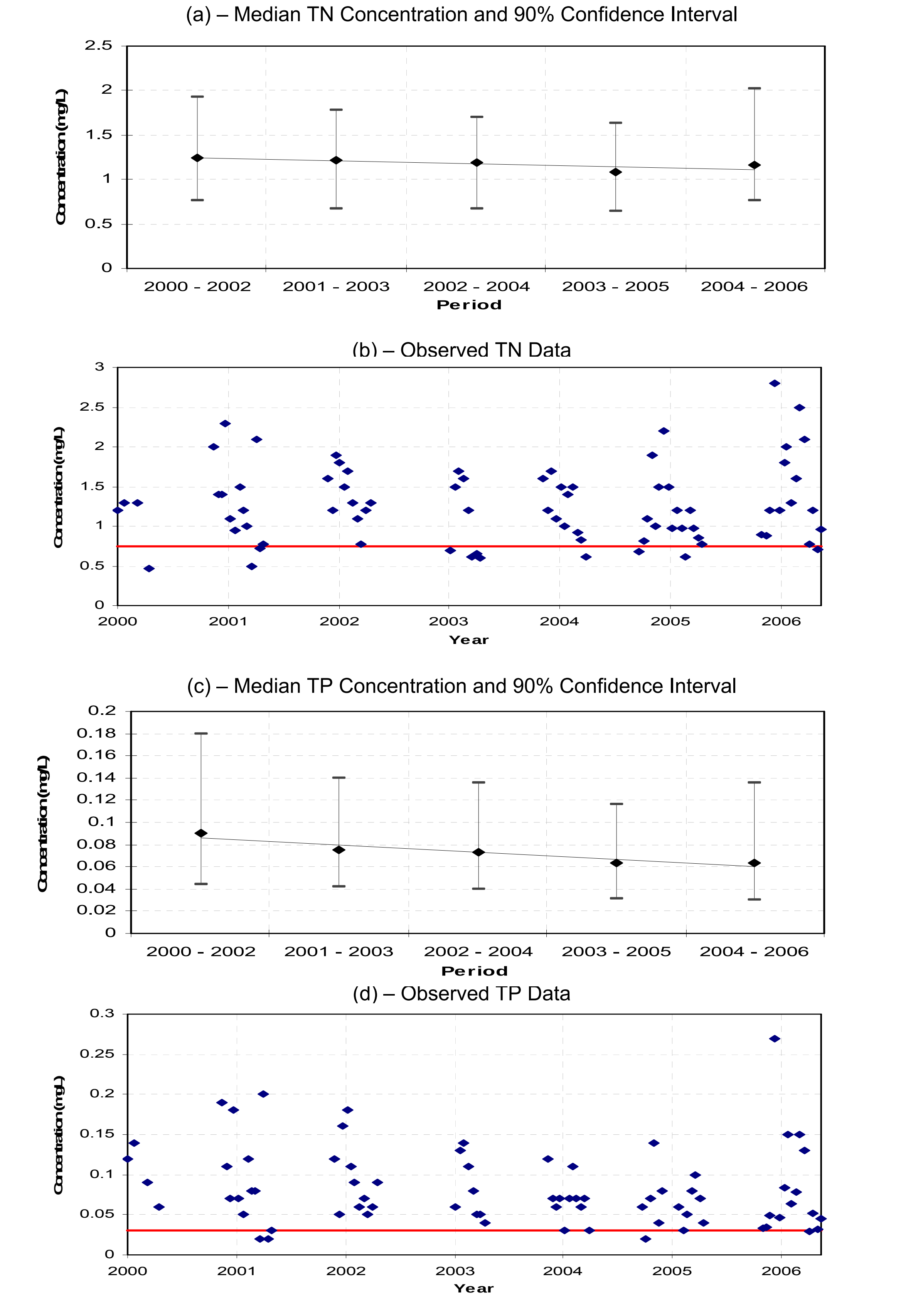


Figure 1.73. Total Nitrogen (TN) and Phosphorus (TP) analysis for Parkfield 1 set between 2000 - 2006 (a) three-year moving median TN concentration with linear trend line (b) Observed TN concentrations with red line indicating ANZECC guideline for TN concentration in estuarine waters (0.75mg/L). (c) three year moving median TP concentration with linear trend line. (d) Observed TP concentrations with red line indicating ANZECC guideline for TP concentration in estuarine waters (0.03mg/L).

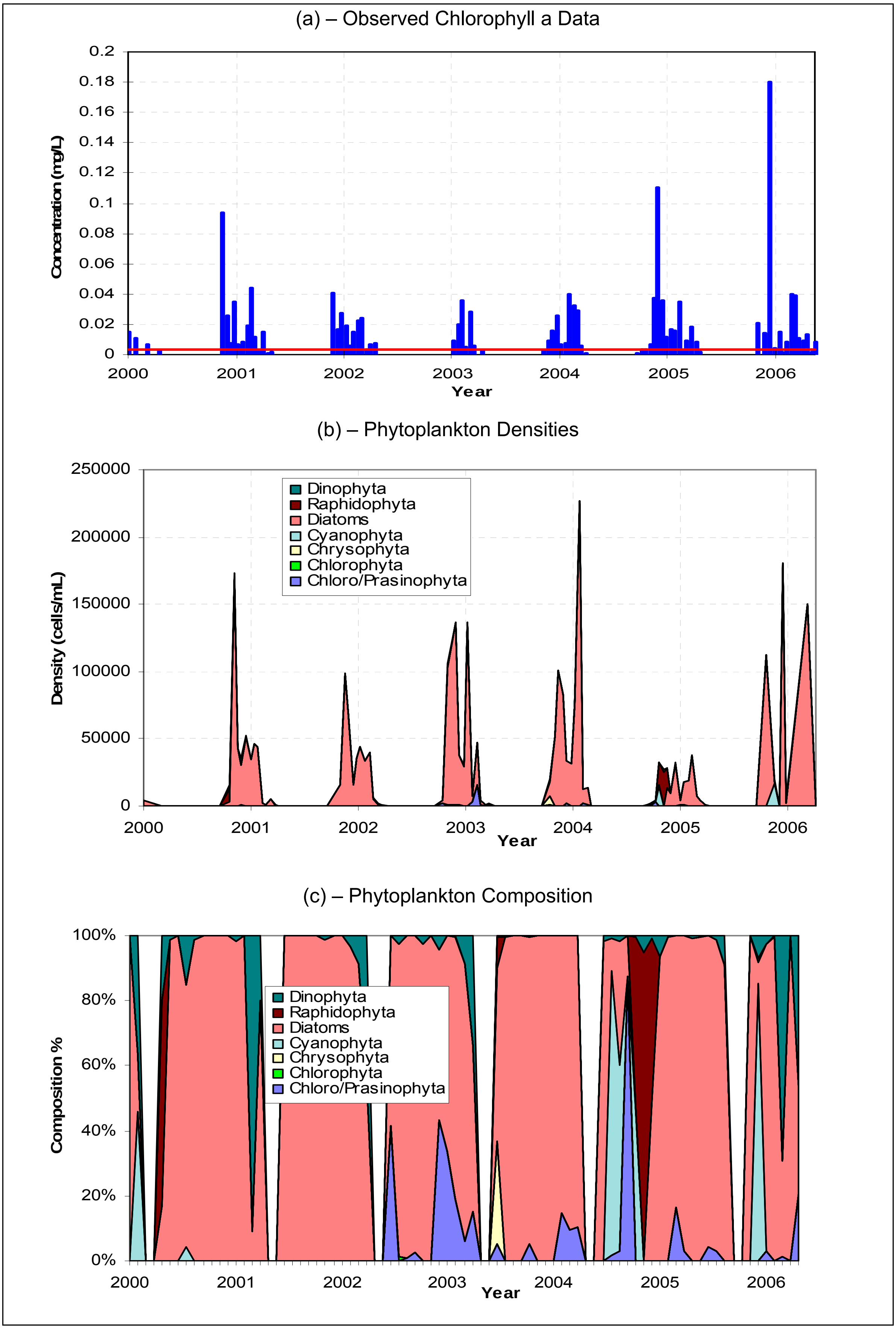


Figure 1.74. Graphical representation of biological activity in the Parkfield 1 water column between 2000 – 2006. (a) chlorophyll *a* concentrations (in mg/L) measured from a surface sample with the red line representing ANZECC guideline for chlorophyll *a* concentrations in estuarine waters. (b) Phytoplankton densities (in cells/mL) measured through integrated depth sample. (c) Phytoplankton composition (in % abundance) measured through an integrated depth sample. Please note: Density graphs are a combined total and should be used with composition %.

