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Estuary Opening Management in Western Victoria

An information analysis

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Estuary opening management in Western Victoria:

An information analysis

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June 2004

Parks VICTORIA

Executive Summary

This report reviews the significant physico-chemical processes and biological communities of five estuaries managed by Parks Victoria in southwest Victoria: Glenelg, Fitzroy, Curdies, Gellibrand, and Aire.

Estuary management can involve the periodic opening of sand barriers at the entrance to release water out to sea. This report aims to synthesise current information regarding how the timing and extent of these artificial opening events affect the various physical processes within the estuary systems. It is expected that this knowledge will facilitate management decision-making.

The estuaries examined in this report have the following characteristics:

- Their marked seasonal inequality in river discharge means they may be totally fresh in winter or spring and marine dominated in summer and autumn.
- Low summer and autumn river discharge results in sand bars obstructing mouths, often for extended periods.

In addition, these estuaries tend to be highly stratified: layers of fresh and salt water that do not mix. This is influenced by the low tides on the west coast of Victoria (low tidal mixing energy) and the state of the mouths.

When the estuary mouths are open, estuaries can fill and empty in response to the forcing of oceanic tides. Marine water flows into the estuaries via their mouths during flood tides and out again on ebb tides. When the mouth is narrow it can have a restrictive or "throttling" effect on water currents. This in turn influences the volume of water exchanged in a tidal cycle.

Other factors that may influence the level of salt water in an estuary include atmospheric pressure, wind, wave action, sedimentation, and seasonal variation in river flows.

The large difference in seasonal flows has a marked impact on the turbulent energy regime of the river's estuaries. Winter floods often flush salt water from the estuaries completely for several weeks at a time. As discharge drops in spring, fresh, well-oxygenated seawater re-enters the estuary. Over summer and autumn the mouth becomes more restricted as it sands up and tidal exchange is reduced. The bottom salt wedge layer stagnates and may become anoxic (*i.e.*, no dissolved oxygen is present).

Dissolved oxygen (DO) concentrations are generally taken as an important measure of the health of aquatic ecosystems. Very low DO or anoxic conditions raise concerns about threats to estuarine productivity and communities.

The highly stratified nature of southwest Victorian estuaries, coupled with the common occurrence of anoxia in deeper saline waters places their ecosystems at a particular risk during mouth opening. Typically the top 1ñ2 m of surface water flows out to sea once the mouth is opened. Most estuarine organisms require water having DO > 5 mg/L and this concentration is typically found in the surface water layer due to physical exchange with the atmosphere and photosynthetic activity. If all water having adequate DO is lost from the estuary, leaving only anoxic or poorly oxygenated deeper water, extensive mortality of estuarine organisms may result.

The point at which artificial opening of estuary entrances is triggered under management license conditions has been determined according to anthropogenic concerns, such as inundation of farmland, rather than by reference to the consequences of the trigger level on estuarine ecology, particularly wildlife or wetland habitat.

Inadequate records of natural and artificial openings and a lack of relevant research mean that it is nearly impossible to say what the impacts of artificial opening have been, what the natural regime was or what the best managed entrance opening regime has been. Artificial opening seems goes back at least 50 years in most estuaries, and it is not known if the frequency of mouth opening has changed over this time.

To attempt to redress the lack of comprehensive information, each of the estuaries considered in this report is given a general physical description, a description of its catchment and coast adjacent to its mouth as well as any alterations to the estuary over time. The estuaryís environmental values and the status of the ecological understanding of the estuary are provided. Finally, the details of existing management plans and past and present opening regimes and protocols are provided for each of the estuaries under consideration.

Contents

Index of Figures and Tables

FIGURES

TABLES

1 Introduction

Estuaries are subjected to many pressures because of their attraction as places for settlement and recreation and as receiving waters for runoff from increasingly disturbed catchments. Victoria is Australiaís most densely populated State and its relatively small number of estuaries are vulnerable to human impact. Management of these natural resources requires an understanding of physico-chemical processes such as water exchange, patterns of inundation, nutrient and pollutant fates, and sedimentation, as well as the way these influence biological communities. There are very few Australian estuaries for which such information is available (Bucher & Saenger 1991; NLWA 2002). This report reviews the significant physico-chemical processes and biological communities of estuaries in southwest Victoria (Figure 1).

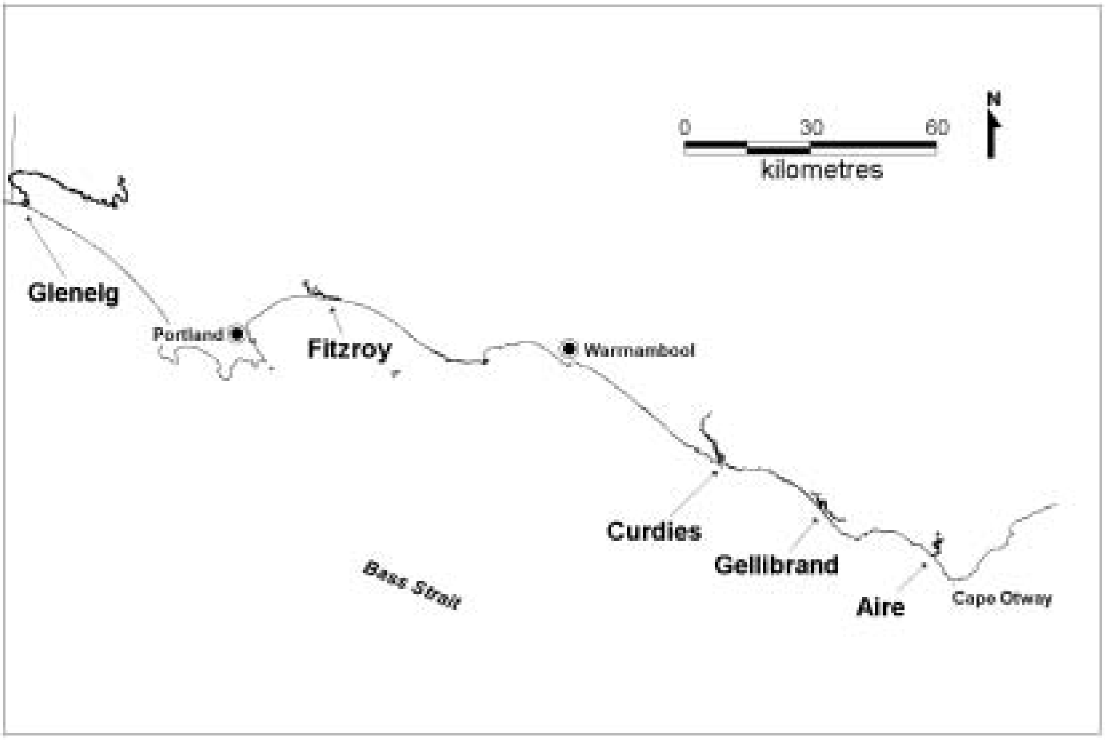


Figure 1. Southwest Victoria showing the location of the five estuaries for which Parks Victoria has management responsibilities.

Parks Victoria manages the land adjacent to the mouths of five estuaries along the west coast of Victoria that are periodically opened and closed at their entrances through the natural formation and erosion of sand bars. Currently Parks Victoria holds the waterway works licence issued under the *Water Act 1989* (Vic) to artificially open these sand barriers to release water out to sea when conditions of the licence are met. An increased understanding is required of how the timing and extent of these artificial opening events affects the various physical and biotic processes within the estuary systems.

Southwest Victoria has a climate characterised by a wet winter and spring followed by a dry summer and autumn. This ìwinter wet-summer dryî pattern results in marked seasonal changes in the regions river discharge. Winter floods are generally large enough to flush sand from estuary mouths creating open entrances. These permit marine inflow as flood flows decrease. The marine water travels upstream beneath overlying freshwater creating stratified or ìsalt-wedgeî estuaries. Over summer and autumn, low discharges are unable to clear sand brought into the estuary mouth by coastal longshore drift systems. The accumulating sand forms a flood tide delta sand bar complex, which greatly reduces the cross-sectional area of the mouth and may eventually close the mouth completely.

Under these conditions exchange of water with the sea is greatly reduced or halted and the estuary water level slowly rises due to river inflow or marine waters added when waves overtop the mouth sand bar. Under natural conditions an estuary would fill until the water level reached the height of the sand bar. Above this point estuary water begins to flow to the sea. Hydrostatic pressure due to the ìheadî of estuary water causes erosion of the sand bar and results in a widening and deepening of the developing entrance channel. Once water level has dropped to near sea level the greatly reduced outward flow can no longer clear sand transported into the estuary mouth by long-shore currents and wave action and the mouth begins to close again.

The frequency with which this cycle repeats itself is dependent on factors such as river flow, tidal and wave energy regimes, wind strength and direction, and atmospheric pressure. During low flow conditions episodes of mouth closure typically last from a few weeks to a few months while periods of open mouth conditions may last from a few days to a few weeks. Estuarine ecosystems, including the aquatic plant and animal communities and those in the fringing wetland systems have adapted to this irregular episodic filling and emptying of estuaries. Since European settlement however a number of developments have altered this natural cycle. Changes to vegetation within river catchments and increasing diversion of river water for domestic and stock use and irrigation has altered river hydrology. Historically, periodic flooding of farmland, buildings, roads, boat ramps and jetties resulted in the development of ìartificialî mouth opening practices. These practices were primarily directed at minimising costs to human activities with little appreciation of ecological impacts.

The need to re-examine estuary mouth opening practices has arisen from both an increased understanding of the relationships between hydrodynamics and biological communities of southwest Victoriaís estuaries and the observations of widespread mortality of estuarine organisms following some artificial openings.

The objectives of the report are to:

- synthesise current information from the international literature and from local sources regarding the management of estuaries, particularly with respect to those estuaries that undergo periodic opening and closing,
- synthesise data and information from all sources relating to the five western Victorian estuaries for which Parks Victoria holds the Waterway Works Licence (Glenelg, Fitzroy, Curdies, Aire and Gellibrand estuaries), and document current operational protocols for opening these estuaries, and
- identify knowledge gaps where additional research is required to provide data to underpin the management decision process for opening estuaries.

The focus of the report is on environmental values, mouth openings and management. This report does not specifically consider geomorphological, archaeological, social or economic values.

2 General Description of Intermittently Open Estuaries

2.1 DEFINITION OF AN ESTUARY

There are several definitions of what constitutes an estuary. This is because of the large variability in both estuarine form and salinity patterns. Attempting to define an estuary raises a number of questions about their spatial extent, for example:

- is it just the water body or does it include adjacent and/or associated lowlands (*e.g.,* salt marsh)?
- does it extend upstream as far as the tidal limit or to where salt water is no longer detectable (these are not always the same place)?
- is it necessary for an estuary to be open to the sea (*i.e.,* are estuaries different from coastal lagoons)?

A widely quoted definition is (Hodgkin, 1994):

> An estuary is a partially enclosed body of water which is either permanently or periodically open to the sea and within which there is a measurable variation in salinity due to the mixture of seawater with water derived from land drainage.

A simpler definition is given in the Victorian Coastal Strategy (2002), where an estuary is an ìinlet or river mouth that is influenced by tides and freshwater inputs from the catchmentî.

In southwest Victoria estuaries are never permanently open to the sea. Mouth closure occurs in all of them during summer and autumn. During drought, when winter rains fail, estuary mouths may remain closed for long periods (months) even during winter and spring. Such estuaries are described as ìintermittentlyî or ìperiodicallyî open.

2.2 CLASSIFICATION OF ESTUARIES

Classification schemes can be important resource management tools, helping to identify different estuary types, simplify their description and make it possible to transfer knowledge between estuaries with similar characteristics. Many schemes have been developed and Hodgkin (1994) points out that while each is valuable when used in context they each have limitations which may obscure the individual nature of a particular estuary if used out of context.

2.2.1 Geomorphological Classification Scheme

Estuaries can be grouped according to similarities in their shape and their origins (Officer 1976). Common Australian types are:

Drowned River Valley estuaries

These estuaries still retain the braided appearance of a river. They were over-deepened at times of lower sea level (when the coast was further offshore) and subsequently invaded by rising sea level. They are very common along the NSW and Victorian coast (for example, Sydney Harbour (NSW), Hopkins and Glenelg estuaries (Victoria)).

Coastal Plains estuaries

Lowland areas may also be submerged as sea level rises leading to broad open estuaries such as Port Phillip Bay.

Barrier or bar-built estuaries

Migrating dunes cut off marine embayments often leaving only a narrow entrance. They are common along the NSW and Victorian coasts (Gippsland Lakes, Snowy and Gellibrand estuaries). Coastal lagoons form when the barrier is almost permanently shut.

2.2.2 Classification based on Salinity Structure

Estuaries are regions where fresh and seawater mix and the nature of this mixing forms the basis of an alternative classification scheme for estuaries (Pethick 1984). Seawater has a salinity (S) close to 35 while freshwaters commonly have $S \leq 2$. Within an estuary, therefore, values of S may range from less than 1 to 35 (or sometimes higher in areas with high evaporation).

The currently used international definition for salinity is based on the ratio of the electrical conductivity of a seawater sample to that of a standard potassium chloride solution, which is unitless. Older definitions were based on the mass of salts present in the seawater with units of parts per thousand (ppt or g salt/kg water). The numerical value of salinity is the same in each convention.

Highly stratified (salt wedge) estuary

In this type of estuary, mixing is relatively ineffective and a layer of lower salinity water lies above a denser saline layer (Figure 2). In between these is a relatively thin mixing zone with an obvious halocline where salinity changes rapidly (ΔS ~ 10ñ15). Because the water bodies are largely separate from each other vertical differences may be found in other water properties such as temperature and dissolved oxygen concentration.

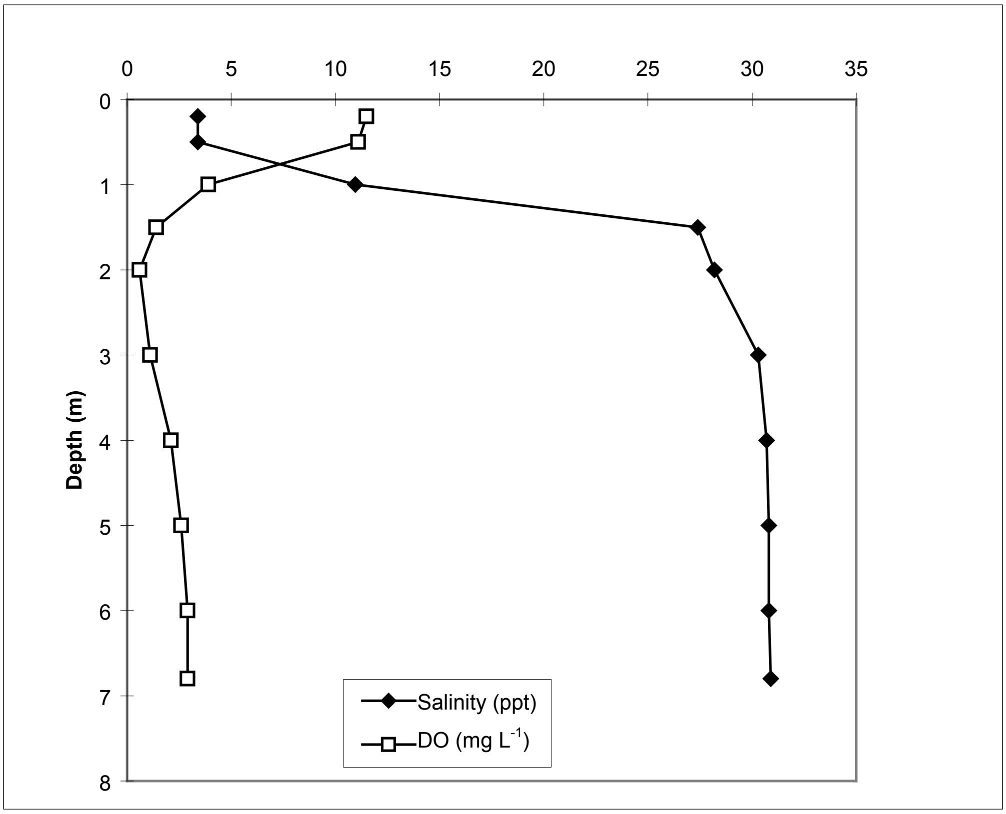


Figure 2. Variation in salinity and dissolved oxygen (DO) with depth at Sapling Creek, Lower Glenelg National Park, 26 km from the mouth on 27/5/98.

Source: Sherwood *et al.* (1998).

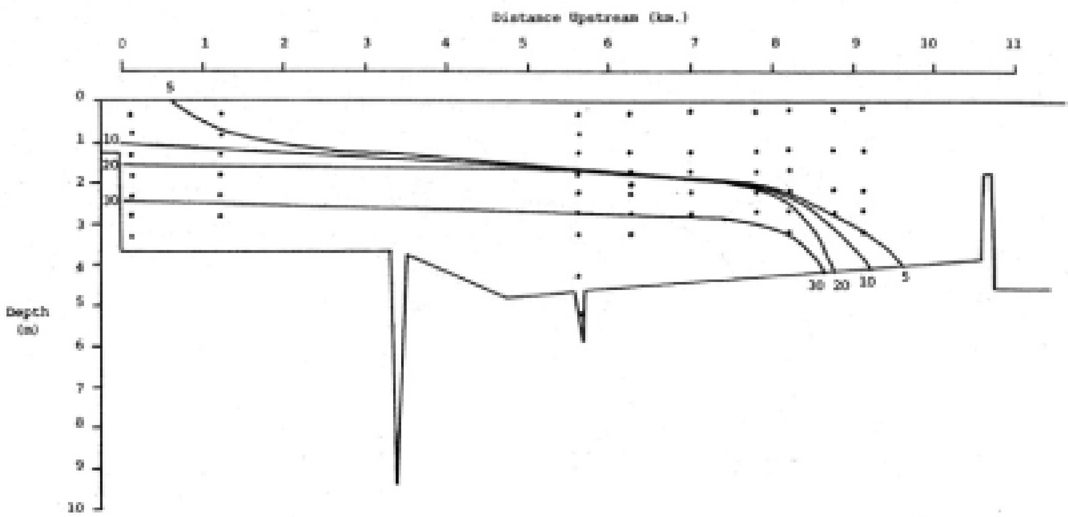


Figure 3. Longitudinal profile of salinity in Gellibrand estuary, 29/1/82.

Source: Sherwood (1984).

Stratified estuaries are found where the oceanic tidal range is small (< 1 m) and there is insufficient energy to efficiently mix the two water layers. The bottom, more saline layer is pushed into a wedge shape due to friction between the out flowing surface layer and the inflowing bottom water (Figure 3). This stratification can also be maintained for long periods following closure of an estuary mouth. Most western Victorian estuaries fall into this category.

Moderately stratified (partially mixed) estuaries

These have greater turbulent mixing due to a greater tidal range. Estuaries of this type include the Barwon estuary where the tidal amplitude is ≈ 1.5 m. They are also found further up Australia's east coast where tidal ranges are 1ñ2 m (Port Hacking (NSW) and Brisbane River (Qld) estuaries). In these estuaries the vertical salinity gradients ($\Delta S \approx 5$) along the estuary are less than those typically found in a salt wedge estuary.

Well mixed estuaries

Well mixed estuaries have a high level of turbulence resulting in no vertical salinity gradient, *i.e.,* water is completely mixed (or $\Delta S \approx 0$). There are not too many examples in southern Australia because of its relatively small tidal range. The Lower Barwon occasionally has this structure during spring tides when river discharge is relatively low. Salinity increases with distance downstream. Mixing can also occur in closed estuaries with little marine or freshwater input.

One difficulty with this salinity-based classification scheme is that estuaries do not always show the same type of behaviour either over time or at different locations along the estuary. At any time their mixing behaviour is influenced by factors such as the magnitude of tides or river discharge. The Barwon estuary for example has a salt wedge above Lake Connewarre in all but the highest river flows (when all salt water is flushed to sea). The lower Barwon (below the lake) is partially mixed when river discharge is high and well mixed when it is low. Stratification also develops in the Lower Barwon when tidal velocities drop (slack water) near high and low tide.

2.2.3 Classification Based on the Interaction of Hydrology and Physical Form

Hodgkin (1994) considered that Australian estuaries could be better grouped into five types which recognised the interaction of hydrology and physical form:

- lagoonal or barrier estuaries having relatively stable and uniform salinities because of restricted exchange with the sea,
- gradient estuaries where salinity progressively increased downstream,
- seasonal estuaries, where salinity varies seasonally rather than tidally,

- closed estuaries which are only intermittently open to the sea. Bars may close the estuaries for months or years, and
- estuaries that show more than one of these features.

Southwest Victorian estuaries are in this latter class. The marked seasonal inequality in river discharge means they may be totally fresh in winter or spring and marine dominated in summer and autumn (*i.e.*, seasonal estuary). On Victoriaís high energy coast low summer and autumn river discharge results in sand bars obstructing mouths, often for extended periods (*i.e.*, closed estuaries).

2.3 NATIONAL ESTUARY SURVEYS

Three independent studies have examined the development of a national classification scheme of Australiaís estuaries (Bucher & Saenger 1991; Digby *et al.* 1999; NLWA 2002). These have been predominately physically based, relying on easily quantifiable and biologically important physical characteristics. However, at a national level this has inevitably meant that the emphasis has been on large rivers and coastal lagoons, and a lot of Victoriaís small estuaries were not considered.

Both Bucher and Saenger (1991) and Digby *et al.* (1999) recognised 35 Victorian estuaries and 783 estuaries Australia-wide (Table 1), whilst NLWA (2002) recognised 62 Victorian estuaries and 970 estuaries nationally. The minimum estuary size adopted for a classification system or inventory is an important determinant of the findings. In State surveys of Victorian estuaries the number recognised differs considerably between the different studies, from 56 to 83 (McCarraher 1986 (a, b, c & d); Tunbridge & Glenane 1988). Much of this variation depends on whether sub-estuaries within the larger estuaries of Port Phillip Bay, Western Port and Corner Inlet are considered separately.

The north coast of Australia has many more rivers and therefore many more estuaries than the south coast (Warner 1986). From the South Australia-Victoria border to Albany in Western Australia only one significant river system, the Murray-Darling, enters the sea along approximately 3000 km of coast line. About 2000 km of this coast borders the riverless Nullarbor Plain.

Table 1. Australian Estuaries identified by Bucher and Saenger (1991) and Digby *et al.* (1999).

State	No. of estuaries
Queensland	307
Western Australia	145
Northern Territory	137
New South Wales	81
Tasmania	63
Victoria	35
South Australia	13
Total	783

2.4 PHYSICAL PROCESSES ACTING IN ESTUARIES

Estuaries are dynamic systems in which conditions are constantly changing. Many physical processes operate simultaneously and over different time scales (Table 2). The interplay of these at any time may influence levels of inundation, water circulation, sediment movement and salinity patterns. All of these in turn affect biological organisms, for example by determining the salinity of water around them or the rate of sediment deposition on bottom-dwelling (benthic) animals or plants.

Table 2. Time scales of various physical processes which act on estuaries.

Process	Time Scale
ebb/flood tide cycle	≈ 12 hours
spring/neap tide cycle	≈ 14 days
wind patterns	hoursñdays
changes in river discharge	daysñweeks

2.4.1 Tidal Exchange

The coast of western Victoria is microtidal, with mean spring tides of approximately 1 m and neap tides of 0.2ñ0.3 m. Only the Barwon estuary is subjected to larger oceanic tides ñ mean spring tides are about 1.6 m (Nelson & Keats 1981). This difference in tidal range has a significant impact on the salinity structure of the estuaries. Those west of the Barwon are highly stratified salt wedge estuaries while the Barwon is predominantly a well-mixed estuary. The state of the mouths is a major influence on the tidal mixing energy.

When the estuary mouths are open, estuaries can fill and empty in response to the forcing of oceanic tides (Figure 4). Marine water flows into the estuaries via their mouths during flood tides and out again on ebb tides (Figure 5).

When the mouth is narrow it can have a restrictive or "throttling" effect on water currents. This means the rise or fall of water level in the estuary is slower than that of the sea outside. There is a lag time (or phase difference) between tides outside the mouth and those inside. In the Glenelg River estuary, for example, tides may be delayed up to 4 hours compared to oceanic tides as the estuary slowly fills up or empties (Sherwood *et al* 1998). One other consequence of this throttling effect is that the tidal range in the estuary may be reduced relative to that of the ocean.

In shallow water the tidal wave is propagated with a speed (v m/s) given by:

$$v \approx \sqrt{gh} \qquad (1)$$

Where h is the mean water depth (m) and g is the gravitational acceleration (9.8 m/s). From Equation 1, if the average estuary depth is 2 m, then the tidal wave will move at 16 km/hr, whereas if the average estuary depth is 3 m the tidal wave will move at 20 km/hr.

Friction between the estuary channel and the moving water acts to reduce tidal energy and so the amplitude of the tidal wave decreases upstream. This effect can sometimes be counteracted by an upstream decrease in estuarine channel cross-sectional area which acts to increase the tide height. Each estuary will show different tidal characteristics because of these factors and others such as the mouth cross-sectional area.

The tidal wave in an estuary also becomes asymmetrical with the ebb (outflowing) tide taking longer than the flood (incoming) (Figure 6). This is because as water depth decreases so does the tidal wave velocity (see Equation 1), so the wave crest ìcatches upî to the preceding trough.

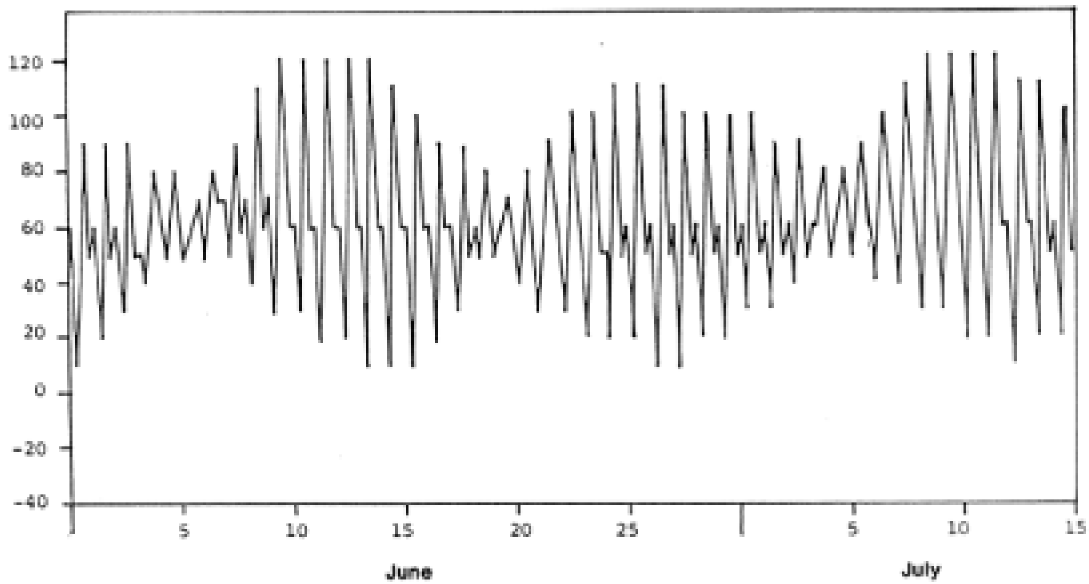


Figure 4. Oceanic tides predicted for Portland, 1982, showing neap/spring cycle and marked diurnal inequality.

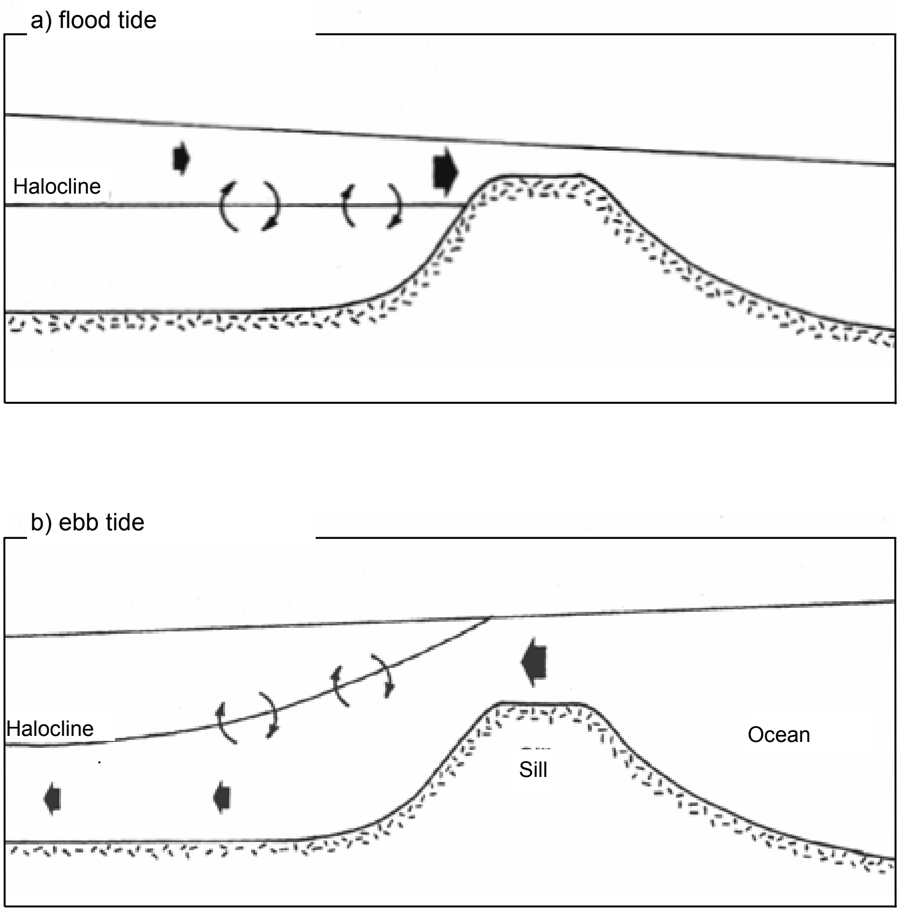


Figure 5. Tidal exchange across the mouth bar.

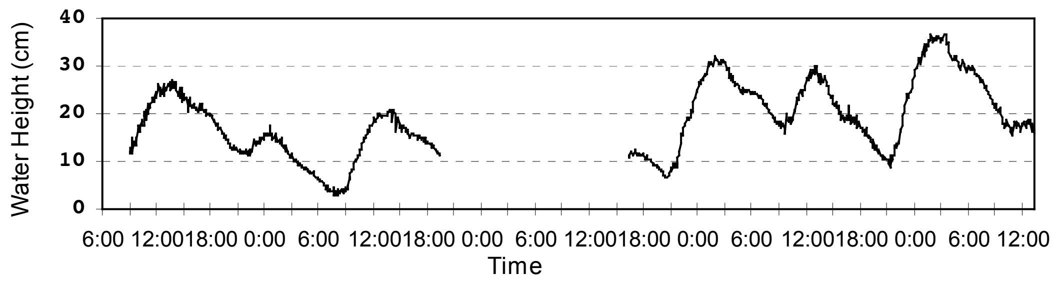


Figure 6. Asymmetrical tide as shown by water height at Nelson jetty, Glenelg River, October 1990.

Source: Sherwood et al. (1998).

Over the neap/spring tidal cycle (Figure 4) estuaries with restricted entrances fill up as tides become larger and then empty as they decrease. This is again due to the throttling effect of the estuary mouth that limits water inflow and outflow. Mean estuarine water level can rise and fall with a periodicity of about 14 days. A four month study of tides in the Hopkins estuary (SepñDec 1981) showed mean water level rose to about 0.5 m AHD (Australian Height Datum) during spring tides and then fell to about 0 m AHD during neap (Sherwood 1985). Haas (1977) and Haas *et al.* (1981) have found that variations in the neap-spring tidal amplitude played a major role in regulating vertical density stratification in rivers entering Chesapeake Bay (Virginia, USA). The effect was observed up to 20 km upstream and was attributed to greater turbulent mixing accompanying increased tidal velocities during spring tides.

The tidal prism of an estuary is the volume of water exchanged in a tidal cycle. It can give an indication of the ability of an estuary to reduce pollution impacts by moving pollutants into the ocean. For the Lower Barwon:

- Mean estuary volume = $2.72 \times 10^6 m^3$
- Tidal prism = $2.8 \times 10^6 m^3$

Here the tidal prism is ≈ 100% of total volume ñ virtually all water in this part of the estuary is exchanged during each tidal cycle (Sherwood *et al.* 1994). It is a well-flushed estuary and pollutants would be rapidly removed. By comparison, in the Hopkins estuary:

- Mean volume = $3.1 \times 10^6 m^3$

- Tidal prism = 3 x 10^4 m^3

The prism is ≈ 1% of the total volume. Complete tidal flushing would take at least 100 tidal cycles (≈ 50 days).

Flushing characteristics are also influenced by the type of estuary and by river discharge. Pollutants in the bottom salt wedge layer of the Hopkins estuary will be exchanged much more slowly than those in the surface water. In fact, pollutants may even travel upstream in this bottom layer before they become mixed in to the surface water and eventually wash from the estuary. The residence time of pollutants may be much longer than predicted on the basis of a simple tidal prism model.

2.4.2 Meteorological Factors

Other factors that may influence salt water intrusion into an estuary include atmospheric pressure, wind and wave action.

Atmospheric pressure leads to sea-level variations, by what is known as the ìinverse barometer effectî (Beer 1983). Theoretically, sea level rises under low pressure systems and is depressed under high pressure by a factor of 1.01 cm/mbar. Hamon (1966) found the sea level rose 1.26 cm/mbar at Port McDonnell, 28 km west of the mouth of the Glenelg. He concluded that the inverse barometric effect accounted for about 80% of non-tidal sea-level variation, with sea level lagging pressure change by less than half a day. Pressure systems move through the region every 5ñ15 days with speeds of 700ñ800 km/day (Morrow 1984) resulting in pressure changes of up to 40 mbar. Sea level may therefore change by up to 50 cm as a result. This is comparable to the tidal range and so has a significant effect on salt water intrusion into these estuaries. Black *et al.* (1981) found substantial net gains of sea water by the Peel-Harvey estuary (Western Australia) as sea level rose about 20 cm due to the inverse barometer effect.