Discussion

Salinity

The Leschenault estuarine system, including the natural water courses of the Collie and Brunswick Rivers, the modified water course of the Preston River and the artificial discharge from the Parkfield Drain experiences high variability in salinities that range between predominantly fresh (0.4ppt) to hypersaline conditions (60ppt) over the 2000 to 2006 sampling period (Figures 1.22 – 1.72). This variability exhibited between and within waterways is a reflection of the relative contribution of a number of factors including rainfall, evaporation, catchment runoff and marine water flushing associated with 'the Cut'.

The Leschenault Estuary's permanent connection to the ocean via 'the Cut' results in estuarine salinities in the lower estuary; and lower river reaches are dominated by seasonal fringing and catchment freshwater inflows during the winter and marine tidal exchange in the summer months.

Minimal stratification of lower Leschenault Estuary waters is observed, with nominal differences in both physical and chemical parameters between surface and bottom waters, due to its shallow nature and mixing of the water column by prevailing winds. In contrast, hypersaline conditions are experienced in the northern end of the estuary (Est3) each year (Figure 1.32) due to its shallow nature, lack of strong tidal exchange and evaporation.

The lower Leschenault riverine reaches experience fresh flushing flows off the catchment during the winter months but as summer progresses stratification begins to develop. The dense saline marine water moves along the bottom of the river channels with the tide, overlayed by the freshwater inflows. At the fringes of the seasonal sampling periods, the influence of the freshwater flushing is observed with stratification diminishing as catchment flow increases (Figures 1.42 – 1.62).

Dissolved Oxygen

The Leschenault estuarine system experiences dissolved oxygen concentrations that range between 0.10 – 12.5 mg/L throughout the water column (Figures 1.22 – 1.72). Surface waters are generally well-oxygenated throughout the system. While the shallow bottom waters of the estuary are generally well-mixed through tide, wave and wind movements resulting in oxygenated deeper bottom waters, those of the lower river reaches are generally oxygen depleted. This is typical of many south-west Australian estuarine systems. This reflects a significantly diminished impact of mixing influences and the predominance of saline stratification.

Saline stratification of the lower riverine reaches prevents exchange of oxygen between the surface and bottom waters, promoting anoxia (oxygen depletion) of bottom waters. Decomposing organic material washed in from episodic storm events utilise the remaining oxygen, depleting concentrations below ANZECC guidelines of five mg/L (Figures 1.42 – 1.62), and in extreme cases below the ANZECC value critical to ecology of two mg/L. This is a common occurrence in the lower Collie and Brunswick Rivers in the context of the contribution of fish kills. These events are detailed further in this report as specific case studies.

pH

pH is measured to determine the acidity or alkalinity of waterways, which often reflects the soils and sediments the water body overlays. The Leschenault estuarine system with its coastal dominated limestone derived soils has values ranging from 6.5 – 9.1 with bottom values generally elevated from surface values due to their relative proximity to the sediment source (Figure 1.22- 1.72).

Nutrients

The nutrients nitrogen (N) and phosphorus (P) are elements that are the building blocks essential for plant and animal growth. The introduction of these macronutrients from catchment inputs, both naturally and artificially leads to increased primary production of phytoplankton and benthic algae (Boulton and Brock, 1999), and ultimately eutrophication of waterways. Increased growths of microscopic algae occur that results in algal blooms, which in turn further reduces the water quality of waterways. As a bloom dies, the decomposing material consumes oxygen within the water column and the rotting masses can cause foul odours, toxin release and stress to in-stream ecology. Fish kills as seen in the Collie and Brunswick rivers in May 2002, 2003 and 2004 can be the end result of this process and are discussed in further detail as case studies in this report.

The main indicators used to monitor nutrient enrichment in waterways are total nitrogen (TN) and total phosphorus (TP) that include both dissolved and particulate components. The general default trigger values for an estuarine system from the ANZECC Water Quality Guidelines have been used to determine the concentration levels that above or below pose risks of adverse biological effects. The Leschenault estuarine system with its tidal marine exchange is considered to be a nitrogen limiting system. This means that when the internal natural nitrogen cycling is disrupted by excessive inputs of nitrogen, conditions for increased plant growth prevail.

In 2000, the nutrient component of the Leschenault Estuary monitoring program was rationalised to collect only TN and TP samples as the dissolved components were removed from the sampling regime. The dissolved components of nitrogen such as NOx (nitrate and nitrite) and NH4 (ammonium) are the most bioavailable forms for uptake by aquatic plants and phytoplankton growth. Likewise, the dissolved phosphorus component, filterable reactive phosphorus (FRP), which is readily available to aquatic plant growth, was also removed. Therefore, direct analysis and relationships between nutrients and phytoplankton activity is difficult to establish as particulate forms of N and P are not available for aquatic plant growth.

The relative nutrient concentrations of the Leschenault estuarine system over the 2000 to 2006 period using the classifications described in Table 1 are described below in Table 2.

Table 2. Classification of nutrient status for the Leschenault estuarine system.

Sample site	Total Nitrogen 2000 - 2006					Total Phosphorus 2000 - 2006				
	00-02	01-03	02-04	03-05	04-06	00-02	01-03	02-04	03-05	04-06
Estuary 4	low	low	low	low	low	low	low	low	low	low
Estuary 3	low	low	low	low	low	low	low	low	low	low
Preston 1	low	low	low	low	low	mod	mod	mod	mod	mod
Collie 2	mod	mod	mod	mod	mod	high	high	high	mod	mod
Brunswick 1	high	high	high	high	high	high	high	mod	mod	mod
Brunswick 2	high	high	high	high	high	high	high	high	high	high
Parkfield	high	high	high	high	high	mod	mod	mod	mod	mod

Please Note:

The nutrient status for a waterway or estuary used in this report is assigned by using the median of nutrient concentration over a three-year period. The three-year period is used to diminish the influence of natural variation between years and the median is used rather than average to diminish extreme events.

Classification systems are very useful for summarising information generated by larges amounts of data. This classification system is a draft version and is under review by Department of Water.

Nitrogen

The Leschenault system experienced TN concentrations between the range of 0.079 mg/L at Estuary 4 and 3.2 mg/L at Collie 2 sample site (figures 1.33 – 1.73). Generally, the estuary sites are considered to have ‘Low’ TN concentrations with all but one sample below the maximum recommended ANZECC guideline of 0.75 mg/L for south-west Australian estuaries. The three-year moving median concentrations indicate a slight decreasing trend (Figure 1.13) in nitrogen concentrations at the Estuary 3 (north) site which has significant tidal exchange, and stable at the Estuary 4 (south) site (Figure 1.23) with both locations having a TN status regarded as ‘Low’.

The scenario changes significantly in the lower reaches of the three river systems. Preston River 1 currently exhibits a ‘Low’ TN status with median concentrations showing no significant trend (Figure 1.33) with only a few random samples returning a value in excess of the ANZECC guideline.