In western Victoria, on-shore winds from the west and southwest are common in all months and may reach speeds up to 30 knots. Such strong winds are often associated with low pressure and cold fronts. Off-shore winds (north to north-westerly) up to 20 knots often follow high pressure systems. A study by Nelson and Keats (1981) of meteorological tides at the entrance to the Barwon estuary between 1975 and 1977 indicated that about 60% of the meteorological tide could be attributed to atmospheric pressure and the westerly vector of wind velocity. They found that actual still water sea levels could be between 0.5 m higher and 0.3 m lower than predicted from astronomical tides. This analysis made no allowances for wave height or wave run-up. Large waves generated by Southern Ocean storms may arrive at the coast any time. These can overtop the sand bar at the mouth and add significant volumes of sea water. In April 1994 the Hopkins estuary level rose 10 cm in 6 hours due to this effect (Rouse 1998)

2.4.3 River Inflow

The regionís climate is classified as temperate humid with a winter rainfall maximum (*i.e.*, ìMediterraneanî or Csb on the Kˆppen-Geiger System; Skinner & Porter 1995). River discharge reflects the rainfall pattern having high discharge in winter and spring, and low discharge in summer and autumn. Mean monthly winter discharges are over 20 times those of the dry autumn months (Sherwood 1988). Discharge patterns vary considerably from year to year and from day to day ñ particularly in the wetter months ñ in response to the passage of frontal and low pressure systems over the region.

Annual rainfall is between 700 and 800 mm along the coastal fringe and decreases inland. Uplift of oceanic air as it encounters the Otway Ranges results in annual rainfall of over 2000 mm in some parts of the Otways.

The large difference in seasonal flows has a marked impact on the turbulent energy regime of the river's estuaries. Winter floods often flush salt water from the estuaries completely for several weeks at a time. As discharge drops in spring, fresh, well-oxygenated seawater re-enters the estuary. Over summer and autumn the mouth becomes more restricted as it sands up and tidal exchange is reduced. The bottom salt wedge layer stagnates and may become anoxic (*i.e.*, no dissolved oxygen is present).

Residence times of river water in the estuary can be estimated in a similar manner to tidal flushing. Clearly both tidal and river flushing act together so estimates of flushing time based on just one effect will tend to be high. The simplest assumption to calculate residence time is that river water completely mixes with estuarine water as it travels to the sea. On this basis:

$$t_f = V/Q \qquad (2)$$

where

t_f = residence time (s),

V = estuary volume (m^3), and

Q = river discharge (m^3/s).

During summer the Hopkins estuary has a typical discharge of 7×10^4 m^3/day. Since $V = 3.1 \times 10^6$ m^3, the residence time can be estimated as about 44 days, provided the estuary mouth is open. This is too high because the highly stratified nature of the estuary means that perhaps half the estuary is occupied by salt water and mixing is slight. Therefore a more realistic residence time for river water may be around 20 days.

Despite the limitations of this method of estimating residence times it is clear that river water spends a long time in the Hopkins estuary during summer. This situation would be similar for most southwest Victorian estuaries. At times when the mouth closes completely, residence time is no longer determined by tidal exchange or river discharge and increases greatly.

2.4.4 Sedimentation

Rivers transport sediment from their catchments to the sea. Some of the planet's large rivers carry very high suspended solids loads (Table 3). Even small rivers such as those of southwest Victoria deliver thousands of tonnes of sediment to their estuaries each year.

Table 3. Comparison of suspended solids loads for selected rivers in Australia and overseas.

River	Suspended Solids (tonnes per year)
Yellow (China)	2.1×10^9
Amazon	4.0×10^8
Mississippi	5.8×10^8
Murray-Darling	3.2×10^7
Hopkins	1.5×10^4

Source: Beer (1983)

It is common for water velocity to drop when rivers enter their estuaries as the estuaries are often much deeper and/or wider than the river. Sediment can be deposited when water velocity is reduced. Similarly, seawater entering on a flood tide may carry a large suspended solids load (chiefly sand). The reduction in velocity as it enters the estuary mouth results in deposition of much of this load close to the mouth, increasing restriction of the mouth and forming a flood tide delta (Pethick 1984).

One other factor is responsible for deposition of riverine suspended solids in estuaries. Under the influence of salts in the estuary fine colloidal particles no longer repel each other and aggregate together. These larger particles settle under gravity. Rivers often transport colloidal clays and organic matter large distances because their low salinity discourages coagulation. This is not so in estuaries (Pethick 1984).

As well as these external sediment sources, the estuary produces its own sediment. Estuarine organisms are responsible for a constant rain of particulate matter to the estuary floor as a result of feeding, defecation and death. Collectively these sedimentation processes lead to the formation of flood tide shoals near the estuary mouth and mud flats and sand banks upstream in the estuary.

Not all sediment is trapped in the estuary. Sediment can be resuspended by major floods or wind generated turbulence and transported out to sea. In large floods most sediment may stay suspended until river velocity eventually drops outside the mouth.

2.5 EVOLUTION OF ESTUARIES

Over geological time scales estuaries are ephemeral, short-lived features of the coastal environment. There are two reasons for this:

1. Sea level has changed significantly and repeatedly over the last 1ñ2 million years in response to climatic oscillations between cold (glacial or ice-age) and warm (interglacial) periods during the Quaternary Period. The actual location of estuaries has shifted across the landscape as the position of the coast has varied with rising or falling sea level. Because of this, estuaries (and their biota) have migrated large distances back and forth across the Continental Shelf.
2. We live in geologically ìunusualî times ñ the seas are higher now than they have been for over 90% of the Quaternary (Gill 1985). Sea levels were last close to or higher than present in the Last Interglacial (about 125,000 years ago; Sherwood *et al*. 1994). For most of the intervening period sea level has been lower (up to 130 m lower 20,000 years ago when the last glacial was at its most severe). The coast was then on the edge of the continental shelf (perhaps 50ñ100 km off shore) and Bass Strait was dry land. As climate warmed and the huge continental ice sheets melted, sea level rose, reaching its present level about 6,000 years ago. This means our present estuaries are all younger than 6,000 years.
3. During relatively stable conditions (as now) estuaries slowly silt up ñ changing both habitat availability and salinity structure. Animals that inhabit the estuary change in response to this and some species may become locally extinct. Table 4 shows the change in estuary fauna in progressively younger fossil shell beds in the Hopkins River estuary (Sherwood 1988). Species less tolerant of lower salinities such as *Notospisula* and *Katelysia* were lost from the estuary.

Table 4. Dominant molluscan fauna from Holocene fossil shell beds located in the Hopkins estuary.

Species	Shell bed age (years before present)					
	2260±70 (1.0)[a]	2500±100 (1.8)[a]	2620±50 (7.6)[a]	3000±50 (5.0)[a]	4960±50 (6.2)[a]	5900±70 (9.0)[a]
Mytilus edulis planulatus					+	
Ostrea angasi	+	+	+	+	+	+
Notospisula trigonella					+	+
Nassarius burchardii[b]				+	+	+
Katelysia rhytiphora			+	+	+	
Solatellina donacioides[b]					+	+
Bembicium auratum			+	+		
Tellina deltoidalis[b]		+	+	+	+	+
Velacumantus australis			+	+	+	+

[a] Figures in brackets give the distance upstream of the shell bed in kilometres.

[b] Presently living in the estuary

Source: Sherwood (1988).

Gill and Lane (1985) obtained a calibrated radiocarbon age of (6110 ± 190 BP; SUA2153) for *Anadara trepezia* associated with *Ostrea* in an aboriginal midden beside Lake Connewarre in the Barwon estuary. *Anadara trepezia* from Curdies Inlet gave a calibrated radiocarbon age of (7000 ±160 BP; SUA2509) while *Ostrea angasi* from the same site yielded an age of (6980±160 BP; SUA2442). In both estuaries these species are no longer found, indicating a change from marine domination to increased river dominance in response to a small sea level retreat and or sedimentation since the estuaries were established at their present location.

2.6 HYDRODYNAMIC CYCLE IN ESTUARIES OF SOUTHWEST VICTORIA

All estuaries in the southwest show a similar annual hydrodynamic cycle (Figure 7). Winter floods flush salt water from the estuaries in all but the driest years. Estuaries become extensions of their freshwater rivers for periods up to several weeks. As discharge drops in late spring/early summer salt water again enters the estuary and moves progressively upstream. By mid-summer the estuaries have relatively stable salinity profiles and a strong marine dominance. Upstream saline waters may become anoxic due to the slow replacement of deeper waters.

The estuaries of the southwest coast of Western Australia show similar hydrological cycles to those in the west of Victoria and have been the subject of fairly extensive investigations (*e.g.*, Hodgkin & Lenanton 1981; McComb & Humphries 1992; McComb & Lukatelich 1990; Stephens & Imberger 1996; Deeley & Paling 1998). In contrast there have been relatively few studies published for estuaries in Australiaís south east (*e.g.*, Becket *et al.* 1982; Geddes & Butler 1984; Sherwood 1988).

Small highly stratified estuaries similar to those described here are also found in South Africa and have been extensively researched (*e.g.*, Heydorn 1984; Largier & Taljaard 1991; Baird & Ulanowicz 1993; Allanson & Baird 1999; Scharler & Baird 2000; Mackay & Cyrus 2001).

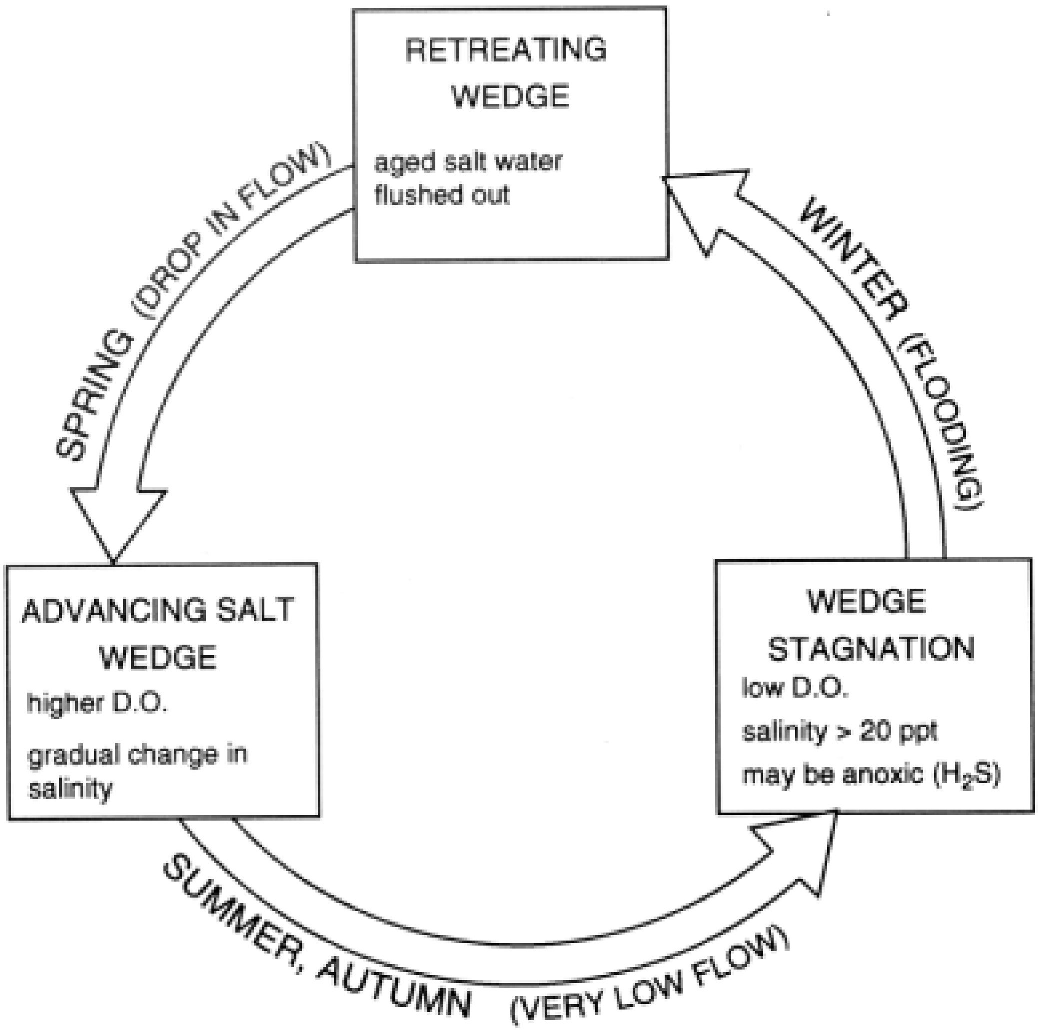
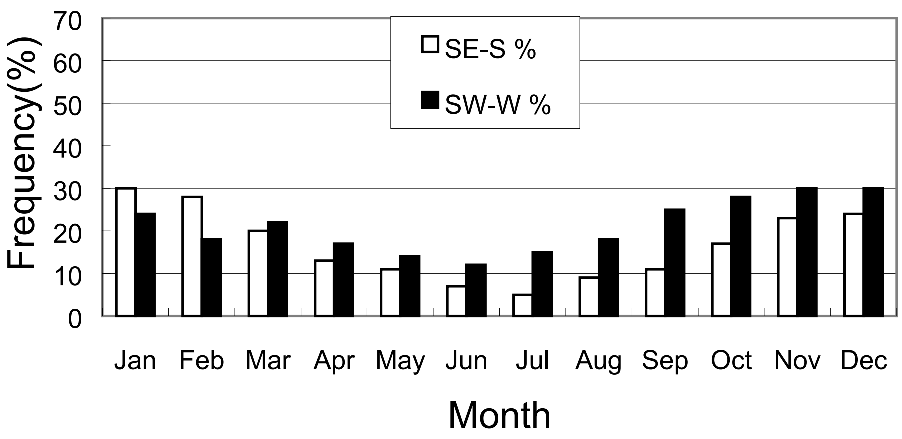


Figure 7. Generalised hydrodynamic cycle of west Victorian estuaries.
Source: Bantow et al. (1995).

2.7 NATURE OF ESTUARY MOUTHS

Gill (1985) has analysed the long-shore drift systems for southwest Victoriaís coastline. Winds from the SW and S are dominant for much of the year (Figure 8) however, during spring and summer winds from the SE and S increase in frequency. This wind pattern results in a predominantly easterly long-shore drift for about 9 months of the year with a westerly drift in summer. This change in direction coincides with the decrease in river discharge and so developing sand bars divert entrance channels to the western side of estuary mouths. In some cases, operation of this process over longer time scales has resulted in coastal dune growth diverting river courses substantially westwards (*e.g.,* Barwon, Curdies, Merri, Gellibrand and Glenelg Rivers).

(a) 0900 hrs



(b) 1500 hrs

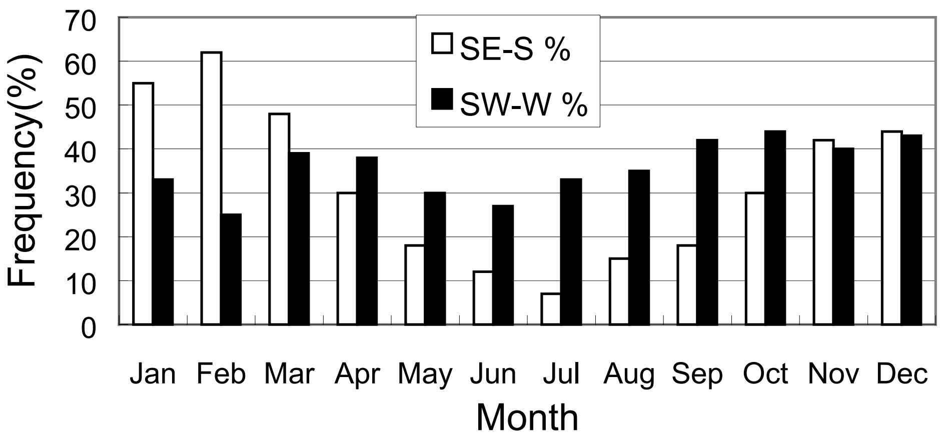


Figure 8. Average monthly frequency of winds from the SE-S and SW-W at Warrnambool for (a) 0900 hours and (b) 1500 hours.

Source: Bureau of Metrology.

During summer freshwater inflow decreases, the exchange across the mouth is greatly reduced and the longitudinal extent of anoxia in the estuary can increase. During winter, freshwater floods erode sand bars at the estuary mouths so that their channel cross-sectional areas are at maximum yearly values. As discharge drops, long-shore drift brings sand back into the mouths and a bar/flood-tide delta system develops, greatly reducing the channel cross-section. Under very dry conditions, typically in autumn, the mouths can sand up completely.

Tunbridge and Glenane (1988) summarised the entrance conditions and abundance of fish species for fish surveys in western Victorian estuaries during 1975ñ1983. Aire River and Curdies River are grouped together as having an îoftenî closed entrance while Fitzroy, Gellibrand and Glenelg River are grouped together as having their entrances only îoccasionallyî closed. The basis for this classification is not described in their report however.

Historical accounts reveal that this seasonal reduction in mouth channels predates the arrival of Europeans. Granville Stapyleton, a member of the first European party to discover the Glenelg River, recorded this diary entry regarding its mouth after an expedition had rowed a long boat over 85 km down river to the sea (Douglas & OíBrien 1971):

> August 22, 1836 ìThe river a hundred yards wide soon after leaving camp and the water fresh to within a few miles of the sea [sic]. From this fact can be inferred what sort of an affair is the river mouth. The channel was scarcely deep enough to float the boat which grounded on sand in one part. The river is deep up to its very mouth, 4 fathoms at the side and 6 and 7 in the middle, and the deep sea outside.î

In 1866 David Curdie reported crossing several creeks ìbarred at the sea with sand but having deep water many miles inlandî during a trip on horseback along the coast between the mouth of the Gellibrand and Warrnambool (Curdie 1866).

Increased river water diversion for irrigation and domestic supply, and changes to catchment vegetation patterns (resulting in a more rapid movement of water through the catchment) might be expected to increase both the incidence and duration of mouth closure.

2.8 ANOXIC CONDITIONS

Dissolved oxygen (DO) concentrations are generally taken as an important measure of the health of aquatic ecosystems. Very low DO or anoxic conditions raise concerns about threats to estuarine productivity. Anoxia is atypical of most of the worldís oceans and coastal areas. Only in marine or estuarine basins where circulation is restricted does it develop. Well documented examples include the Black Sea (Codispoti *et al.* 1991), the Cariaco Trench

(Richards 1975; Deuser 1975), and fjords such as Saanich Inlet in Canada (Emerson *et al.* 1979; Burrell 1988) and Norwayís Framvaren Fjord (Skei 1988). Chemical studies of oxygen deficient waters in Australian estuaries are sparse (*e.g.*, Butler & Smith 1985). Recently, problems of anoxia have received increasing attention in coastal and estuarine waters of the USA (Turner *et al.* 1987; Kuo & Nielsen 1987; Kuo *et al.* 1991). Anoxia appears to have become more widespread and of longer duration in Chesapeake Bay since the 1930s (Flemer *et al.* 1983) and significant ecological effects appear to have resulted (Seliger *et al.* 1985).

Research since 1980 into southwest Victorian estuaries has shown that anoxic bottom waters commonly occur in most over summer and autumn. Concentrations of toxic substances such as ammonia and hydrogen sulphide can reach elevated levels (Table 5; Sherwood & Rouse 1997). There is little known of the significance of anoxia for estuarine biota and the processes involved in the establishment and maintenance of anoxia.

Table 5. Comparison of maximum concentrations of sulphide, iron (II) and manganese (II) found in anoxic basins of the Hopkins estuary (Sherwood & Rouse 1997) to values reported for other anoxic waters (Millero & Sohn 1992).

Basin	Location	Maximum Concentration		
		H_2S (mM)	Fe^{2+} (μM)	Mn^{2+} (μM)
Hopkins Estuary	Australia	1.09	2.2	17.9
Framvaren Fjord	Norway	8.00	2.6	18
Black Sea	Europe	0.35	2	16
Cariaco Trench	Caribbean	0.16	0.31	0.43
Saanich Inlet	Canada	0.25	ñ	ñ

Anoxia has been observed annually in Hopkins estuary surveys since 1980 and, in unusually dry winters may persist for 12 months or more (Cawthray 1991; Saywell 1992; Perryman 1995). Anoxic water may comprise between 16% and 35% of the estuary volume and represents a significant store of nutrients for the overlying aerobic community. Under calm conditions, when turbulence is low, utilisation of nutrients by bacterial communities just below the oxycline may reduce their migration into overlying waters. Bacterial ìlidsî acting in this manner have been suggested for a number of anoxic systems (Burrell 1988). More commonly, vertical transport of nutrient-rich water will be generated by wind-mixing or intrusion into the basin of ìnewî deep water from downstream. Under these conditions the anoxic water may contribute significantly to overall estuarine productivity (Rouse 1998).

Processes occurring at the boundary between oxic and anoxic conditions need to be studied in more detail to determine the extent to which exchange across it is mediated by physical, chemical and biological processes. The dominant mechanisms for, and the significance of, anoxic water nutrient supply to overlying waters are not quantified.

Anthropogenic changes to estuaries resulting from river water diversion for domestic, agricultural or industrial purposes may reduce the depth of lower salinity, oxygenated surface water. Alternatively, increased inputs of nutrients have the potential to alter the spatial and temporal extent of anoxic conditions through their impact on productivity. In both, cases the predominantly aerobic estuarine community may become more vulnerable to a major loss of habitat if the oxycline is brought closer to the estuary surface.

2.9 EUTROPHICATION OF ESTUARIES

Nutrient enrichment of estuarine waters increases their vulnerability to înuisanceî algal blooms. In southwest Victoria algal blooms have been recorded in the Hopkins (Rouse 1998) and Curdies (Maher 2001) estuaries. The Gippsland Lakes in eastern Victoria and the Peel-Harvey system in Western Australia have also had extensive blooms. Those of the Peel-Harvey are probably the most studied in Australia. Blue-green algae (*Nodularia*) blooms have been a problem in the Peel Harvey estuaries since 1980 (McComb & Lukatelich 1986), with large blooms causing fish deaths. *Cladophora,* a green algae, has been a problem since the early 1960s. Excessive phosphorus use in the sandy catchment and low flushing rates have been identified as causal factors.

Blue-green algal blooms have been recorded in Curdies Inlet in 1991, 1998 and 2001 (Maher 2001). In the first two cases, blooms were of *Anaebena* and *Microcystis* when estuarine surface water salinities were below 10. The 2001 bloom was of *Nodularia spumigena* when salinities were above 20. The *Nodularia* species is also responsible for blooms in the Peel-Harvey system. The two estuaries share similar characteristics ñ both have large shallow lagoons prior to their mouths (which act as sediment traps) and rich farmland catchments. Maher (2001) suggested that nutrients are delivered to the Curdies in winter high flows and are subsequently re-mobilised from bottom sediments during the low flow seasons of summer and autumn.

Other conditions during summer and autumn also favour algal growth: a stable water column (*i.e.*, no flow), shallow waters (favouring sediment re-suspension), warm temperatures and a strong light climate. The only other recorded bloom in the southwest was of *Ceratalina* (a diatom) in autumn in the Hopkins estuary (Rouse 1998). Here nutrient input after the first rain-generated run-off was thought to be the cause.

While the particular causes and timing of blooms can not yet be predicted for individual water bodies the general causes are understood. Nutrient management is seen as a key action to reduce their incidence and severity (ANZECC 1999). Trigger levels have been developed for Australian estuaries (Table 6). If nutrient concentrations exceed these, management action is recommended. As Table 6 shows, concentrations of nitrogen and phosphorus in southwest Victorian estuaries are commonly above the trigger levels. Catchment management of nutrients is a high priority for the Glenelg-Hopkins and Corangamite Catchment Management Authorities.

Table 6. ANZECC Guidelines and measured estuarine nutrient concentrations for west Victorian estuaries.

Estuary	Total Nutrient Concentration (mg/L)		Source
	Nitrogen	**Phosphorus**	
ANZECC Trigger	0.08	0.045	ANZECC (1999)
Curdies	0.77ñ3.44	0.04ñ0.51	Maher (2001)
Gellibrand	0.16ñ2.1	0.01ñ0.42	Kelly (2000)
Glenelg	0.44ñ0.97	0.021ñ0.22	Sherwood *et al*. (1998)

2.10 ENVIRONMENTAL FLOW NEEDS OF ESTUARIES

Australia is the driest inhabited continent and freshwater is its scarcest resource. Mean precipitation is only about 420 mm/annum with slightly more than 50 mm annual runoff (Warner 1986). Australians are also coastal dwellers ñ 80% of the population live on 1.6% of the land area and over 85% live within 80 km of the sea (Holmes 1986). As populations increase more water is diverted from rivers for irrigation, domestic and industrial use. Victoria already annually harvests 4.6 x 10^9 m^3 of ground and river water, about half the estimated total resource (9.1 x 10^9 m^3; NREC 1989). Water impoundments are currently installed on the Glenelg and Barwon Rivers while water for domestic supply is pumped directly from the Gellibrand to supply west Victorian towns and the City of Warrnambool.

In South Africa where freshwater is also in short supply, Schlacher and Wooldbridge (1996) have analysed the ecological implications of a reduction in freshwater flow to estuaries. They argue that river inputs of adequate quantity and quality are necessary:

- for flooding events to scour accumulated estuarine sediments,
- for riverine nutrient inputs to drive estuarine production,

- to maintain a broad range of salinities to support a diverse set of habitats and communities, and
- to maintain open entrance channels to allow tidal flushing and migration of species into and out of the estuaries.

Such considerations are undoubtedly also important for southwest Victorian estuaries (see Sherwood 1988). These estuaries also have an additional environmental flow need. During winter, flow sufficient to flush all anoxic bottom water from the estuaries and to inundate the fringing wetlands is important (Table 7).

Table 7. River discharges necessary to flush salt water from southwest Victorian estuaries.

Estuary	Discharges (x 10^3 m^3/day)
Gellibrand	600
Glenelg	6000
Hopkins	4000

Source: Sherwood (1988).

There is increasing evidence that the life cycles of many organisms are attuned to the estuarine hydrodynamic cycle. Spawning of fish and zooplankton coincides with the return of oxygenated seawater to the estuary following winter flooding (Newton 1996). Some fish species require water of a particular temperature and salinity for spawning (Sherwood 1988). In the absence of flushing the development of anoxia and high concentrations of ammonia and sulphide, which are toxic to many organisms (Table 5), may limit spawning success. At present all rivers have winter discharges sufficient to completely flush their estuaries except in severe drought years (such as 1982). During 1982ñ1983 anoxic waters persisted for nearly 18 months in the Gellibrand estuary (Sherwood 1992).

Also of concern is the quantity of freshwater available in summer and autumn to prevent hypersalinity and maintain entrance channels in an open state. Evaporation rates (over 20cm/month) in southern Australia commonly exceed rainfall over summer and autumn. This coincides with periods when river flow is at its lowest. Estuaries with large ratios of surface area to depth may become hypersaline when water exchange is reduced by the combination of lower discharge and restricted mouths. Salinities of 40ñ50 have been reported in Western Australiaís Peel-Harvey estuary (McComb & Humphries 1992) and 70ñ100 in the Coorong, South Australia (Geddes & Butler 1984).

2.11 ECOLOGY AND ENVIRONMENTAL VALUES OF ESTUARIES

As a system, an estuary is more than the tidally influenced water in the channels. It also includes the fringing wetlands along the channel edges. These wetlands are inundated during freshwater floods, floods associated with mouth closure, or during high tides. Inundation both submerges the floodplain, and raises groundwater levels, wetting floodplain soils. The estuary channel and its associated wetlands need to be considered together when identifying estuarine environmental values.

Environmental values of estuarine wetlands may be considered in three different categories ñ those involving ìprocessesî, ìgoodsî and ìservicesî (Keddy 2000). ìProcessesî include hydrological storage, biological productivity, biogeochemical cycling and biological diversity. ìGoodsî include food, medicinal plants and tourism. ìServicesî include regulating climate, cleansing air and water and detoxifying pollutants. More specific estuarine environmental process values include: containing unique habitat types; habitat(s) for rare or endangered species; and breeding/nursery grounds for fish. The following discussion on environmental values deals primarily with processes, and specifically the biology of estuarine wetlands and the associated estuarine catchment. An estuary catchment is defined here as that part of the whole river catchment that directly drains into the estuary, and is subject to inundation or increased soil moisture because of the hydrology of the estuary.

2.11.1 Estuarine Wetlands

Estuarine wetland communities or ecosystems are reflections of multiple environmental factors acting simultaneously. To understand and manage estuarine wetlands, it is important to determine the quantitative relationships between the environmental factors and the properties of the estuarine wetlands, and how these change through time (Keddy 2000). Estuarine wetlands are a result of the meeting of freshwater and marine environments, and because of this they are a highly variable and demanding environment for biota. Both in the water and in the soils, salinity, nutrient and oxygen concentrations play an important role in the functioning of the ecosystem and the organisms present.

Estuarine wetlands provide one of the major reducing systems present in the biosphere, functioning as transformers of nutrients and metals. Nitrogen, phosphorus, sulphur, iron and manganese cycles are closely tied to different layers of oxidation, and flooded soils are critical in biogeochemical cycles (Keddy 2000). Flora and fauna living in estuarine wetland soils are often specialised, having to contend with a shortage of oxygen, accumulations of toxic gases, and atypical concentrations of ions in the soils (Keddy 2000). Estuarine sediments are also very rich in organic matter and essential elements such as nitrogen and phosphorus. They provide an important habitat for burrowing and surface dwelling fauna (Moverley & Hirst 1999; Herman et al. 1999; Edgar *et al.* 1998; Deeley & Paling 1998). Biota living in the water column of the estuary are also subject to large variations in salinity, dissolved oxygen, and hydrology (Newton 1996; Chan & Hamilton 2001; Wortmann *et al.* 1998).

2.11.2 Terrestrial vegetation

Records from the Victorian Flora Information System (NRE 2001a) list 337 species of flora, including 71 introduced plant species, in the five estuary catchments (Appendix 2). The number of plant species in each estuary varies widely, and is a reflection both of the area and condition of the remnant vegetation as well as the amount of times the catchment has been surveyed (Table 8). Fitzroy River has the lowest number of plant taxa (31) but also the lowest number of sites surveyed in its catchment. Gellibrand has the highest number of taxa (177) from 51 sites indicating good remnant vegetation. The Curdies estuary has the highest number of surveyed sites (146) but only 59 taxa, perhaps because of a small amount of remnant vegetation left in the estuary catchment.

Table 8. Summary of flora in estuary catchments of the five estuaries.

	Glenelg	Fitzroy	Curdies	Gellibrand	Aire
Number of Sites	20	12	146	51	21
Plant taxa	115	31	59	177	145
Conservation listed plants	5	1	3	3	5
Weeds	20	5	16	28	33

Source: NRE (2001a).

Ecological Vegetation Classes

NLWA (2002) conducted preliminary mapping of estuarine habitats from aerial photos identifying areas of saltmarsh/saltflats, but no ground truthing was conducted so the species of plants are not known. OSRA (2001) has conducted vegetation mapping with ground truthing but not west of Cape Otway. Victoriaís vegetation communities have been mapped State-wide as Ecological Vegetation Classes (EVC) in conjunction with the Regional Forest Agreement process (Yugovic et al. 1999; RFA 2000). An EVC contains one or more floristic communities grouped by similarities in their environments. EVCs are developed by a multivariate analysis and classification method based field sampled quadrats (Yugovic *et al.* 1999). There are approximately 900 EVCs recognised in Victoria.

Based on 1:100,000 scale maps of both extant and pre-1750s vegetation there are eight major EVCs associated with the five estuaries of this report (Yugovic et al. 1999; RFA 2000). The EVCs are Coastal Dune Scrub Mosaic (EVC 1), Damp Sands Herb-rich Woodland (EVC

3), Estuarine Wetland (EVC 10), Coastal Saltmarsh Complex (EVC 52), Swamp Scrub (EVC 53), Damp Heath Scrub (EVC 165), Shallow Freshwater Marsh (EVC 200) and Floodplain Reedbed (EVC 863) (Appendix 3). Water depth and period of inundation are especially important in the classification of these EVCs. Coastal Dune Scrub Mosaic, Estuarine Wetland, and Swamp Scrub EVCs occur at all five estuaries. Shallow Freshwater Marsh is only mapped at Glenelg, and Floodplain Reedbed at Aire and Gellibrand, although the large scale of the maps and brief descriptions make it difficult to determine accurately if small remnants of these or the other three EVCs occur in all five estuaries.

Coastal Saltmarsh Complex is one of the least studied vegetation types, and coastal ecosystems in Australia (Adam 1998; Fairweather 1990). Saltmarshes are highly productive ecosystems which export energy and nutrients to adjacent shallow sheltered waters (Wong *et al.* 1993). They are important as a winter feeding grounds for the Orange-bellied Parrot, roosts for waders during high tide (Wong *et al.* 1993) and have been extensively cleared or drained in many Victorian estuaries.

EVC mapping does not include submerged vegetation such as seagrass (Yugovic *et al.* 1999). Seagrass occurs in all five estuaries, but which species occur, their extent, and temporal variability are unknown. Phytoplankton and benthic microfauna are also important floral communities in estuaries (Underwood & Kromkamp 1999) and have not been specifically surveyed in southwest Victorian estuaries.

There has been considerable decrease in both the number and extent of EVCs since European settlement (Yugovic et al. 1999; RFA 2000) and this is more fully discussed latter. The number of EVCs in an estuarine catchment influences habitat diversity, it also reflects the inundation regime of the catchment. Crown Land at estuary mouths contains important remnants of EVCs and their associated fauna (Yugovic *et al.* 1999). Swamp Scrub is particularly important because of rare orchids (Swamp Greenhood and Small Sickle Greenhood) associated with this EVC (A. Pritchard, pers. comm. 2002).

Threatened Vegetation

All five estuary catchments contained species that are listed as Rare or Threatened Australian Plant Species (ROTAPS), or Victorian Rare or Threatened Species (VROTS) (NRE 2001a; Table 9; Appendix 2). Only Fitzroy River contains a listed endangered plant, the Lime Fern (VROTS). Three plants are listed nationally as vulnerable, the Leafy Greenhood (Glenelg, Curdies Inlet, Gellibrand and Aire), Swamp Greenhood (Glenelg, Curdies Inlet and Gellibrand) and the Square Raspwort (Curdies Inlet). Two plants are nationally listed as rare, the Bog Gum (Glenelg, Fitzroy, Gellibrand and Aire) and the Elongate Woodruff (Glenelg). All of the estuaries contain state listed rare plants, and except for Fitzroy estuary, contain state listed vulnerable plants. The conservation status of four species of plant is poorly known, nationally the Hairy Shepherdís Purse (Gellibrand and Aire), and in Victoria the Austral Trefoil (Glenelg), Elongate Woodruff (Glenelg), and the Coast Stackhousia (Gellibrand and Aire) (Table 9; NRE 2001a).