Collie River 2 is considered problematic with the occurrence of algal blooms in most years. Median concentrations demonstrate the variability within the system (Figure 1.43) with 65 per cent of samples recorded exceeding the recommended ANZECC value. There is a distinct shift in the last two years of sampling with up to 60 per cent of samples falling below this guideline. The concentration of TN often reflects phytoplankton density, so distinguishing between possible reducing nitrogen components or plant activity without the fractional measures is difficult to quantify and generally inconclusive. The severe anoxia experienced at the bottom of the system potentially drives sediment release of ammonium (relatively harmless) which also influences TN concentrations. This ammonium, in the presence of elevated pH values in the order 8.5 – 9, has the potential to convert into ammonia. Ammonia is highly toxic and potentially lethal to in-stream ecology.

Both Brunswick River sites (1 and 2) are considered the most problematic of all the sampled sites in terms of excessive nutrients, algae and bacteria adversely affecting water quality. Brunswick 1, near the confluence of the Collie River currently maintains a 'Moderate' nitrogen concentration status and further upstream at Brunswick 2, exhibits a TN status of 'High'. At both sites over 95 per cent of samples recorded exceeded the recommended maximum ANZECC TN value (Figures 1.53 – 1.63) indicating increased risk of problems associated with nutrient enrichment. Over 65 per cent of the TN load that passes through the lower Brunswick River comes from the Wellesley catchment (Bussemaker, 2006), which contains an extensive irrigation and drainage network from mainly dairy farming land use.

The drainage catchment of Parkfield Drain comprises mixed land use including intensive horticulture, grazing and extractive industries, and enters the estuary from the north. Approximately 85 per cent of samples taken from the site exceeded the ANZECC guideline for TN. This is the most likely source of nutrients reflected in sampling at the Estuary 4 sample site. Of particular concern is that 32 per cent of all samples from this site were considered to be of 'Very High' nitrogen concentration status and the Parkfield site reflects a nutrient status of 'High'.

Phosphorus

The Leschenault estuarine system experienced a range of TP values from 0.007 mg/L at Estuary 4 to 0.33 mg/L at Brunswick River 1 over the 2000-2006 sampling period (Figure 1.13 – 1.63). While the Estuary is considered to have a 'Low' TP concentration status, a collective 28 per cent of the total samples recorded exceed the maximum recommended ANZECC value of 0.03 mg/L (Figures 1.13 – 1.23). The ratio of N to P is relatively low and is facilitated by the good tidal exchange experienced at both sites.

The lower Preston River has a slightly decreasing trend over the last six years in TP median concentrations and is ranked as a 'Moderate' TP concentration status. Nearly 51 per cent of all samples taken exceed the ANZECC guideline (Figure 1.33), decreasing to 20 per cent exceedence in the 2006 summer period.

The problematic lower Collie River displays a slight decreasing TP trend with initial median concentrations in 2000 bordering a 'High' phosphorous concentration status at nearly 0.1 mg/L to a final concentration in the lower portion of the 'Moderate' status at 0.06mg/L in 2006 (Figure 1.43). Nearly 95 per cent of all samples recorded over the 2000 to 2006 period exceeded the recommended maximum ANZECC value with over 10 per cent of all samples classified as exhibiting a 'Very High' TP concentration. While this analysis indicates slight decreasing trends, this may only be a true reflection of the entrapment in the catchment of the particulate bonded form of TP due to low waterways flows during this period. Therefore, it could be assumed that sediment loading to which particulate forms are bound have reduced with lower flows. As bioactivity over this period is still regarded as substantial (as observed in chlorophyll *a* and phytoplankton data in Figure 1.44), the dissolved phosphates (FRP) available for plant growth may not have reduced. As there was no analysis of the phosphorous fractions during the sampling period, this could not be confirmed.

Both Brunswick River sites exhibit a ‘High’ TP status with no identifiable trends. Nearly 98 per cent of all samples taken exceed the ANZECC guideline for TP (Figures 1.53 – 1.63). Nutrient enrichment is a permanent feature of the lower Brunswick resulting in problematic algal blooms arising most years. Similarly to TN, over 65 per cent of all TP loading in the lower Brunswick River comes out of the Wellesley catchment. (Bussemaker, 2006)

While Parkfield exhibits a TP status of ‘Moderate’, over 95 per cent of all samples exceed the recommended ANZECC TP value though only 15 per cent of TP values fall in the ‘Very High’ category.

Phytoplankton

Phytoplankton is described as the microscopic aquatic plants in the water column that form the photosynthetic basis for the open water food web. Assessments of phytoplankton communities include biomass (measured as Chlorophyll *a*) and community composition (cell counts of phytoplankton groups).

Chlorophyll *a* concentrations in the Leschenault estuarine system over the 2000-2006 period range from undetectable limits of <0.0005 mg/L to the extreme value of 0.092 mg/L in the lower Preston River which is 30 times greater than the maximum recommended ANZECC value of 0.003 mg/L (Figures 1.14 – 1.64).

The Leschenault Estuary is considered to be a clear water macrophyte-dominated system and rarely exceeds the ANZECC value for Chlorophyll *a* and for the most part is algal bloom free. The Estuary 3 site at the north end of the estuary is potentially influenced by the inflow of the eutrophic Parkfield Drain and as a result the ANZECC trigger value was exceeded on a few occasions. In the late spring of 2001 a diatom bloom of 32,000 cells/mL occurred which was likely in response to slightly elevated TN values, resulting in a brief stint of oxygen depletion (Figures 1.22 – 1.24).

In the lower reaches of the rivers, the system undergoes transition from a stable state, clear water, macrophyte-dominated system to one that is slightly turbid in nature and phytoplankton dominated. The lower Preston River sampling identified two large peaks of Chlorophyll *a* in the problematic years of 2002 and 2004, with 70 per cent of samples taken over the 2000-2006 period (Figure 1.34) exceeding the ANZECC value. While diatom blooms occur most years there is an evident influx of *Chlorophyta* and *Dinophyta* species in recent years with little evidence of the harmful *Cyanophyta* (blue-green algae).

Over 80 per cent of the lower Collie Chlorophyll *a* samples exceeded the ANZECC trigger value with an average sample concentration approaching 0.01 mg/L (Figure 1.44). Algal blooms occur most years with diatom and *Dinophyta* species dominant; in particular the dinoflagellate *Karlodinium micron*. A number of these major blooms had densities exceeding 50,000 cells/mL. Such is the size of these blooms that the anoxia present at the bottom of the river bed becomes temporarily oxygenated and surface waters become saturated with dissolved oxygen. This state generally collapses as the bloom consumes all available nutrients for growth and, on decomposing, utilises the available oxygen.

Common to the riverine reaches is a shift away from diatom-dominated systems to the larger presence of *Dinophyta* species and the lower Brunswick River is no different – also showing the emergence of the potentially harmful cyanophytes. Over 80 per cent of all Chlorophyll *a* samples exceed the trigger value with an average concentration of around 0.014 mg/L. These elevated levels are indicative of the 'High' nutrient status of the lower Brunswick River resulting from changing land use pressures that are placed upon the catchment of the coastal plain.

Conclusion

The water quality parameters of the Leschenault estuarine system, like almost all estuarine systems, are dependent upon the relative contribution of factors such as rainfall, runoff, tidal movement, mixing influences and marine exchange. Circulation patterns within the estuary are considered to result in well-mixed fresh and saline water during the summer months, and in winter exhibits lower salinities towards the head, with the central basin and water next to 'the Cut' approaching that of the adjacent ocean water. This seasonal winter transition along both the south-north lagoon transition and the east-west Collie River to 'the Cut' transition is a consequence of increased rainfall and flood events. Similarly, as a consequence of freshwater inflows from the Preston and Collie/Brunswick river catchments, some stratification occurs in the water column in the lower to mid regions of the estuary lagoon and in each of the lower river systems as buoyant, low salinity fresh water floats above the intruding, denser marine water.