Swamp greenhoods are listed as nationally Vulnerable under the Commonwealth Environment Protection and Biodiversity Act 1999 and as Vulnerable in Victoria (Craig & Pritchard 2001). There are 13 populations in Victoria, with six being in the Gellibrand, Curdies and Glenelg estuaries. Their critical habitat is the tall closed shrubland of Leptospermum lanigerum, Woolly Tea-tree, which is known as Swamp Scrub (EVC 53; RFA 2000) and is endangered in West Victoria. This vegetation occurs on black, alkaline soils on swamps or along watercourses seasonally inundated with freshwater. Current threats are grazing or trampling by cattle, clearing of remnant Woolly Tea-tree, weed invasion and changes to the hydrological regime. This latter threat has particular relevance to artificial opening of estuaries.

2.11.3 Fauna

Records for the five estuary catchments from the Atlas of Victorian Wildlife (NRE 2001b) list 85 species of fauna, including 34 native birds, 6 native mammals, 1 native reptile and 38 native fish (Appendix 4; Table 10). This list does not reflect the true diversity of fauna in or between the estuary catchments as it is biased towards fauna that is conservation listed and those catchments that have been intensively surveyed. The animals that have been listed as having a significant conservation status are shown in Table 11.

The relationship between the flora and fauna of estuarine wetlands is poorly understood. Most of the current ecological understanding of southwest Victorian estuarine wetlands is based around the occurrence, and known habitat requirements of fish and birds. Fish have a high recreational and commercial interest, and fishing is one of the primary activities of visitors to estuaries. Bird watching is also of high recreational value, and birds can be a very visible part of an estuarine fauna.

Table 9. Summary of conservation status of flora in the estuary catchments of the five estuaries.

ROTAPS	VROTS	Common name	Scientific name	Estuary				
				GI	F	C	Ge	A
	e	Lime Fern	Pneumatopteris pennigera		H			
		Helmet Orchid	*Corybas* sp. aff. *diemenicus*		+	+		
V	v	Leafy Greenhood	*Pterostylis cucullata*	H		▲	●	●
V	v	Swamp Greenhood	*Pterostylis tenuissima*	H		+	H	
	r	Broad-lip Leek orchid	*Prasophyllum lindleyanum*				●	●
	r	Ruddy Bent	*Agrostis rudis*				H	H
	r	Neat Spear-grass	*Austrostipa mundula*	H				
	r	Short Water Starwort	*Callitriche brachycarpa*				●	●
	v	Long Rope-rush	*Calorophus elongatus*				●	●
	r	Velvet Correa	*Correa backhousia*				●	●
K	v	Hairy Shepherd's Purse	*Microlepidium pilosulum*				●	H
	v	Glistening Saltbush	*Atriplex billardierei*					H
	r	Currant-wood	*Monotoca glauca*			H		
	k	Austral Trefoil	*Lotus australis*	H				
V	v	Square Raspwort	*Haloragis exalata* ssp. *exalata* var. *exalata*			H		
R	r	Bog Gum	*Eucalyptus kitsoniana*	▲	H		●	●
R	k	Elongate Woodruff	*Asperula charophyton*	H				
	r	Compact Bedstraw	*Galium compactum*					H
	r	Coast Ballart	*Exocarpos syrticola*				●	H
	r	Coast Pomaderris	*Pomaderris oraria*				H	H
	k	Coast Stackhousia	*Stackhousia spathulata*				H	H

ROTAPS: V = vulnerable; R = rare; K = poorly known

VROTS: e = endangered; v = vulnerable; r = rare; k = poorly known

Source: H (NRE 2001a); + (A. Pritchard, pers. comm. 2002); ● (NRE 1996) ▲ (CLS 1981)

Table 10. Summary of number of species of fauna reported for the five estuaries: Glenelg, Fitzroy, Curdies, Gellibrand and Aire.

Fauna type	Estuary				
	Glenelg	Fitzroy	Curdies	Gellibrand	Aire
Conservation listed species	30	18	12	13	16
Fish	34	18	10	20	23
Invertebrates	3				1
Birds	19	15	11	9	15
Mammals	4	2		3	1
Reptiles	1				1

Refer to Appendix 4 for full list and sources.

Table 11. Occurrence and conservation listing of fauna in the five estuaries. Glenelg (Gl), Fitzroy (F), Curdies (C), Gellibrand, (Ge) and Aire (A).

Common name *	Estuary					Conservation listing			
	Gl	F	C	Ge	A	J/C	VROTS	FFG	AROTS
Fish									
Pouched Lamprey		H		H	H		v	L	V
Short-headed Lamprey				H					
Australian Mudfish					H		v	L	
Mountain Galaxias					H		k		
Spotted Galaxias	H				H		r		
Australian Grayling					H		v	L	
Yarra Pigmy Perch	H	H	H		H		v	L	V
Freshwater Blackfish	H	H			H		k		
Invertebrates									
Glenelg River Crayfish	H						k		
Southern Victorian Spiny Crayfish	H								
Glenelg Freshwater Mussel	H						r		
Otway Black Snail					H		v		
Butterfly	H						v		
Birds									
Australian Pelican							+		
Black Faced Shag					**H**		+		
Pied Cormorant					**H**		+		

Table 11 (continued).

Common name *	Estuary					Conservation listing			
	GI	**F**	**C**	**Ge**	**A**	**J/C**	**VROTS**	**FFG**	**AROTS**
Great Egret	**H**	**H**	**H**	**H**	**H**	J&C		L	
Intermediate Egret	**H**				**H**		+		
Little Egret					●		+		
Royal Spoonbill					**x**		+		
Australasian Bittern	**H**	**H**	**H**	**H**	**x**		k		
Little Bittern	**H**		**H**				r		
Cape Barren Goose	**H**		**H**	**H**	**H**		r		
Blue-billed Duck	**H**			**H**			r		
Grey Goshawk	**H**	**H**	**H**	**H**			r		
Letter-winged Kite				**H**			r		
White-bellied Sea-Eagle	**H**						r	L	
Grey Falcon		**H**					v	L	
Black Falcon				**H**			r		
Lewin's Rail	**H**	**H**			**H**		r		
Baillon's Crake		**H**					k		
Brolga	**H**	**H**	**H**				r	L	
Australian Bustard		**H**					e	L	
Bush Stone-curlew		**H**					v	L	
Hooded Plover	**H**	**H**	**H**				v	L	
Lathamís Snipe					**x**	J&C			
Pacific Gull					**H**		+		
Little Tern	**H**	**H**					e	L	E
Caspian Tern					**H**	J&C	+		
Fairy Tern	**H**		**H**				v	L	
Red-tailed Black-Cockatoo	**H**	**H**	**H**				e	L	E
Orange-bellied Parrot	**H**		▲				e	L	E
Swift Parrot	**H**						e	L	V
Ground Parrot					●				
Powerful Owl	**H**	**H**	**H**	**H**	**H**		r	**L**	
Rainbow Bee-eater					**H**			L	
Southern Emu Wren					**H**			L	
Rufous Bristlebird	**H**	**H**	**H**	**H**	**H**		r	L	

Table 11 (continued).

Common name *	Estuary					Conservation listing			
	Gl	F	C	Ge	a	J/C	VROTS	FFG	AROTS
Mammals									
Heath Mouse	**H**						r	L	E
Smoke Mouse					**o**				
Swamp Antechinus	**H**			**H**	**H**		r		
Broad-toothed Rat				**H**	**o**		r		
Spot-tailed Quoll		**H**		**H**			v	L	E
Tiger Quoll					**o**				
Common Bent-wing Bat	**H**						c	L	
Reptiles									
Swamp Skink	**H**				**H**		?		

* see Appendix 4 for scientific name

AROTS: E = endangered; V = vulnerable; R = rare; K = poorly known

VROTS: e = endangered;, v = vulnerable; r = rare;, k = poorly known

FFG, L = listed

+ = restricted colonial breeding or roosting sites (NRE 1996);J/C J = JAMBA, C = CAMBA

Sources: **H (**NRE 2001b); ● (NRE 1996); **x** (Parr-Smith *et al.* 1993); ▲ (CLS 1981); **o** (NRE 1997)

Fish

Fish may live in, or pass through an estuary, during different times in their life history (Figure 9; Table 12). There are estuarine dependent fish, fish in the juvenile or adult stage of their marine life history, and opportunistic marine species that can live in either estuarine or marine waters (Figure 9). The natural cycles of mouth opening and closing, wetland flooding and drying play important roles in the life history of many fish and are major factors influencing the diversity of fish and other fauna in estuaries at any particular time (Moverley & Hirst 1999; Deeley & Paling 1999).

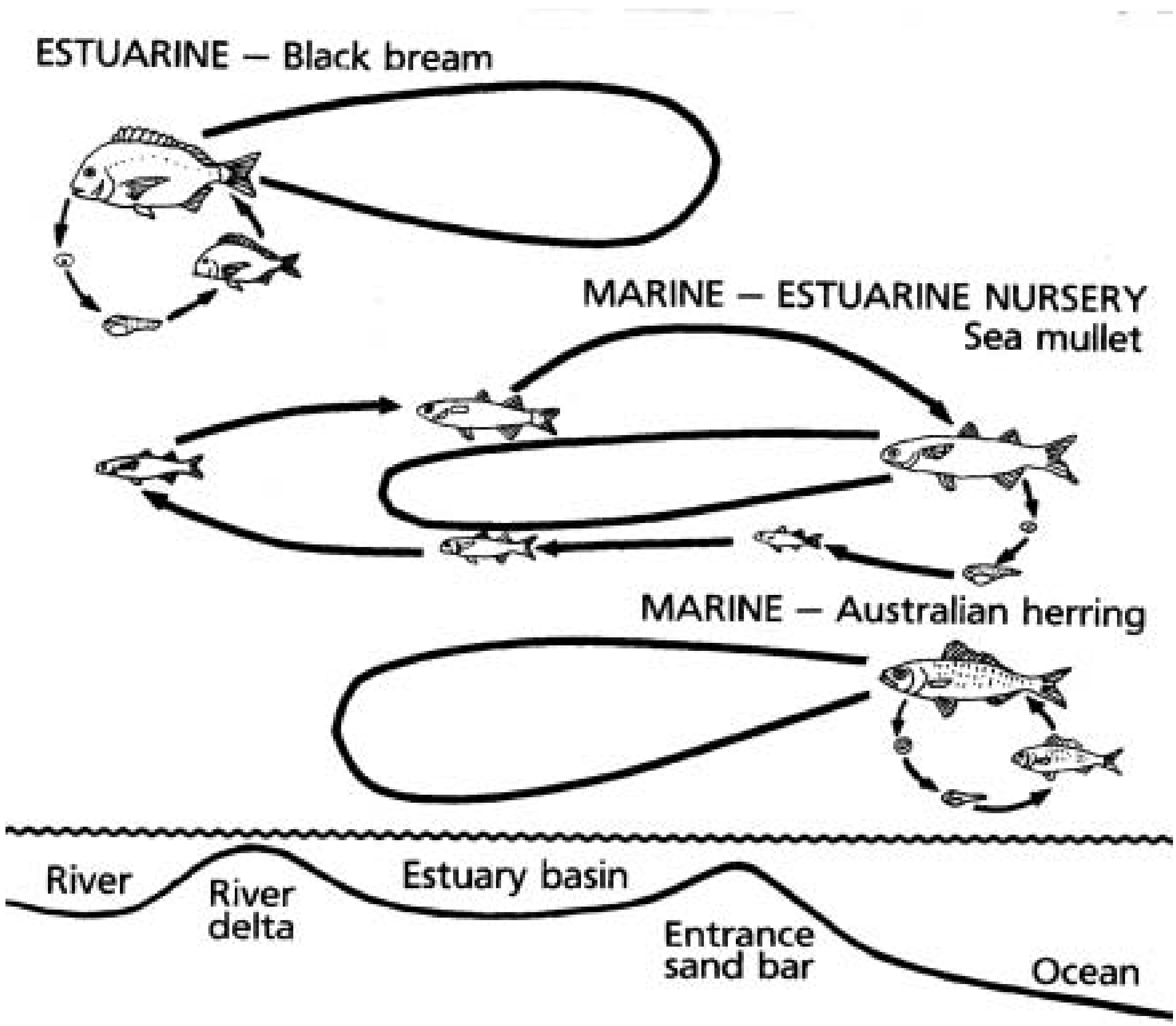


Figure 9. Utilisation of estuaries by different types of fish.

Source: Hodgkin (1994).

Nine migratory species of fish have been reported in southwest Victorian estuaries (Table 12; RFA 2000). Four species spawn either at sea or in estuaries (Short-finned Eel, Australian Mudfish, Common Galaxias and Tupong) with an upstream migration of juveniles. Five species spawn in the upstream reaches (Australian Grayling, Spotted Galaxias, Pouched Lamprey, Short-headed Lamprey, Broad-finned Galaxias) with larvae moving downstream to the estuary or sea during high flows in winter/spring, to migrate back upstream in a later stage of life. Passage between the river and the sea is critical for these species

Many fish species have fairly specific habitat requirements for their survival (Table 12). For instance the Common Galaxias requires access downstream to tidal marshes to spawn in Autumn on high spring tides so they can attach their eggs to the base of recently flooded vegetation (Cadwallader & Backhouse 1983). The eggs hatch two weeks later, when the next spring tides inundate the spawning area, although hatching can be delayed up to eight weeks. The larvae are carried out to sea on a high tide where they spend the first 6ñ7 months of their lives before migrating back up through the estuary to the freshwater reaches. The stimulus for the migration from the sea is thought to be related to spring rains and subsequent floods. Movement through the estuary is on daylight rising tides.

Short-finned Eels spend most of their life in lakes and upper reaches of the rivers and return to sea in November to December to spawn. At 1ñ3 years old, the juveniles, known as glass eel, enter the estuaries. Peaks in glass eel migrations into estuaries occur 3 to 4 days after new and full moons (Koehn 1984). These migrations only occur during the winter and late spring, the peak migration is late October (Cadwallader & Backhouse 1983). There is a secondary migration of glass eels and elvers, from the estuary to lakes and rivers. A proportion of glass-eels and elvers remain in the estuaries and lower reaches or rivers and creeks where the majority mature into males (Koehn 1984). The majority of eels that migrate into freshwaters mature into females. Mature eels, silver eels, migrate out of the estuaries during late summer-autumn with the migration reaching a peak around the last quarter of the moon.

Adult Lampreys move upstream from August to November to spawn, and juvenile immature Lampreys move downstream to the sea in with flooding in July to September (Tunbridge & Glenane 1988). Mature Tupong also migrate downstream to the estuary during high flows in June-July, presumably to spawn (Tunbridge & Glenane 1988).

The response of each species or age class of estuarine fish to the changing hydrodynamics of salt wedge type estuaries is essentially unknown. It is therefore difficult to identify the major reasons for changes in distribution and abundance of fish in an estuary. However, DO, closure of the entrance and salinity are considered likely to be the three factors either alone or together having the greatest influence on the fish populations (Tunbridge & Glenane 1988). Generally fish require dissolved oxygen levels of at least 5 mg/L. Anoxic waters are also not favourable for the survival of eggs or larvae which are less mobile than adults. Persistant anoxia may interfere with breeding success of many estuarine species. Closure of the mouth can prevent migration. Salinity changes can affect spawning and the early life history of some fish species (Tunbridge & Glenane 1988).

High inflows of freshwater from May to November have a major influence on fish species, distribution and abundance (Tunbridge & Glenane 1988). They seem to be an important trigger for many species migration and breeding. High flows may remove the salt wedge from the estuary, imposing a freshwater regime throughout the estuary for periods of several weeks or more. Black Bream and Estuary Perch inhabit the estuary and its immediate freshwater reaches (Cadwallader & Backhouse 1983). Adult Black Bream and Estuary Perch can tolerate a wide range of salinities, but can experience spawning failure if oxygenated waters of correct salinity (close to S = 15) are not in the estuary (Tunbridge & Glenane 1988;

Sherwood & Backhouse 1982). The fish move upstream behind the peak of the flood and shed large numbers of eggs which drift downstream. November is the peak bream breeding season in Western Victoria; Yellow-eye Mullet and galaxiids also breed at this time

Yellow-eye Mullet can tolerate low salinities and spawn in the estuaries from July to mid-December, corresponding to the period of highest river inflow (C. Cooper, pers. comm. 2002). They are common in estuaries all year but leave the estuary when it becomes totally fresh (Tunbridge & Glenane 1988). Luderick and Trevally are never found in low salinity water, and so are seldom present in estuaries in winter. Freshwater Herring are found in the upper reaches of coastal streams, and its young migrate from estuaries back into freshwater, but it is not known if the adults spawn in fresh or estuarine waters (Cadwallader & Backhouse 1983).

Significant data gaps exist in life history and population characteristics for most estuary-associated fish species (Table 12). Most of the current information is derived from casual observations during other research, rather than targeted scientific surveys and research (RFA 2000). In particular, the most significant gaps relate to spawning behaviour, including spawning cues, the location of egg laying sites in the stream or estuary, preferred larval habitats and larval tolerance to turbidity and temperature. The protection of natural habitats is one of the most important requirements for management of fish resources in the smaller inlets and estuaries (CLS 1981).

Table 12. Knowledge of the ecology of fish and crustacea found in the five PV managed estuaries.

Common Name	Breeding			Feeding		Migration/Movement+	
	Timing	**Habitat requirements***	**Flow requirements**	**Food**	**Habitat requirements***	**Where**	**When**
Pouched Lamprey	Late spring/early summer	unknown	unknown	unknown	unknown	Juv mig est to sea Adults mig sea to est	July to Sept Aug to Dec
Short-finned Eel	unknown	unknown	unknown	carnivore	unknown	Glass eels mig into est Elvers mig from est to fw Adults mig to sea	May to Oct Oct to Feb Nov to Dec
Common Galaxias	Early autumn	Grassy river flats, estuarine wetlands	Spring tides to flood grassy flats	unknown	Adults, freshwater lowland rivers and streams	Larvae migrate to sea Juv mig sea to fw Adults mig fw to est	Autumn Spring flooding Autumn
Spotted Galaxias	Winter?	unknown	Possible high flow trigger	unknown	Lower, slower flowing FW reaches	Juv mig sea to FW	Out Winter/spring high flows In Spring/summer
Mountain Galaxias	unknown	FW	unknown	unknown	FW	None	none
Australian Grayling	Late summer	FW	unknown	omnivore	unknown	Larvae move to sea after hatching Juv mig sea to FW	Winter to spring high flows Spring to summer

Table 12 (continued).

Common Name	Breeding			Feeding		Migration/Movement+	
	Timing	Habitat requirements*	Flow requirements	Food	Habitat requirements*	Where	When
Small Mouthed Hardy Head	Late Spring to summer	unknown	unknown	Bottom feeder	unknown	unknown	unknown
Black Bream	August to January	unknown	unknown	omnivore	unknown	Estuarine species	
Estuary Perch	mid-October and early November	salinities between 10 & 24 ppt	unknown	carnivore.	Water under tidal influence.	unknown	unknown
Variegated Pygmy Perch	July to November	Aquatic vegetation	High flow	unknown	unknown	unknown	unknown
Southern Pygmy Perch	Late winter early spring	FW species	Unknown	carnivores	unknown	unknown	unknown
Yarra Pygmy Perch	Sept to Oct	unknown	Unknown	unknown	Slow flowing, lots of veg	unknown	unknown
Yellow Eye Mullet	Winter to Spring	unknown	Unknown	omnivore	unknown	unknown	unknown
Tupong	Late April to mid August	Sandy, weedy, tidal estuary	Slow	carnivores	Slow flow	Juv mig Adults mig to est	April to Aug
Flathead Gudgeon	Late autumn to early spring	unknown	Unknown	carnivore	Abundant cover, bottom dwelling	unknown	unknown
Bridled Goby	Spring to Summer	unknown	Unknown	carnivore	Still water	None	none

Table 12 (continued).

Common Name	Breeding			Feeding		Migration/Movement+	
	Timing	Habitat requirements*	Flow requirements	Food	Habitat requirements*	Where	When
Tamar Goby	Sept-Nov	unknown	Unknown	carnivore	Burrowing in estuary	None	none
Blue-spot Goby	Early to late Spring	unknown	Unknown	carnivore	Slow flow, vegetation	None	none
Glenelg Spiny Cray	Early to late spring	unknown	Freshwater	unknown	Damp soils	unknown	unknown

* FW = Freshwater, + Juv = juveniles, mig = migrate

Source: Primarily from Cadwallader and Backhouse (1983).

Birds

Estuarine wetlands are an important water bird habitat, supporting a large variety of birds that occupy different habitat niches (Table 11; CLS 1981). The number and species of birds present fluctuates seasonally and with changing water levels as different habitats become available for feeding (Reilly 1998). Heavily vegetated swamps are the feeding areas of Night Herons, Bitterns, Rails, Crakes and Waterhens. Sparsely vegetated margins are the habitats of crustaceans and other invertebrates which inhabit the mud and are fed on by Plovers, Dotterals, Snipe, Sandpipers, Stilts, Wagtails, Sparrows and Mud Larks (CLS 1981). Shallow waters support emergent and submergent vegetation together with their associated aquatic insects, crustaceans, molluscs and small fish. Birds using such areas include Pelicans, Herons, Egrets, Spoonbills, Ibis, Ducks and Swans. In deeper waters submerged plants and bottom dwelling molluscs and crustaceans provide food for the Blue-billed and White-eyed Ducks and Coots, while fish and crustaceans provide food for Cormorants, Grebes, and some Ducks.

Roosting sites of migratory wader and shorebirds are found in sheltered locations adjacent to intertidal feeding areas (Ball & Patterson 1998). These sites are crucial for waders which retreat to them when their intertidal feeding areas are submerged. Waders require undisturbed roosting sites to rest while awaiting the next low tide so that they donít waste their energy resources and as a result they are particularly vulnerable to disturbance whilst roosting.

Most of the waders that migrate to Australia are trans-equatorial migrants that breed in central and north-eastern Asia (Lane 1987). Many of the waders are subject to the terms of the Japan Australia Migratory Birds Agreement (JAMBA) and the China Australia Migratory Birds Agreement (CAMBA) both of which provide for the protection of specific bird species that migrate between the respective countries. Migratory waders typically arrive in Australia in August/September to feed, returning northward to their breeding grounds at the end of summer around April. Juveniles of some species from the previous breeding season remain behind in Australia to ìover-winterî for the first year.

The Double-banded Plover has a different migration pattern, breeding during the southern hemisphere summer in New Zealand and migrating to Australia during winter. It is Australiaís only east-west migrant and is largely absent from Australia during summer (Lane 1987).

Other significant shorebird and coastal bird species are the Orange-bellied Parrot, Hooded Plover, Rufous Bristlebird and the Peregrine Falcon. White Egrets and Cormorants are often found in the estuaries (Table 11; CLS 1981).

Orange Bellied Parrots migrate from Tasmania to feed on seed and the fruit of the saltmarsh species *Halosreia pergranulata, Sarcocornia quinquiflora* and *Sclerostegia arbuscula* over the winter months (April ñ October; Ball & Patterson 1998).

The Hooded Plover breeds in estuaries. It is listed as a threatened species under the *Flora and Fauna Guarantee Act* 1988 and the total population in Victoria is about 600 birds (Ball & Patterson 1998). The Hooded Plover is a small to medium-sized shorebird (approximately 20 cm long) found predominately on sandy, ocean beaches. They favour creek mouths or inlet entrances with large flat areas of sand and beaches with washed up seaweed (CLS 1981), nesting directly on the beach above the high tide mark, or on sand dunes. The breeding season extends from August to March, but is typically from October to March and nesting frequently occurs in the same area of the beach or dune each year. The incubation period is approximately 28 days and the young do not fly for at least 8 weeks (Lane 1987).

The Rufous Bristle Bird is a medium-size (23ñ27 cm long), primarily ground dwelling bird. It feeds on ground-dwelling invertebrates and nests close to the ground in tussock or low shrubs. It is listed as a threatened species under the provisions of the *Flora and Fauna Guarantee Act* 1988 because its coastal habitat has decreased or been degraded and its ground nesting and feeding behaviour make it vulnerable to introduced predators such as foxes and cats (CLS 1981).

Peregrine Falcons nest in cliffs from August ñ September, and chicks remain in the nest from mid-November until the following April (Ball & Patterson 1998) this threatened species uses the estuarine wetland for feeding.

Other fauna

The Swamp Antechinus and Swamp Skink also inhabit estuarine wetlands (RFA 2000). Most of the amphibians found in the coastal plains are found in lowland rivers and their associated swampy margins. The frogs *Geocrinus laevis*, *Limnodgnastes peroni*, *Litoria ewingi* and *Ranidella signifera* are the most widespread and common species (CLS 1981).

Some quantitative invertebrate studies have been conducted in southwest Victorian estuaries, predominately in the Hopkins estuary (Appendix 5). Walsh (1994) investigated the factors affecting the distribution and abundance of epifaunal Caridean shrimps in seagrass meadows of the Hopkins River. In addition, Walsh also studied the life history patterns that permit the freshwater shrimp *Paratya australiensis* to utilise estuarine habitats. The population of the estuarine bivalve *Solatellina alba* varies with freshwater floods, but little is know about the effects of the hydrodynamic cycle on this bivalve (Matthews 2001). Studies have also been conducted into the relationships between the hydrodynamics and zooplankton (Newton 1994), and phytoplankton (Rouse 1998) communities of the Hopkins River estuary.

There have been a few studies on the community structure of aquatic invertebrates in southwest Victorian estuaries (McKay 2000; Moverley & Hirst 1999), but little is really known on the occurrence, nor the requirements of most estuarine macroinvertebrates. McClusky (2001) found that different life histories of crustaceans and bivalves did seem to influence their genetic dispersal between estuaries in the region.

2.12 CHANGES IN ESTUARIES SINCE EUROPEAN SETTLEMENT

The southwest of Victoria was diverse in ecosystems in 1750 (Figure 10, a & c); the land close to the coast carried dense forests and large tracts of swamps and heath. The widespread and disproportionate loss of these habitats has been a significant factor in the decline of many species, causing regional and local population declines, and is largely responsible for the current threatened status of many species (RFA 2000). Relatively little of the original biodiversity now remains, with most of the area cleared and converted to agriculture (Figure 10, b & d). Clearing for agriculture and alteration of hydrological regime or drainage are still major threatening factors for most coastal lowland vegetation and associated fauna (RFA 2000).

The large scale of Figure 10 means it is not possible to determine specifically if or how much of many of the Ecological Vegetation Classes (EVCs) are still found in estuarine catchments, but gross changes are evident. All EVC areas are considerably smaller and more fragmented now than in the pre-1750 distribution. The preferential clearing of flat, floodplain areas is evident for the Gellibrand and Aire estuarine catchments (Figure 10, c & d). Of the five estuarine catchments the loss of EVC area and types in the Curdies (Figure 10d) and Fitzroy (Figure 10b) estuaries is particularly noticeable. Gellibrand estuary had a varied mosaic of EVCs and seems to have kept at least a small example of each. The EVC most affected seems to be the loss of large areas of Damp Heath Scrub to the West of Curdies Inlet (Figure 10d). The introduction of marram grass in 1883 has also had a major impact on the Coastal Dune Scrub Mosaic; it has stabilised dunes, but has also created monospecific communities on the dunes (CLS 1981).

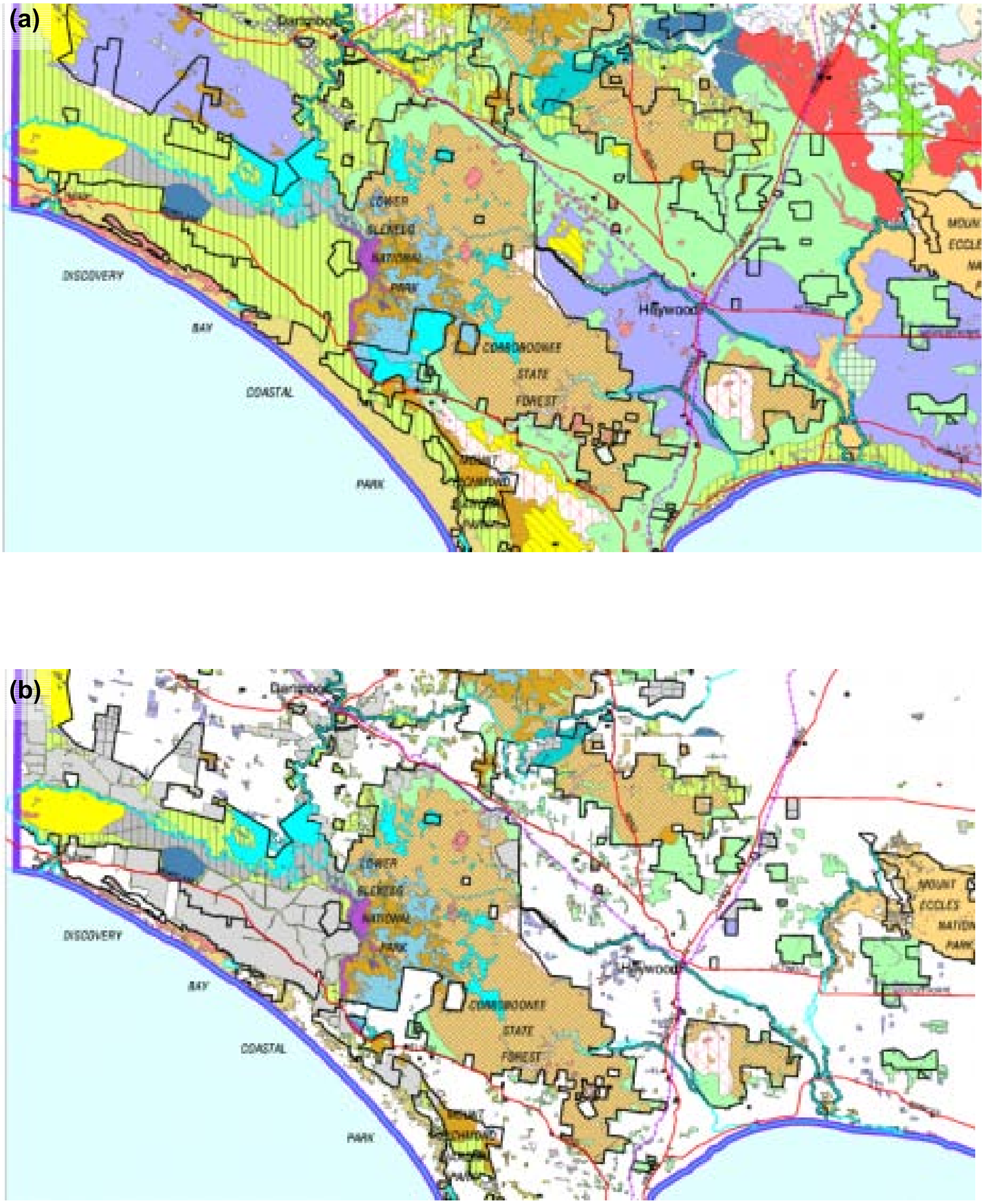
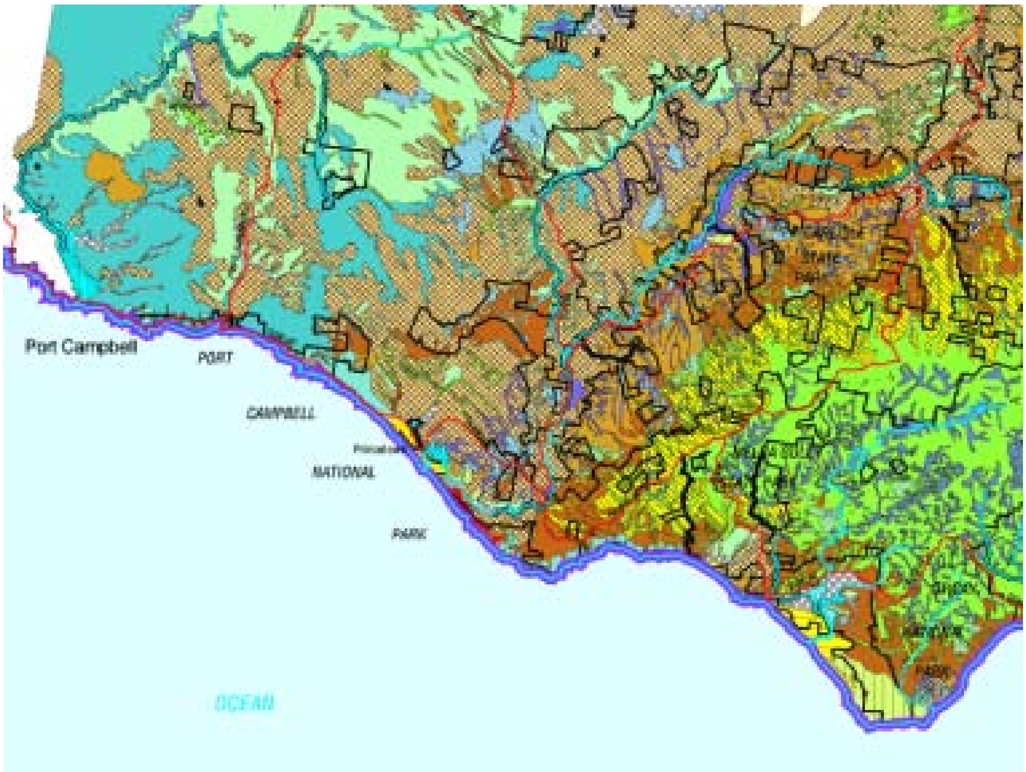


Figure 10. Broad scale changes in EVCs modelled pre 1750 and extant.

Modelled pre 1750 (a) Glenelg and Fitzroy, and extant (b) Glenelg and Fitzroy, (mapped at 1:100,000). The white areas have been cleared.

Source: RFA (2000).

(c)



(d)

Figure 10 (continued). Broad scale changes in EVCs modelled pre 1750 and extant.

Modelled pre 1750 (c) Curdies, Gellibrand and Aire estuary catchments, and extant (d) Curdies, Gellibrand and Aire estuary catchments (mapped at 1:100,000). The white areas have been cleared.