The hydrodynamics, and the associated salinity fields and gradients, of the Leschenault Estuary are now largely controlled by the interplay of the restricted exchange with the ocean through 'the Cut', freshwater inputs during winter, and evaporation; the area of influence decreasing the further north up the estuary. Other factors that have contributed to changes in hydrology patterns of the Leschenault estuarine system include the construction of the Wellington Dam on the Collie River, which reduces fresh water flows into the estuary during winter, summer irrigation practices, and the Parkfield Drain which empties directly into the north of the estuary.

The hydrodynamics of the lower river systems are governed by tidal influences from the estuary, but more strongly from climatic patterns of rainfall and catchment runoff. Salinity stratification occurs in each of the lower river systems as buoyant, low salinity fresh water 'floats' above the intruding, denser marine water. The seawater/freshwater interface is generally regarded to extend upstream with a variable downstream movement in winter to reflect increased freshwater flows over these months.

Nutrient concentrations in waterways often reflect land uses and land practices within the catchments where they are located, as well as soil profiles as a measure of nutrient retention. Nutrient release from the catchment is also dependent upon rainfall and irrigation practices. The nutrient concentrations of the Leschenault estuarine system are generally lower than those of neighbouring systems on the Swan Coastal Plain such as the Vasse/Wonnerup to the south and the Peel-Harvey to the North. While adverse water quality conditions are not as severe as those systems, there are still problems with eutrophication that lead to annual summer algal blooms and episodic fish kill events. This will likely continue if catchment issues and problems are not addressed.

The Leschenault Estuary and its lower riverine reaches are of varied nutrient status and health. The estuary itself with its strong exchange of tidal marine waters maintains a generally ‘Low’ nutrient status and is in relatively good condition in comparison to other south-west estuarine systems. Algal blooms are not common and it exists as a clear water macrophyte-dominated system. The four major inflows to the estuary – the Preston, Collie and Brunswick rivers and the Parkfield Drain all exhibit water quality conditions of stressed catchments under increasing land use pressures. Of particular concern are the Collie and Brunswick rivers, which succumb to annual summer phytoplankton blooms that, in combination with summer storm events, either triggered or were the catalyst for fish kill events in 2002 and 2004.

Both these incidents were largely due to natural occurring storm events whereby organic material built up in the catchment is washed into the rivers by first flushing rains. This decaying material has a high biological oxygen demand, effectively stripping oxygen from the water column and, in combination with high turbidity, adversely effecting in-stream ecology. Of particular concern in these events was the occurrence of the *Listonella anguillarum.* While not the cause, it contributed to the fish deaths.

There were some positive trends at some of the sampling sites over the study period with decreasing trends identified at Estuary 3 (for both TN and TP), Preston River 1 (TP) and Collie River 2 (TP). Analysis of the other sites indicates that they are stable with no site producing an increasing trend. These results could reflect better catchment management, changes to the land use or reduced waterways flows from the catchment.

The 2000-06 study period for the Leschenault estuarine system was sampled over the summer – generally between the months of November to May. This period included the lowest annual rainfall recorded in 2001 and the largest-ever recorded fish kill event in 2004. Data quality from this program is derived from sound sampling techniques, though the sampling regime had been modified from the study period from 1996 to 1999. This includes reduced sample sites, increased frequency of summer sampling to fortnightly and the fractional components of nutrients being cut from the program. As a consequence, the data described in this report must be considered in isolation to the 1996-99 period.

Recommendations

1 Recommence sampling for the fractional components of nitrogen (NOx & NH4) and phosphorus (FRP) which are the most bioavailable components for uptake by aquatic plants.

2 Carry out further statistical analysis of nutrient data versus rainfall to assess whether decreasing TP trends are related to lower annual rainfall events.

3 Continue the current summer sampling program frequency, extending the sampling period by a month to include the period of first flow events.

4 Re-establish the sampling sites that existed prior to 2000 rationalisation of the program.

5 Undertake sediment spore sampling to determine which sediment bound spores are contributing to algal blooms, especially on the Brunswick and Collie rivers.

Glossary

Phytoplankton – the photosynthetic plankton (algae and Cyanobacteria).

Chlorophyta (green algae) – The single cells, colonies, filaments or more complexly structured algae are usually grass-green. Motile cells have usually two or four flagella of equal length.

Chrysophyta (golden-brown algae) – The single cells, colonies or filaments are yellow, golden-brown and rarely green. Motile cells usually have two anterior flagella of unequal length.

Cryptophyta – The single cells are red, blue-green or olive brown. All cells are motile, usually with two slightly unequal flagella.

Cyanophyta (Cyanobacteria blue-green algae) – The single cells, colonies and more complexly structured algae are blue-green, brownish, olive green or rarely bright green. The cells are without compartments (no membrane-bound organelles): in particular there is no nuclear region defined by a membrane and photosynthetic pigments are disturbed throughout the cells (not in chloroplasts). Sexual reproduction and motile cells are absent.

Dinophyta (dinoflagellates) – The single cells are brown or brownish green. Motile cells have a prominent transverse furrow in which two flagella are inserted.

Raphidophyta – Single cells or filaments are green or yellow-green. Motile cells have two anterior flagella of unequal length and a distinctive cell wall structure.

Diatom – are a major group of eukaryotic algae, and is one of the most common types of phytoplankton. Most diatoms are unicellular, although some form chains or simple colonies. A characteristic feature of diatom cells is that they are encased within a unique cell wall made of silica.
http://en.wikipedia.org/wiki/Diatom

Case Study 1: 2002 Fish Kill

On 30 April 2002, a fish kill event occurred on the Brunswick River which resulted in the death of approximately 90 fish, mainly Black Bream. Figures 2.01 and 2.02 demonstrate the in-stream water quality conditions on the lower Collie and Brunswick rivers for the summer period leading up to the event. Of significance is that the event followed the lowest annual rainfall in 2001 experienced in catchment in recorded history (Pickett pers comm., 2006).

The Collie River system (Figure 2.01) appeared to be relatively normal during the start of summer 2002. The occurrence of oxygen levels was typical for that time of the year with aerobic surface and anoxic bottom waters. While levels of both macronutrients (TN and TP) ranged from 'Moderate' to 'High', the phytoplankton activity was relatively low in comparison. The bioactivity appeared to have consumed the P content over the February to March period before an influx of TP occurred towards the end of March, which coincided with a small summer rain event and elevated stream flows from Brunswick River (Figure 2.3b). This appears to have triggered a mixed diatom and a harmless small estuarine dinoflagellate *Katodinium* bloom with oxygen levels saturated throughout the water column. Once again in May, TP levels increased and a large 70,000 cell/mL dinoflagellate bloom (*Gyrodinium estuariale* and *Katodinium sp*) occurred, possibly in response to the inflow from Brunswick River and increased flow from the lower Collie River catchment (Figure 2.0 & 2.3b).

The Brunswick River system (Figure 2.02) showed very early seasonal signs of stress, with high to very high macronutrient values and the presence of a very high phytoplankton density of the harmless estuarine diatom *Cyclotella sp*. Nutrient levels appeared to vary in response to the growing and dying bloom which finally gave way to a harmless small estuarine dinoflagellate *Katodinium sp* beginning in April. The bloom appears to have been driven by very high TN values delivered by first waterways flushing flows (Figure 2.0) as the oxygen levels in both surface and bottom waters were saturated by this high bioactivity (Figure 2.01). With a large organic component and reducing bloom, oxygen levels decreased below critical levels, which appear to be the precursor to the fish kill.