Source: RFA (2000).

Swamp scrub vegetation type (EVC 53; RFA 2000) is severely depleted within the region and its protection requires urgent action (A. Pritchard, pers. comm., 2002). This vegetation contains a range of species that have National and State wide conservation status ñ Swamp Greenhood, Small-sickle Greenhood, Swamp Antechinus, Swamp Skink, Variegated Pigmy Perch, Southern Emu wren, Rufous Bristle Bird, Olive Whistler (Glenelg form), and Barred Galaxias. The long-term security of these species is dependant on the conservation of these areas (A. Pritchard, pers. comm. 2002; RFA 2000).

Yugovic *et al.* (1999) recommend that for management purposes, modelling of pre-1750s and mapping of extant vegetation needs to be conducted at 1:25,000. This is especially relevant for wetlands, as they were under sampled in the RFA process, where the primary focus was terrestrial vegetation, and so received less attention. Determination of the types and extent of EVCs pre-1750 in each estuary catchment would help inform managers of subsequent changes related to hydrology and drainage. It could also help determine an appropriate hydrological regime for estuary mouth opening to protect and extend remnant EVCs. Too much or too little water is detrimental to many EVCs and their associated rare plant species such as orchids (Craig & Pritchard 2001).

Agricultural development, urbanization and industrial development on the coastal fringe, have resulted in increased loads of sediment, nutrients and other pollutants to estuaries, these have led to significant changes to many estuarine habitats (Heron 1989; SOMER 1995; Edgar *et al.* 2000). The nature of impacts caused by increased sediment and pollutant loads on biological communities in estuaries is not well understood (Deeley & Paling 1999). Similarly the effects of mouth opening and dredging, changing the freshwater flow hydrology, and catchment clearing on estuarine ecosystems are not understood (Hodgkin & Hesp 1998).

Human activity has altered the hydrology of streams in Victoria. Quantity and timing of flow has been affected by dams, diversions, and changes in catchment landuse including drainage and urbanisation. Changes in stream hydrology as a result of human activity include alteration to: flood frequency and magnitude, flow seasonality, frequency of overbank flooding, and occurrence of low flows as well as changes in flow peakiness (Ladson & White 1999). The influence of changes in hydrology on stream ecology, impacts on wetlands and floodplains, channel morphology and substrate, fish populations, invertebrates, algae, riparian vegetation, water quality, and submerged and emergent aquatic macrophytes has been extensively investigated for streams (Ladson & White 1999), but little is known about the specific impacts on estuaries (Hodgkin & Hesp 1998).

3 Artificial mouth opening

3.1 ECOLOGICAL ISSUES

The highly stratified nature of southwest Victorian estuaries, coupled with the common occurrence of anoxia in deeper saline waters places their ecosystems at a particular risk during mouth opening. Typically the top 1ñ2 m of surface water flows out to sea once the mouth is opened. Most estuarine organisms require water having DO > 5 mg/L and this concentration is typically found in the surface water layer due to physical exchange with the atmosphere and photosynthetic activity. If all water having adequate DO is lost from the estuary, leaving only anoxic or poorly oxygenated deeper water, extensive mortality of estuarine organisms may result. Highly visible fish kills are a clear indication of this adverse effect and have been recorded for the Surrey and Gellibrand estuaries. Unconfirmed reports suggest they have also occurred in the Aire River and Yambuk Lake.

In the case of the Gellibrand estuary, an additional factor contributed to a fish kill in 2000 (Kelly 2000). Extensive wetlands associated with the lower estuary contained water of low DO (< 5 mg/L). This appears to have been a consequence of warm, calm weather associated with consumption of DO during the decaying of aquatic organic matter. Water draining from this wetland, once the mouth was opened, filled the channel with anoxic water. It took 4 days until the wetlands had drained and oxygenated seawater was able to re-enter the estuary (Kelly 2000). The absence of DO in the lower estuary for such a long time killed a large number of fish, crabs, shrimp and other organisms.

As a result of such instances it is now clear that artificial mouth opening should occur only if the surface waters have DO > 5 mg/L for > 2 m depth. If extensive wetland areas border the main channel of an estuary the DO level in these should also be measured to check that they will not contribute low DO water to the main channel as they empty into it. In addition, the effect of artifical mouth opening on ecological processes, such as habitat availability and wildlife breeding need to be more fully considered.

3.2 PAST AND PRESENT OPENING REGIMES AND PROTOCOLS

Artificial opening of southwest Victorian estuaries has been happening since European settlement and the clearing of many estuarine catchments for agriculture (Parr-Smith *et al.* 1993). In the past, rivers were opened by various groups with conflicting interests and with no authority or supervision. Since the late 1990s management arrangements have resulted in a more regulated approach to river openings.

In the early 1990s, public and management agency concerns about fish kills led to the identification of the following issues that needed to be taken into account when considering artificial opening (A. Pritchard, pers. Comm. 2002):

- Extent and duration of wetland inundation
- Ecology of aquatic animals and vegetation
- Times of wildlife breeding
- Fish health
- Effect of rapid salinity changes
- Fishing, boating and other river pastimes
- Sand dune and beach erosion when the river is opened
- Access points to the beach for equipment
- Presence of algal blooms
- Effect on mosquito problems
- Weather conditions necessary to allow maximum effectiveness of opening

In the late 1990s, the Southern Rural Water Commission (SRW) further developed these into the conditions of a formal licence between it and the body responsible for the physical opening. Catchment Management Authorities took over licensing in 1997. The general licence includes agreed trigger levels, and requirements for notification of SRW and NRE, and consultation with other bodies with expertise or responsibility for river management. Under licence agreements a broad range of natural, hydrological, cultural and economic factors are to be taken into account when considering the artificial opening of any estuary, including:

- whether a substantial ìbreakî (rainfall) has occurred in the upper catchment,
- the presence of significant instream flows moving towards the river mouth,
- offshore winds,
- tidal conditions,
- time of year,
- social activities on the water,
- possible effects on wildlife values (*e.g.*, nesting water birds),

- possible effects on fisheries values,
- water quality, and
- long term effects.

On the whole, however, the licences do not provide detail into what the important aspects of these features are or how they should be weighted against or balanced with each other. A specific trigger height for each estuary is also specified in the licence agreement. The responsible authority to open the mouth is generally the manager of the land immediately adjacent to the mouth. Some estuaries, such as Surrey River, have a Committee of Management (SKM 2000).

Gellibrand estuary, which has a management plan, has more specific criteria. Its licence specifies the amount of catchment rain, or streamflows needed prior to opening. As well as the trigger height, the estuary may also be opened if the mouth has been closed for more than 60 days. Opening must not occur on spring tides (new or full moon), or three weeks before the opening of duck hunting season. Monitoring, both pre- and post- opening, must be carried out at specified sites, and public safety warning signs erected.

Proposed permit conditions for the Aire estuary specify the minimum amount of rain needed in the seven day period prior to opening, and monitoring before and for three days after opening. Opening is only allowed in exceptional circumstances during summer school holidays, the two weeks prior to Easter Monday and the two weeks prior to the proclaimed duck season opening.

None of these licences identify vulnerable times for the flora and fauna when artificial opening may be detrimental, nor the maximum frequency of opening. Having a trigger level above which the estuary may be opened reduces or prevents medium to large floods across the floodplains. These floods are probably important in the functioning of the system, as has been found for freshwaters, providing cues for flora and fauna, and maintaining connectivity of the wetlands.

To allow more accurate determination of the trigger point for considering artificial opening, gauge boards, surveyed to Australian Height Datum, were put into some southwest estuaries in 1997. Varied levels of community consultation were sought in establishing trigger levels. Most trigger levels were set to continue the status quo and prevent flooding of farming land (Parr-Smith *et al.* 1993). There is no known review of the consequences of the trigger height on estuarine ecology, particularly wildlife or wetland habitat. The Glenelg estuary trigger height was set through extensive public consultation, and it is thought to be the minimum height at which an artificial opening will be successful (B. Mackereth, pers. comm. 2002).

Even after extensive consultation the Glenelg trigger height is still a debated issue, as riverside boatsheds in South Australia are inundated before the trigger height is reached.

The trigger height is generally used as the point at which consideration is given for mouth opening in light of the licence criteria. Physico-chemical surveys of the estuary provide important information on the risk of fish kills due to loss of oxygenated waters. Falling tides are considered desirable to try and create as large an opening as possible, to allow full drainage and tidal flushing. However, when there is shallow stratification, fast drainage of the waters may leave fauna exposed to the deoxygenated bottom waters, and a rising tide may be a better option.

The method used to physically open the estuary is usually based on access to the mouth and the width of the sand bar that needs to be dug through to connect the estuary to the sea. The depth of the channel does not have to be great (generally around 1 m), but there needs to be sufficient fall from the estuary to the sea, so that the water flows down the channel quickly enough to enlarge it (B. Mackereth, pers. comm. 2002). Depending on the sand bar width and available resources the mouth can be opened with shovels, bobcats, or excavators. In one instance explosives were used due to the great width of the sand bar. The latter obviously carries additional risk to the estuary, with the possibility of shock waves causing harm, particularly to fish.

Estuary mouth opening is generally not successful on a rising tide, during stormy sea conditions, with onshore winds and when there is no freshwater flow coming down the estuary. It is also generally not successful if the channel is too shallow, or in the wrong place. Southwest Victorian estuaries generally open to the west of the beach, against a western headland or rock outcrop, where the sand bar is generally narrower.

No records of the natural opening and closing cycles of southwest estuaries have been found. In recent years better records have been kept of artificial opening by the relevant management agencies, but these records often do not include natural openings or closures. The Gellibrand, Aire, Curdies and Glenelg estuaries have each had the same contractor or person open them for at least the past decade. Records from the Glenelg are available, but contractors should be contacted to try and construct records for the other estuaries.

Inadequate records of natural and artificial openings and a lack of relevant research mean that it is nearly impossible to say what impacts of artificial opening have been, what the natural regime was or what the best managed entrance opening regime has been. Artificial opening goes back at least 50 years in most estuaries, and it is not known if the frequency of mouth opening has changed over this time. The ecology of the estuaries, whilst impacted by land clearance, settlement and drainage alterations, would also be influenced by any artificial regime of mouth openings. Finding out as much as possible about historical drainage, vegetation clearance and artificial opening in the estuary catchments is a priority. The memories and recollections of older people whose families have used the estuary and its catchment should be collected and recorded. Long term visitors to each estuary as well as landowners may be able to provide information on long term changes in the estuary. Each estuary seems to have a cohort of regular users who often camp and fish beside the estuary for weeks at a time. Some users have done so for several generations.

More detailed, 1:25,000 mapping of the remnant EVCs will indicate their former distribution. It also important to identify the current inundation regimes of remnant EVCs, and any associated endangered wildlife, before any decisions are made to change the current opening frequencies further, unplanned changes may threaten these remnant communities.

4 Relevant estuarine management and policy

4.1 ENVIRONMENTAL RESPONSIBITIES OF PARKS VICTORIA

Under the 1988 *Water Act*, Parks Victoria holds the licence for the artificial opening of the Glenelg, Fitzroy, Curdies, Gellibrand and Aire estuaries because it manages the coastal land at the mouth of the estuaries. Under the provisions of the *National Parks Act 1975* it has to preserve and protect the natural condition of the Parks and their natural or other features, and to provide for public enjoyment, recreation and education, subject to the other Parks values. Values can be measured in terms of ecological attributes such as biodiversity.

Environmental responsibilities of Parks Victoria, for management of estuaries with in its Parks, are specified in the following Commonwealth and Victorian Acts and Agreements.

Commonwealth Legislation

Environment Protection and Biodiversity Conservation Act 1999

International Union for the Conservation of Nature (IUCN)

Interim Biogeographical Regionalisation for Australia (IBRA)

JAMBA/CAMBA Agreements

Register of the National Estate

BONN Agreements

RAMSAR Convention

Victorian Legislation

Environment Protection Act 1970

Flora and Fauna Guarantee Act 1988

National Parks Act 1975

Catchment and Land Protection Act 1994

The Catchment and Land Protection (CALP) Board was established in December 1994 under the *Catchment and Land Protection Act 1994* as part of the framework for implementing a coordinated strategic approach to catchment management across Victoria. Their Regional Catchment Strategies provide a long term strategy for land and water management in the Glenelg/Hopkins and Corangamite regions. The CALP Boards were replaced by the Catchment Management Authorities in 1997.

A number of other regional planning documents, guidelines and management plans influence the management of estuaries with the Parks. These include:

The *Glenelg Hopkins Regional Catchment Strategy (GHCALPB 1993),* for Glenelg and Fiztroy estuaries, and

The *Corangamite Regional Catchment Strategy (CCALPB 1997)* for Curdies, Gellibrand and Aire estuaries.

4.2 SPECIFIC VICTORIAN ESTUARINE PLANNING DOCUMENTS, GUIDELINES AND MANAGEMENT PLANS

4.2.1 Victorian Coastal Strategy

The Victorian Coastal Strategy provides scope to address any activity or process that may have an impact on the coastal and marine environment, both now and in the future (VCC 2002). It also sets the direction for the protection of environmental features, sustainable use of natural resources and the identification of appropriate development opportunities in the coastal environment.

Estuaries and the near shore environment are critical habitats and interact closely with processes taking place on the land. Major objectives of the VCC are to protect and improve estuarine biological diversity, improve Victoriaís marine and estuarine research and scientific capability, and reduce the impact of effluent in marine and estuarine environments. To protect biodiversity the VCC recommended the establishment of environmental flows, the pursuit of better ecological understanding, and a strategic approach to protecting and improving the condition of coastal and estuarine wetlands, including saltmarsh. The VCC also advocates development of best practice guidelines for the management of estuarine mouth openings, incorporating environmental, social and economic issues (VCC 2002).

4.2.2 South West Estuaries Coastal Action Plan

The South West Estuaries Coastal Action Plan (CAP) was developed under the *Coastal Management Act 1995.* Its aim is to ìestablish a regional planning framework and statutory basis which sets out how and what to consider when preparing south west Victoriaís estuariesî (Harty 2001a, p. 7) The CAP identifies major management issues for 10 estuaries between Cape Otway and the South Australian border, including the 5 estuaries considered here. It also reviews the management arrangements (as at September 1999) with respect to their river entrances and the various management roles and responsibilities of government agencies and community organisations.

4.2.3 Draft South West Victoria Regional Coastal Action Plan

Estuary management is only one component of coastal management. The South West Victorian Regional CAP aims to ensure the long term protection and enhancement of the regionís coastal and marine environments while ensuring development is sustainable and consistent with environmental objectives. Management responsibilities and government policies for the coastal zone, including waters to the State Territorial Limit (3 nautical miles) are outlined in the report.

4.3 ESTUARINE MANAGEMENT IN OTHER STATES

It has been difficult to establish what the management practices of other states are for intermittently open estuaries. Some details have been established for Western Australia and New South Wales.

Western Australia has probably had the most coordinated approach to estuarine research in Australia, with the Swan River and Peel Harvey estuary being the two main foci of research. Nutrification and algal bloom problems were recognised in the Swan River estuary in the early 1940s (Riggert 1978). Estuarine management in Western Australia is the responsibility of the Water and Rivers Commission. The estuaries of the far southwest are probably most comparable to the ones in this study, and artificial opening of these intermittent estuaries is also a management issue (Water and Rivers Commission 2002).

The focus in NSW has been on their large rivers and coastal lagoons, which often have high fisheries values. Individual management plans have been developed for these major estuaries. NSW Fisheries have had public education programs since the early 1990s to increase public awareness and ownership of estuaries (NSWF 1993). Estuarine Habitat Management Guidelines (NSWF 1993) set out the legal requirements and management guidelines for activities liable to affect estuarine habitats. The NSW Coastal Policy (1997) coordinates planning and management in the coastal zone. Recently a series of major enquires by the Healthy Rivers Commission of NSW examined entire river systems, including issues and management of their estuaries and mouths (HRC 1999, 2000a & b). Small intermittently open estuaries are only now being recognised in planning and research (HRC 2001; Roy *et al.* 2001).

4.4 INTERNATIONAL APPROACHES TO ESTUARY MANAGEMENT

It has been difficult to locate international literature on management of intermittently open estuaries. South Africa probably has the most comparable estuaries to southwest Victoria in regard to their size and variability in freshwater flow. Environmental flow to the South African estuaries has been a major issue for the last two decades. An Index of Estuarine Health was developed in the early 1990s to assess the condition of their estuaries, and this is the model for the Index of Stream Condition in Victoria (Cooper *et al*. 1993; Ladson & White 1999). Recently a general document on managing estuaries in South Africa was released, and in this the need for research into of artificial mouth opening and its impacts is emphasised (Breen & McKenzie 2001).

In the USA, a National Estuaries Program under the Water Quality Act (1987) was developed to address pollution control in estuaries and is dedicated to developing a comprehensive and consistent national policy on the use and management of estuaries. The focus of estuary management in the USA is on large systems, and there is little available literature on temperate intermittently closed estuaries.

5 Existing Data and Information on the Five Estuaries Managed by Parks Victoria

The following is based on an extensive search of all published literature, Deakin University research, government documents, consultancy reports, and websites. An important component of information and knowledge on these five estuaries came from discussions with regional staff of both Parks Victoria and the Department of Sustainability and Environment.