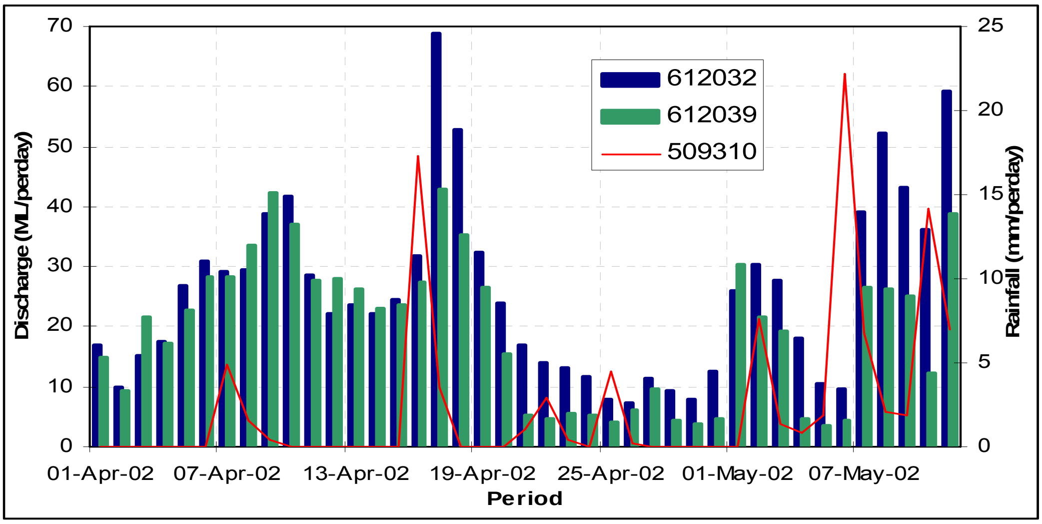


Figure 2.0. Flow regime for Cross's Farm (612032) on the Brunswick River and Wellesley River (609039) from April 1 – May 11 2006, with the associated rainfall from Vendictive (509310) for the fish kill period.

Dead fish were seen floating down the Collie River for up to a week after the initial kill but were all associated to the Brunswick River event. In early June, a new fish kill event was observed in the Eaton area of the Collie River. There was a minor sewerage spill and a substantial river flow event, but no definitive cause for the deaths was established. Less than 10 fish were found dead and approximately 30-40 fish distressed. Once again, the cause of death appeared to be the presence of a high content of organic matter causing the oxygen depletion of the water column and elevated levels of bacteria. The following is a summary from the incident report:

2002 Fish Kill Incident Report

After a report of sewerage spill near the Collie River in Eaton, investigations indicated that there were some dead and gasping fish in the Collie River. On further investigation, it appears that although some areas of the river did smell of effluent the most likely cause of fish deaths were recent rains and riverine flows. This would have caused an increase in organic matter, reduction of salinity and possible anoxic conditions.

Nursery fish from a connected wetland may have been flushed into the adjacent Collie River and suffered from salinity shock, as although the Collie became fresher from the recent rain, the water in the wetland was probably lower in salinity.

Phytoplankton results indicate and organic rich, oxygen poor, bottom water situation which may have contributed to stressing the fish.

It is widely accepted now that the south-west of Western Australia is experiencing significant climate variability/change. There has been on average a 20 per cent reduction in rainfall since 1974, which correlates to a 30 per cent reduction in mean annual inflows. (Pearcey, 1999) This 2002 fish kill event follows a period of extremely low rainfall and stream flows which, it is believed, leaves a large percentage of organic matter in the catchment as there is no significant flush effect. The Wellesley catchment contributes a large proportion of the nutrients in the lower Brunswick River (Paps *et al*, 1998) and in summer a majority of the flow is from irrigation water. So potentially, when extended periods of low rainfall events precede a relatively large summer storm event, high concentrations of organic matter and nutrients enter the system. Then through the natural process of decomposition, water quality conditions are severely reduced to levels that are fatal to in-stream ecology.

Photo: (C. Webb 2002) A view of the lower Collie River during the 2002 fish kill event. A brown discolouration from the high organic content dominates the water column.

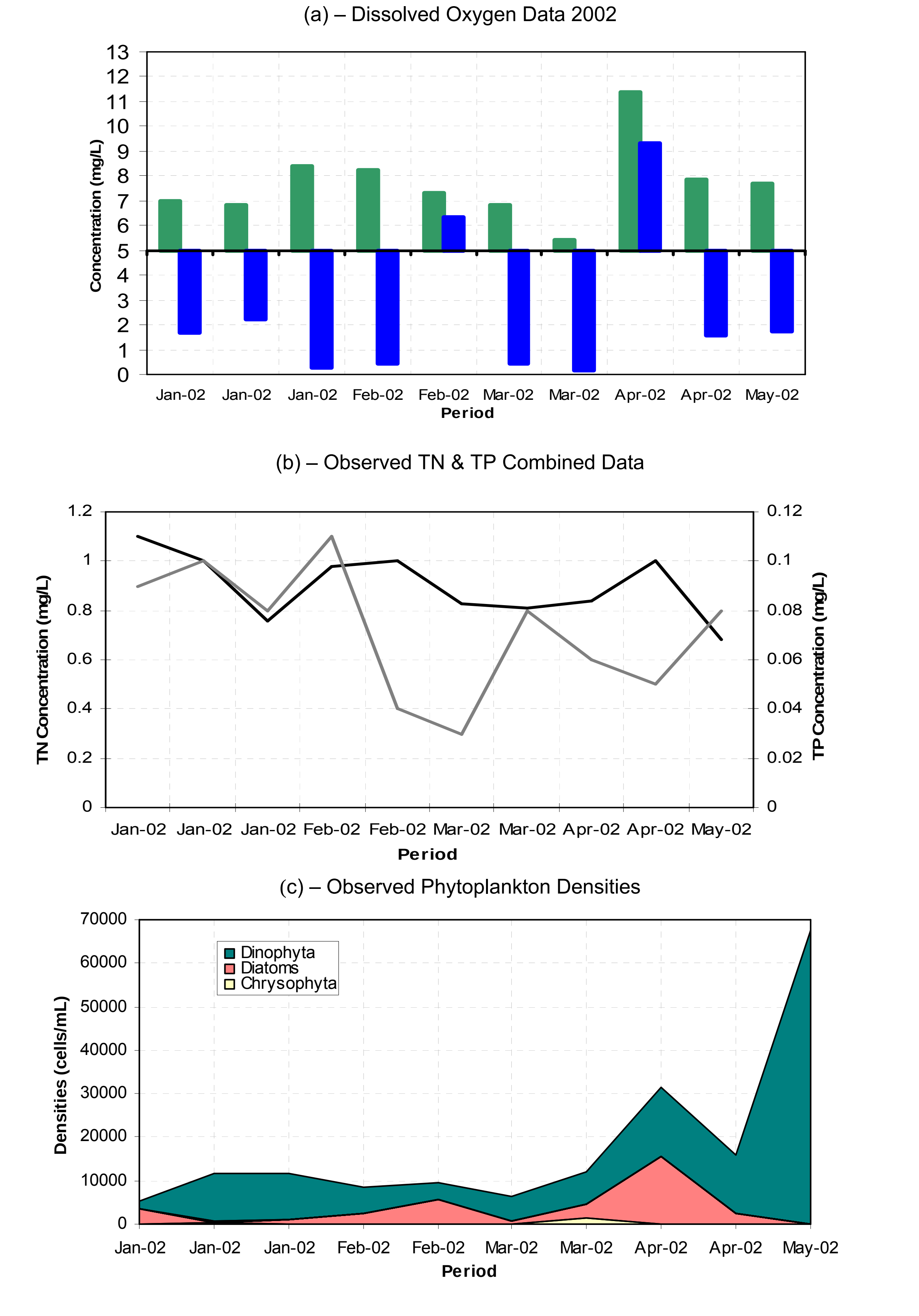


Figure 2.01. Focused data set of the water quality events leading up to the 2002 fish kill at Collie 2. (a) Observed Dissolved Oxygen concentrations for surface (green) and bottom (blue) samples in mg/L. Here the x-axis runs through the 5mg/L value which is the ANZECC guideline to estuarine health, above is considered healthy and below indicates reducing health and at 2mg/L critical to ecology (b) Combined TN (black) and TP (grey) concentrations in mg/L (c) phytoplankton densities in cells/mL

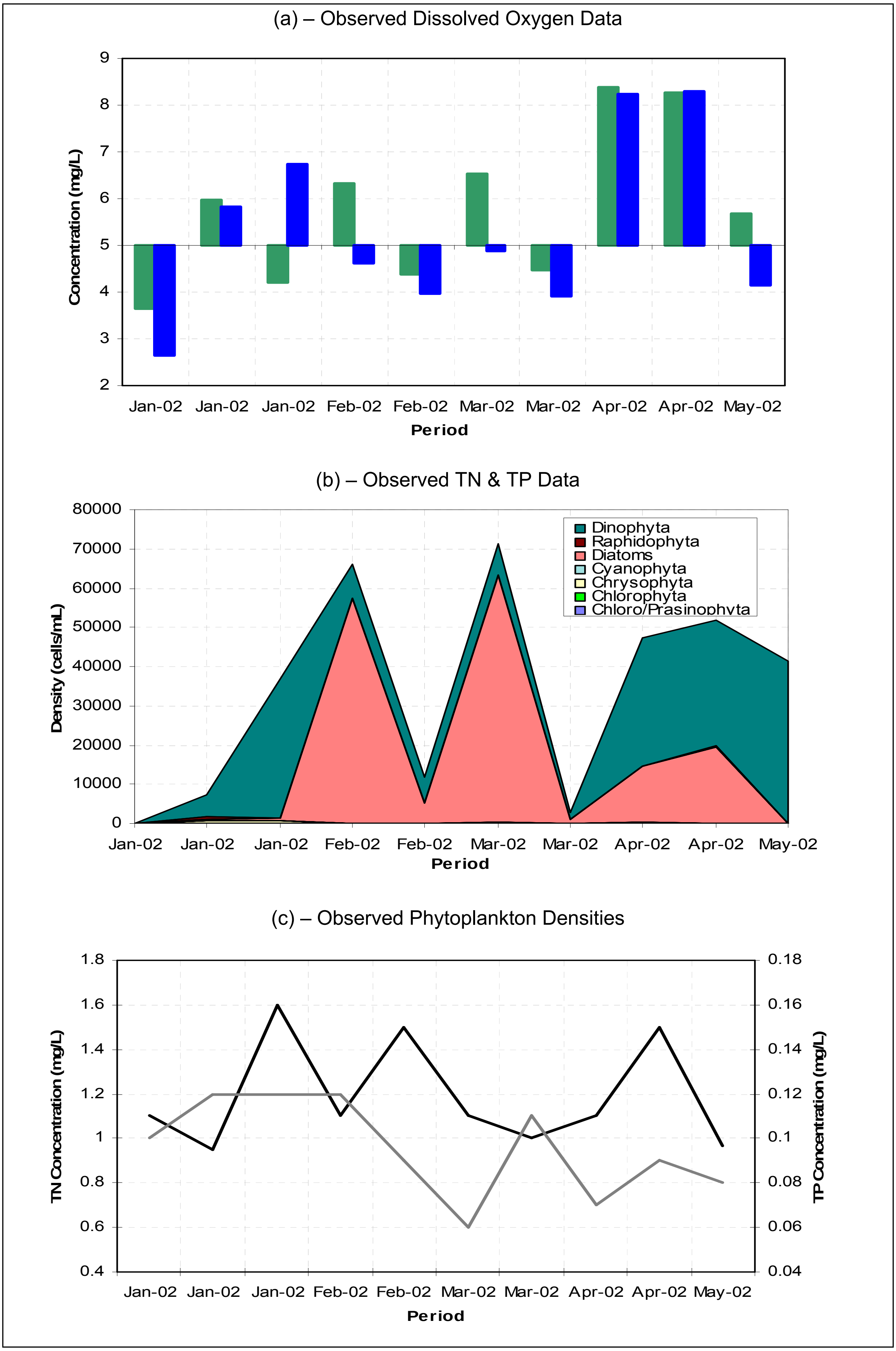


Figure 2.02. Focused data set of the water quality events leading up to the 2002 fish kill at Brunswick 1. (a) Observed Dissolved Oxygen concentrations for surface (green) and bottom (blue) samples in mg/L. Here the x-axis runs through the 5mg/L value which is the ANZECC guideline to estuarine health, above is considered healthy and below indicates reducing health and at 2mg/L critical to ecology (b) Combined TN (black) and TP (grey) concentrations in mg/L (c) phytoplankton densities in cells/mL

Case Study 2: 2004 Fish Kill

On 24 May 2004, a fish kill event occurred on the Collie River which involved the death of around one thousand fish of mixed species. This was the largest fish kill event of its kind to be documented in the Leschenault Estuary and its estuarine reaches (Pickett pers comm., 2006). Figures 2.11 and 2.12 demonstrate the in-stream water quality conditions on the lower Collie and Brunswick rivers for the summer period leading up to the event.

Establishing the cause was complicated because the last sampling event to take place on the Leschenault system was on 9 May 2006, 15 days prior to this event. This occurred because the sampling rational was that sampling ceases after the first flushing flows. In the Brunswick River, sampling had temporarily ceased at Brunswick 1 during 2003-04 due to restricted access through the confluence to the Collie River, so no data is available. Figure 2.1 demonstrates the large first flushing flow that occurred on 22 April 2004 that would ultimately be the major contributor to a reduction in water quality to levels that cause fish deaths. Comparison of figures 2.0 and 2.1 show the difference in magnitude (5-fold) between the first river flushing flows of 2002 and 2004.

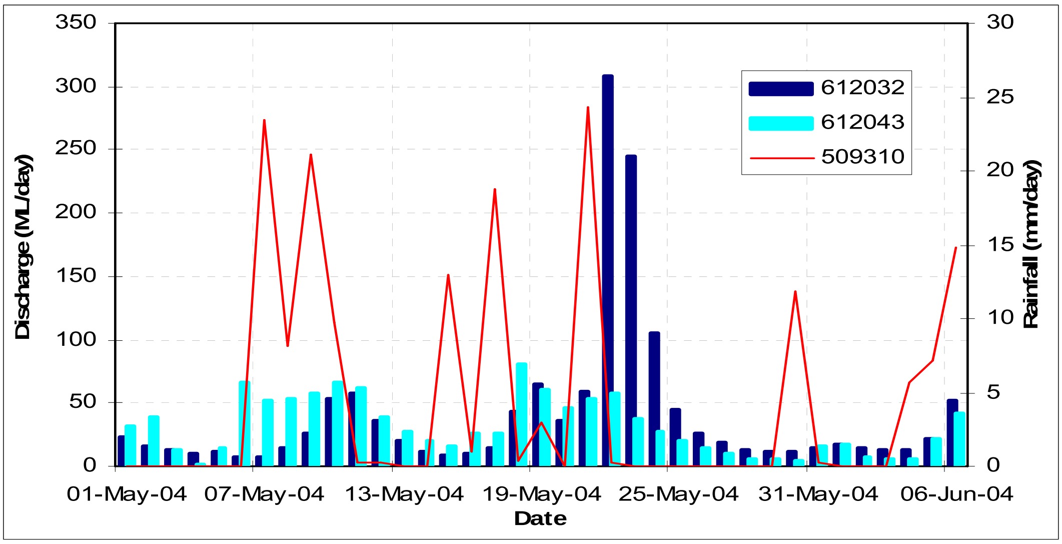


Figure 2.1. Flow regime for the lower Brunswick (612032) and Collie (612043) Rivers with rainfall totals from nearby Vendictive pluvio (509310) for 2004 fish kill period.

The Collie system in 2004 (Figure 2.11) showed the typical summer scenario of high levels of TN and TP, deoxygenated bottom waters and a phytoplankton bloom of dinoflagellate *Katodinium sp* which coincided with an early summer storm event (Figure 2.3c). As this early summer bloom died off, surface oxygen reduced before an elevation of high to very high TP concentrations led to a very large diatom/dinoflagellate bloom. The algae bloom died and in the processes of decomposing consumed the oxygen leaving the water column once again anoxic (devoid of oxygen). In April the potentially ichthyotoxic dinoflagellate *Karlodinium micrum* was detected in a dinoflagellate bloom that also contained *Katodinium* sp, *Heterocapsa* sp that continued into May. The last sampling event occurred on 18 May where levels of TN and TP were elevated to very high concentrations most likely in response to the increased flows from both Brunswick and Collie River catchments (Figure 2.1) carrying with them high organic matter.

The Brunswick system at Brunswick 2 sample site (Figure 2.1) indicated that this system was under stress in early summer, with extremely high TN and TP concentrations and supersaturating of oxygen in the water column due to a mixed phytoplankton bloom. The very tiny cyanophyta *Merismopedia* was detected at ca 13,000 cells/mL and was considered satisfactory. This appeared to be a result of the early summer storm event (Figure 2.3c). While TN and TP values remained very high for the 2004 summer period there was relatively low phytoplankton activity for the remainder of the summer. Dissolved oxygen levels reduced and remained around the ANZECC trigger value of five mg/L.

On 21 May 2004, the Leschenault catchment received approximately 25 mm of rainfall (Figure 2.1) in a 24 hr period which was preceded by at least three rainfall events of similar size in the weeks leading up to this event. In response, the Brunswick River gauge station at Cross's Farm (612032) recorded flows that increased from 50 to 308 ML for the day of which 90 per cent came from the Wellesley River sub-catchment. This carried with it high organic loading of organic wastes, fertilizers and eroded sediments accumulated in the drains. On 24 May 2006, the Department of Environment (now the Department of Water) was notified of dead fish on the lower Collie and Brunswick rivers. Preliminary results indicated high turbidity and low dissolved oxygen, which are conditions associated with naturally occurring fish kills.

In the week following, continued reports of fish deaths were received by the Department, media releases were issued, and a massive cleanup effort was underway. The PEU reported that preliminary phytoplankton results indicated dinoflagellate *Heterosigma* sp*, Karlodinium* sp *and Cryptoperidinoid* sp were present in the samples. *Karlodinium micron,* a mobile dinoflagellate is known to clog the gills of fish when densities are high. Fish pathology reported back that as with the 2002 event, the *bacteria Listonella anguillarum,* was present in some fish and may have contributed to their death. In all, 1,000 fish were estimated to have died due to first flushing rains washing decaying organic material into the river and a large dinoflagellate bloom reducing water quality to levels that are fatal to in-stream ecology.

Photo: (C. Webb, 2004) The sad reality. In events such as that experienced in May 2004 even the biggest fish succumb to the adverse water quality conditions.

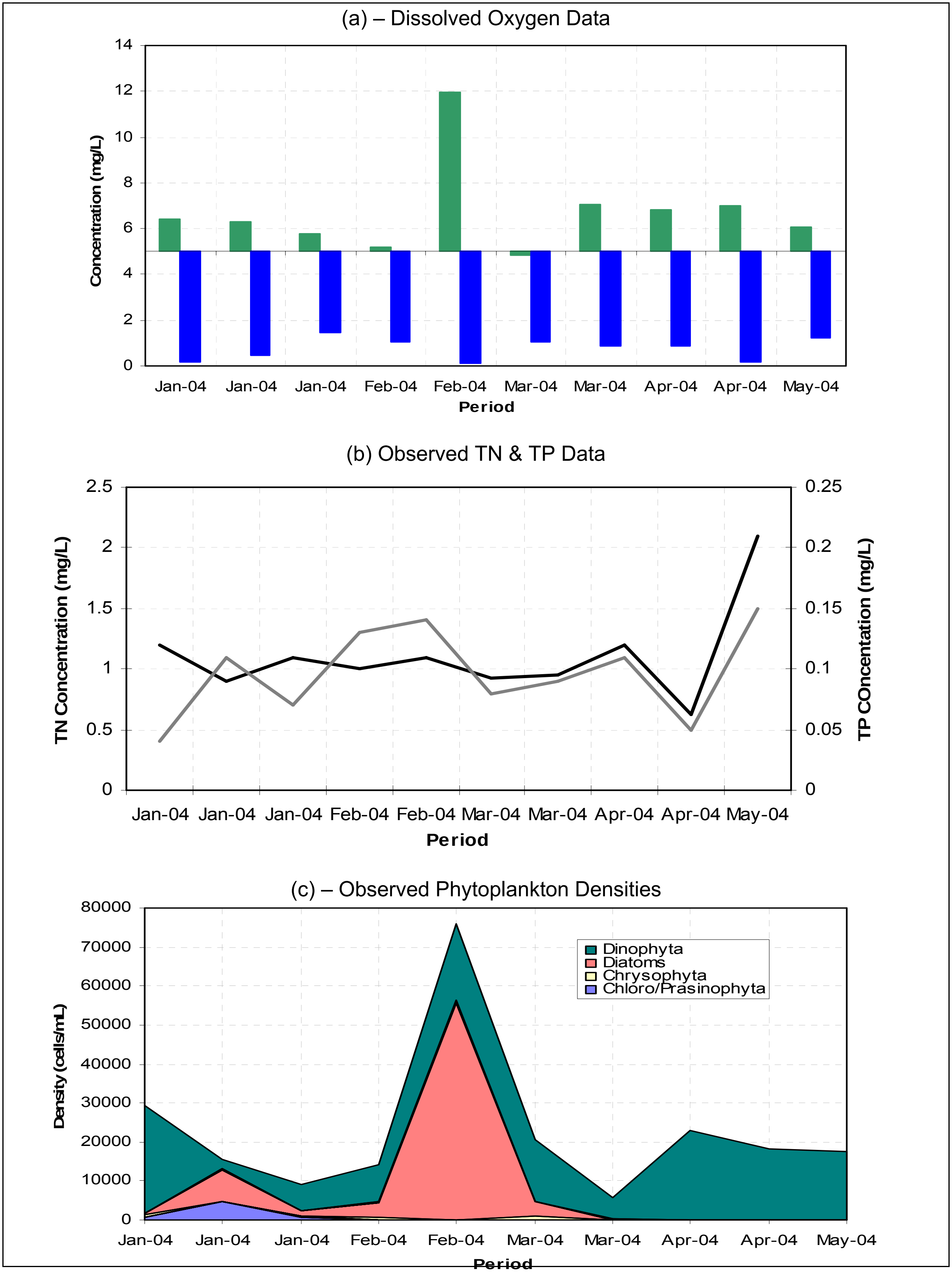


Figure 2.11. Focused data set of the water quality events leading up to the 2004 fish kill at Collie 2. (a) Observed Dissolved Oxygen concentrations for surface (green) and bottom (blue) samples in mg/L. Here the x-axis runs through the 5mg/L value which is the ANZECC guideline to estuarine health, above is considered healthy and below indicates reducing health and at 2mg/L critical to ecology (b) Combined TN (black) and TP (grey) concentrations in mg/L (c) phytoplankton densities in cells/mL.

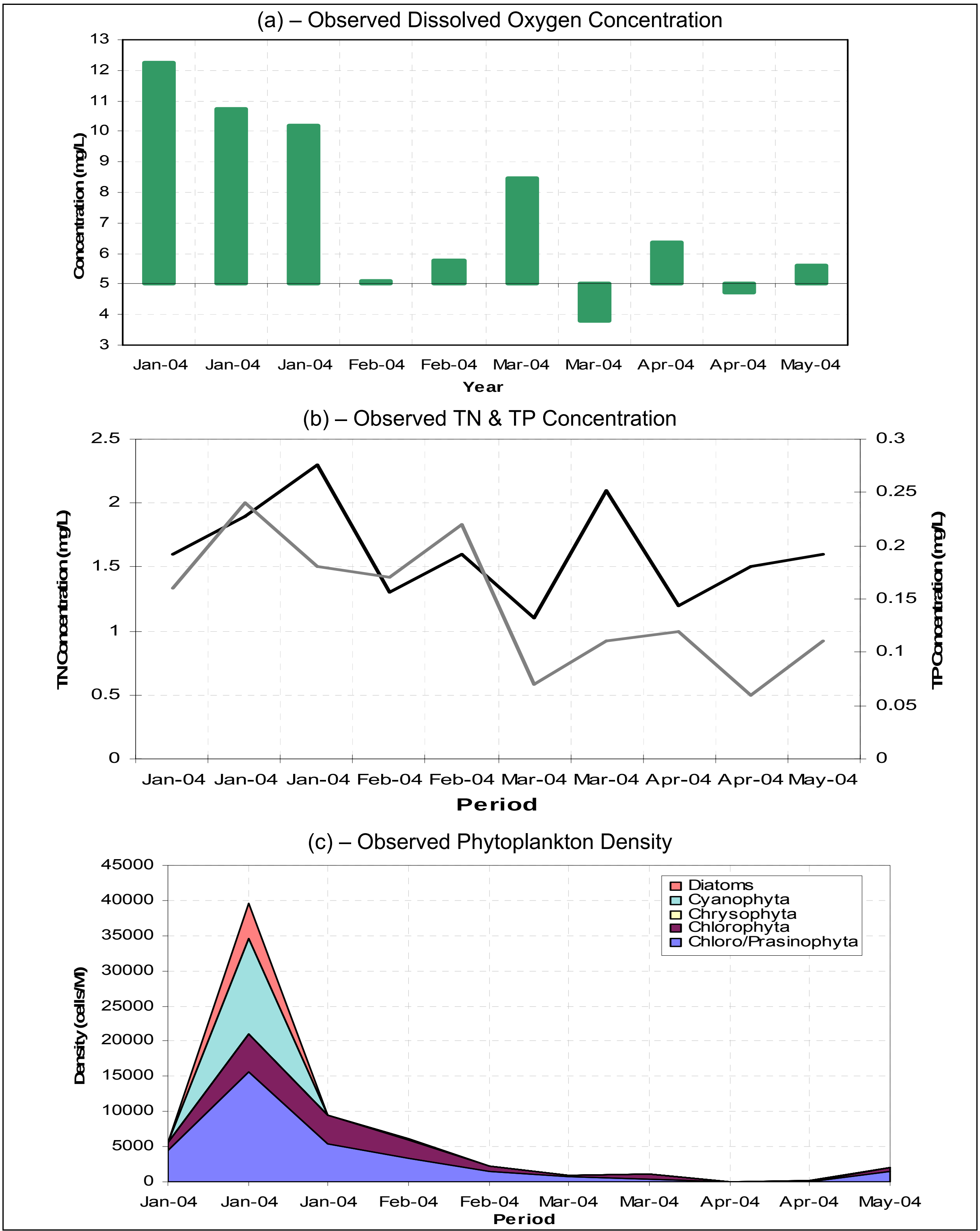


Figure 2.12. Focused data set of the water quality events leading up to the 2004 fish kill at Brunswick 2. (a) Observed Dissolved Oxygen concentrations for surface (green) and bottom (blue) samples in mg/L. Here the x-axis runs through the 5mg/L value which is the ANZECC guideline to estuarine health, above is considered healthy and below indicates reducing health and at 2mg/L critical to ecology (b) Combined TN (black) and TP (grey) concentrations in mg/L (c) phytoplankton densities in cells/mL.

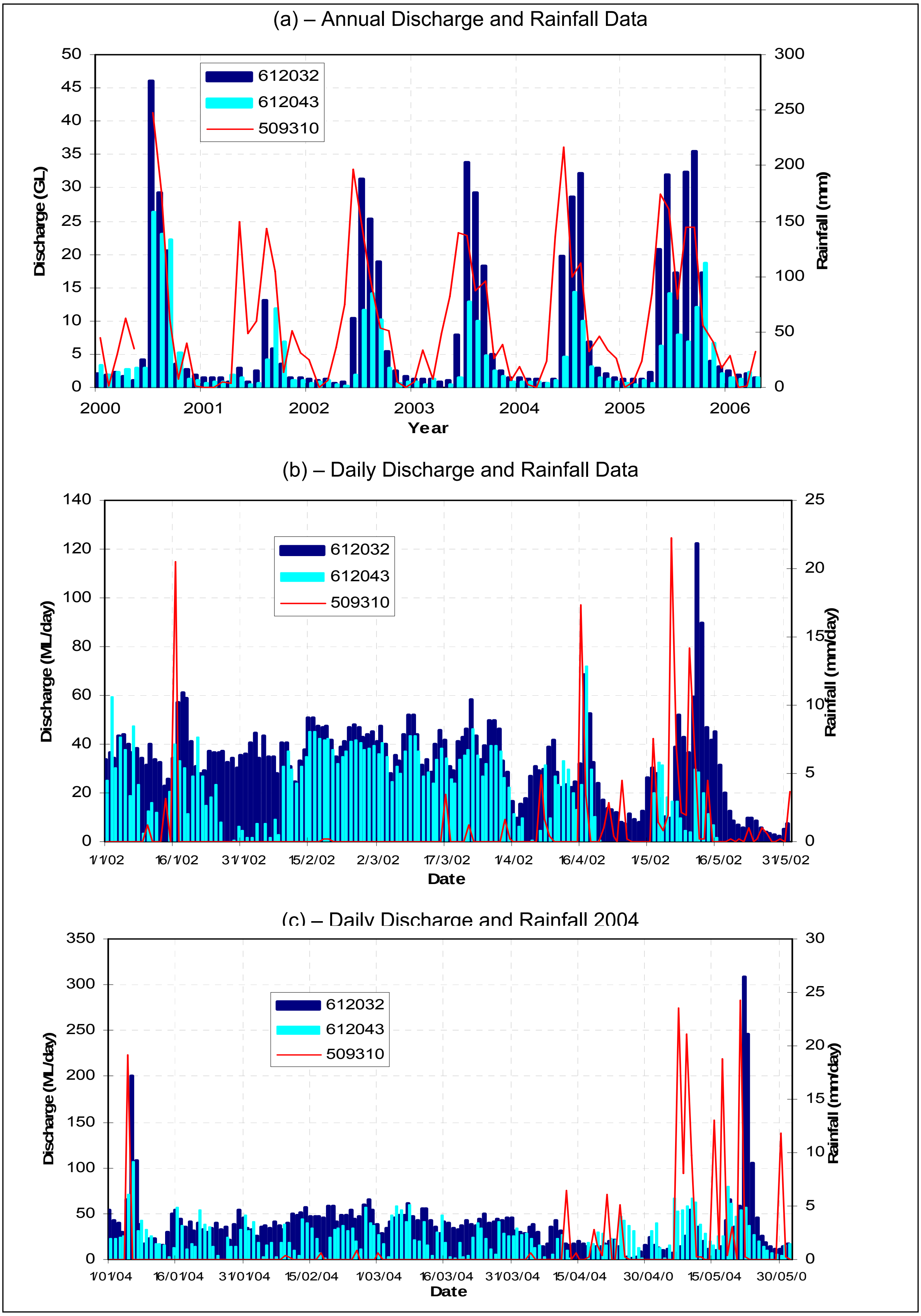


Figure 2.3. (a) Annual discharge and rainfall data over the study period of 2000 – 2006 from lower Brunswick River 612032 (blue) and lower Collie 612043 (aqua) with associated rainfall from nearby Vindictive rain gauge 509310 (red). (b) Daily discharge and rainfall data leading up to and including the 2002 fish kill event from lower Brunswick, Collie and Vindictive rain gauge. (c) Daily discharge and rainfall data leading up to and including 2004 fish kill event from the lower Brunswick and Collie Rivers and Vindictive rain gauge. Please note difference in discharge scale between figure b and c.

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