Extensive use has been made of the Index of Stream Condition (ISC) for determining the degree of flow alteration to the estuaries and the condition of the the rivers immediately upstream of the estuaries (Victorian Water Resources Data Warehouse 2002; Ladson & White 1999). ISC was developed as a tool to assist management of waterways in Victoria and is applied on a reach scale (a length of stream relatively homogenous in hydrology, geology and vegetation). For each reach the ISC provides a summary of the extent of changes to hydrology (flow and seasonality), physical form (stream bed and bank condition, physical habitat), streamside zone (quality and quantity of streamside vegetation), water quality (nutrients, turbidity, salinity and acidity) and aquatic life (diversity of macroinvertebrates). A score out of ten is made for each of these five components, which is a measure of change from natural or ideal conditions (10 = natural/ideal). We have used the hydrological index component to express the degree of change of freshwater flow to the estuaries. This index has only been conducted once and compares natural modelled flows to actual measured flows in 1999. The former are derived from actual flows, taking into account irrigation diversions, urban offtake, stock and domestic diversions and changes in storge and return flows.

The National Estuaries Audit (NLWA 2002) also provided a general assessment of estuary condition, however the audit, like this report suffers from lack of detailed data on which to base its assessments.The Oil Spill Response Atlas (OSRA 2001) has also been a valuable source of information on the Victorian coast, and it was from this atlas that individual maps of each estuary were generated. Environment Australiaís national web based directory of Important Wetlands in Australia was relied upon to help assess values of individual estuaries (EA 2002). Aerial photos were made available by the Western Coastal Board and are copyrighted to QUASCO.

5.1 GLENELG ESTUARY

5.1.1 General Physical Description

The Glenelg estuary flows to the sea in the middle of Discovery Bay, below the township of Nelson, 2 km east of the South Australian border. It is one of the longest estuaries in Victoria, extending 75 km to just below Dartmoor (Figure 11; Sherwood *et al.* 1998). For most of its length it is enclosed by gorges in the Lower Glenelg National Park. At Nelson it opens to a winding channel across the narrow coastal lowland, fringed by salt marshes and swamps (Figures 11 & 12). On the southeastern side of the mouth is a wide and shallow tidal bay edged by rushes and saltmarsh, known as Mud Lagoon or Oxbow Lake. At low tide it is almost cut off from the estuary by exposed sand shoals. Long Swamp to the east of the estuary is connected to Mud Lagoon by Eel Creek. Holloway Creek flows into the estuary on the west side, within 1 km of the mouth.

The Glenelg River estuary meets the sea through a gap in the coastal dune fringe, where its channel is typically 20ñ30 m wide. Its mouth faces southwest (Figure 13). Sand washed into the estuary by ocean waves forms shoals, and so the river course varies in position, sometimes dividing into more than one channel as it approaches the sea. The mouth widens when the Glenelg rises after periods of high rainfall. Floodwaters sweep away the sand to form an outlet that can widen to more than 500 m.

The estimated surface area of the Glenelg estuary is 440 ha (44 x 10^5 m^2) and its volume is 22000 ML (220 x 10^5 m^3; Sherwood *et al.* 1998). Estuary cross-sectional area increases almost linearly from 50 m^2 at 75km upstream to 550 m^2 near the mouth. Midstream depths, above Nelson, are typically 6ñ8 m but deeper basins occur on bends (Sherwood *et al.* 1998). At the mouth the estuary is shallow (1ñ2 m).

The present mouth of the Glenelg River estuary lies directly behind an incised sea floor gorge (known as Nelson Canyon), which runs southward across the continental shelf. This was cut when the Glenelg extended its course across the emerged sea floor during a Late Pleistocene low sea level phase, and indicates that in recent times the river has generally flowed out close to its present mouth (Bird 1993).

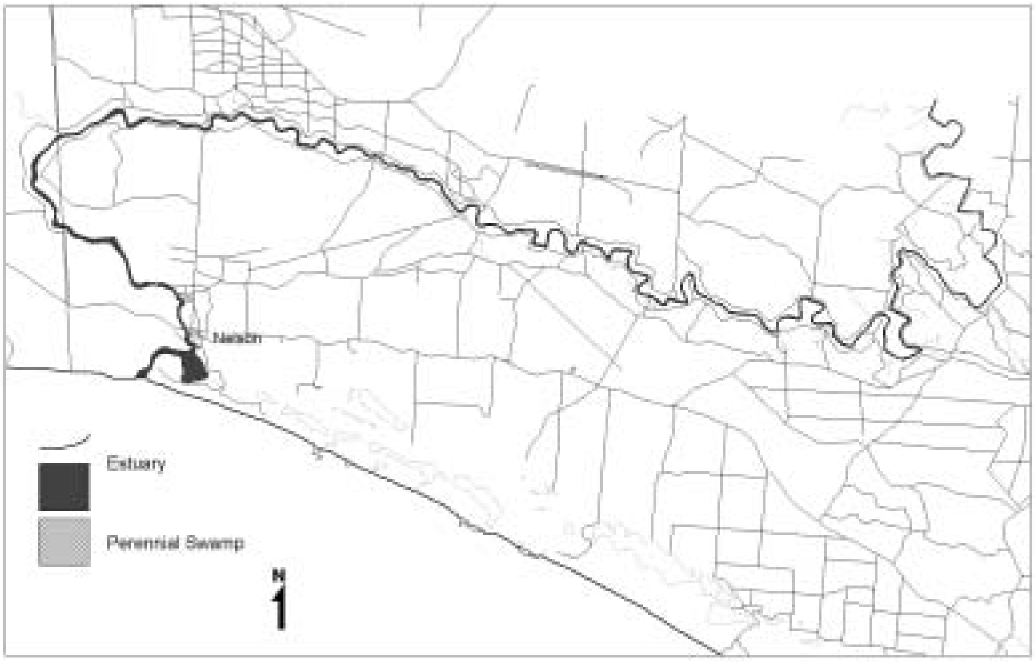


Figure 11. Map of the Glenelg estuary, and estuary catchment, showing the extent of tidal influence upstream, and the area of estuarine waters and wetlands.

Source: Generated from OSRA (2001).

5.1.2 Description of Catchment

Beyond the boundaries of the Lower Glenelg National Park the catchment has been extensively cleared for sheep and cattle grazing. Softwood and blue gum plantations are found in the lower catchment. Rocklands Reservoir collects runoff from the upper Glenelg downstream of the Grampians. A major tributary, the Wannon River, also has headwaters in the Grampians.

There is a streamflow gauging station upstream of the Glenelg estuary at Dartmoor (Gauge No. 238206). From this gauging station the monthly flow to the lower Glenelg estuary was determined for the Index of Stream Condition, in 1999 (Figure 14). The hydrological condition of the lower Glenelg estuary was estimated to be good (8/10; Victorian Water Resources Data Warehouse 2002).

Figure 12. Aerial photo of the lower Glenelg estuary at Nelson, 23/2/00, scale approximately 1:25000.

Source: WCB © QASCO.

Figure 13. Aerial photo of the mouth of Glenelg estuary at Nelson, 23/2/00.

Source: WCB © QASCO.

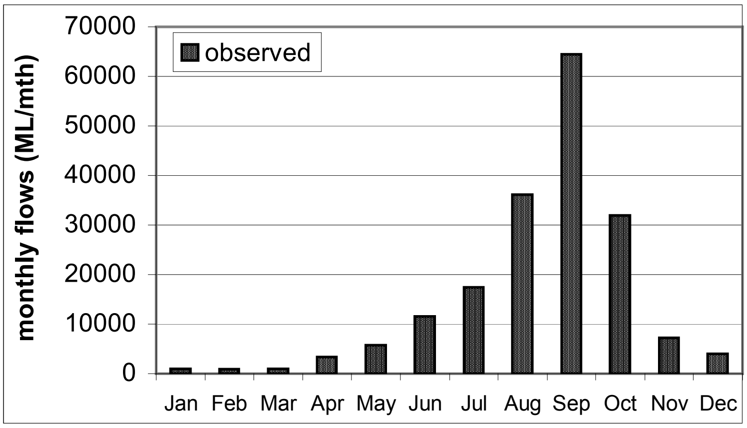


Figure 14. Monthly flows (ML/month) observed for the Glenelg estuary in 1999.

Source: Victorian Water Resources Data Warehouse (2002).

5.1.3 Description of Coast Adjacent to Mouth

The Glenelg River flows out into Discovery Bay, which is an open, 50 km long bay that faces southwest and has some of the highest energy beaches and most active sand dunes in Southern Australia (Figures 11 & 12; Short 1996). The Holocene coastal dunes extend a few hundred metres inland and reach heights of 10ñ20 m. The beach receives waves averaging over 1.5 m, which combine with the fine sand to maintain a 400 m wide triple bar system, with rips. Tidal currents and shifting shoals are associated with the Glenelg River mouth (Short 1996).

5.1.4 Environmental Values

Both the Glenelg River from below Dartmoor (VIC159), and the Glenelg Estuary below Nelson (VIC028) are recognised as being highly significant wetlands and are listed on the directory of important wetlands in Australia (EA 2002). Glenelg Estuary is listed because of six values, and Glenelg River because of the first three values:

- It is a good example of a wetland type occurring within a biogeographic region in Australia.
- It is a wetland that plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex.
- It is a wetland that is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge in adverse conditions such as droughts.
- The wetland supports 1% or more of the national populations of any native plant or animal taxa.

- The wetland supports native plant or animal taxa or communities that are considered endangered or vulnerable at the national level.
- The wetland is of outstanding historical or cultural significance.

Native fish diversity and riparian communities are environmental values recognised by LCC as in neeed of protection in the lower Glenelg River (LCC 1991).

The Glenelg River estuary catchment has six conservation listed plants (Table 9). These are the Leafy Greenhood, Swamp Greenhood, Neat Spear-Grass, Austral Trefoil, Bog Gum and the Elongate Woodruff. The Bog Gum (*Eucalyptus kitsoniana*), a small, bushy tree usually found on damp areas near coastal flats, occurs in the Lower Glenelg and is locally abundant (CLS 1981). It is endemic to Victoria, and only found elsewhere at South Gippsland and Cape Otway (CLS 1981)

The Glenelg River estuary catchment has three conservation listed fish, the Spotted Galaxias, Australian Grayling and Freshwater Blackfish (Table 11). In total 31 species of native fish have been recorded from the Glenelg River estuary (Appendix 4). While estuary perch are widely distributed throughout Victoria, the Curdies and Glenelg Rivers rank highly because they contain populations of large perch (McCarraher & Mckenzie 1986).

Thirty-three waterbirds have been recorded in the estuary (Appendix 4) and the estuary catchment has 18 conservation listed birds recorded from it (Table 11). These include the Great Egret, Intermediate Egret, Australasian Bittern, Little Bittern, Cape Barren Goose, Blue-billed duck, Grey Goshawk, White-bellied Sea-Eagle, Lewinís Rail, Brolga, Hooded Plover, Little Tern, Fairy Tern, Red-tailed Black-Cockatoo, Orange-bellied Parrot, Swift Parrot, Powerful Owl and Rufous Bristlebird. Little Terns have been observed breeding on the spit since at least 1987.

The estuary has four conservation listed invertebrates, the Glenelg River Crayfish, the Southern Victorian Spiny Crayfish, Glenelg Freshwater Mussel and a butterfly (Table 11).

5.1.5 Alteration of the Estuary

In the National Estuaries Audit the Glenelg estuary was classified as modified, based on possible changes to the estuarine ecology due to changed landuse (NLWA 2002). Catchment land degradation has caused sanding and siltation in the Glenelg River (SOMER 1995).

Rocklands Reservoir in the headwaters of the Glenelg diverts water from the upper Glenelg catchment. Holloway Creek used to take flow from Piccaniny Ponds before that was diverted. Long Swamp to the east has had two artificial cuttings made for eel fisheries and no longer flows into the Glenelg (B. Mackereth pers. comm. 2002).

The Glenelg River runs for 4 km through South Australia, where there are activities contrary to Victoriaís Heritage River Management Plan, *i.e.*, effluent discharge, house boats, people living on the river banks in shacks (NRE 1997).

5.1.6 Ecological Understanding

This estuary is not well understood. Its length is often not appreciated as it is often thought to be only the lower section below Nelson. The estuarine ecology of the gorge section has not been investigated. There is also little information on the wetlands around the mouth. Macroinvertebrates have been sampled in the estuary in 1997 as part of a south-eastern Australia survey (Moverley & Hirst 1999).

5.1.7 Existing Management Plans

There currently is no specific management plan for the estuarine water body. The estuary catchment is managed as part of the Discovery Bay Parks and Lower Glenelg National Park management plans (PV 1998).

5.1.8 Past and Present Opening Regimes and Protocols

Concerns about river flora and fauna led National Parks (now Parks Victoria) to take over mouth opening with SRW consent from 1997 onwards. In March 1997 public comment on artificial opening was canvassed and in April 1997 a proposed release level marker was erected for public comment. This level was accepted and is marked on the public jetty at Nelson. The trigger level height was selected based on observations that opening the mouth when water levels were below it was generally unsuccessful.

The estuary is considered closed when there is no run out over the sand bar (B. Mackereth pers. comm. 2002). As soon as the mouth is closed, PV rangers start checking the level daily. The level typically rises about 2 cm/day initially but then slows to about 1 cm/day as the water spreads out over paddocks and fills marshes fringing Mud Lagoon. Access for machinery to open the mouth is via the beach to the west, from Piccaniny Ponds in South Australia (B. Mackereth pers. comm. 2002).

The best estuary conditions for opening are considered to be a falling tide with an offshore wind (B. Mackereth pers. comm. 2002). The usual opening procedure involves digging a trench across the sand bar, creating a 1:50 fall from inside the mouth to the beach. The last bit of the channel to be dug is at the estuary end and from here the trench is continued into the shallow water to try and get enough drop (Figure 15). Once the trench is opened it starts widening or fanning out from the beach end, working up the river for 300 m as water rushes out.

After the mouth is opened, about 1 m of water runs off the top over about 24 hours. A day after opening the channel can be 100ñ200 m across and 1ñ2 m deep (Figure 15). There have been no fish kills associated with mouth opening since records started in 1984 (B. Mackereth pers. comm. 2002).

The community of Nelson continue to be supportive of the trigger level and tolerant of minor flooding incurred with mouth closure. Pressure for mouth opening below the trigger level comes from Donovans Landing, South Australia, especially around public holidays. Grant Council, SA would like the trigger level lowered. At the trigger height, PV has 35 of its structures (jetties, boat ramps, parking etc) underwater. Donovans Landing has house boats, shacks, boat sheds, and jetties that are affected by flooding 70 mm below the trigger level.

Glenelg River estuary has the best records of mouth condition for any of the five estuaries in this report (Table 13). The same park ranger has been keeping records since 1983. While these records are incomplete for the early 1990s, they give a good indication of mouth opening and closing frequency. After the spring floods of 1983 the mouth was not closed until the early 1990s, (B. Mackereth pers. comm. 2002).

Prior to the opening on 2 May 2001 (Table 13) a survey of water quality at 5 sites along the Glenelg estuary showed that DO exceeded 5 mg/L to a depth of 3 m at all sites. Since about 1 m of surface water is lost on opening the risk of adverse ecological effects was considered low.

Table 13. Record of the mouth condition of the Glenelg River estuary.

Date blocked	Date Opened	Days closed
17/3/01	2/5/01	46
4/5/00	30/5/00	26*
7/3/00	27/4/00	48+
19/12/99	15/2/00	58
26/10/99	11/11/99	16
12/5/99	29/5/99	17
2/4/99	2/5/99	30
11/1/99	8/3/99	56
16/3/98	28/4/98	43
20/12/97	8/2/98	50
12/8/97	19/9/97	38
16/7/97	26/7/97	10
1/5/97	12/5/97	11
21/3/96	30/4/96	40
22/4/95	9/5/95	17
?	15/4/95	?
?	22/1/95	?

* This was 46 cm above the trigger level when opened.

+ a failed opening attempt preceded this, opened before reaching the trigger height. Seven days later the water level was at the trigger height and the mouth was sucessfully opened.

Figure 15. Artificial opening of the Glenelg Estuary mouth, February 2000.

(a) mouth closed (9/2/00), (b) boat hire at Nelson inundated (8/2/00), (c) jetty flooded & trigger mark (8/2/00), (d) trigger mark (8/2/00), (e) opening mouth with bobcat (15/2/00), (f) mouth day after opening (16/2/00).

Source: B. Mackereth (2002).

5.2 FITZROY ESTUARY

5.2.1 General Physical Description

The Fitzroy River flows east from Heywood, and enters the sea between Narrawong and Codrington in Portland Bay (Figures 16 and 17). Darlot Creek is a major tributary of the Fitzroy River. The Fitzroy River estuary extends to just above the Princes Highway, and presumably up Darlot Creek (Figure 16). The Tyrendarra lava flow crosses the Fitzroy River channel 0.5 km above the Princes Highway bridge, creating a rock ledge and riffles that prevents further tidal influence. The river mouth is deflected to the east by Holocene dunes before it enters the sea. The position of the river mouth has been variable over time (CLS 1981).

The estuary is shallow, particularly near the mouth where the depth is less than 2 m (N. Turoczy pers. comm. 2002). Depth elsewhere in the estuary is generally in the range 2ñ4 m. The maximum recorded depth is 5.5 m. The estuary was stratified when sampled by Deakin University Water Quality Lab in May 2000 and 2001.

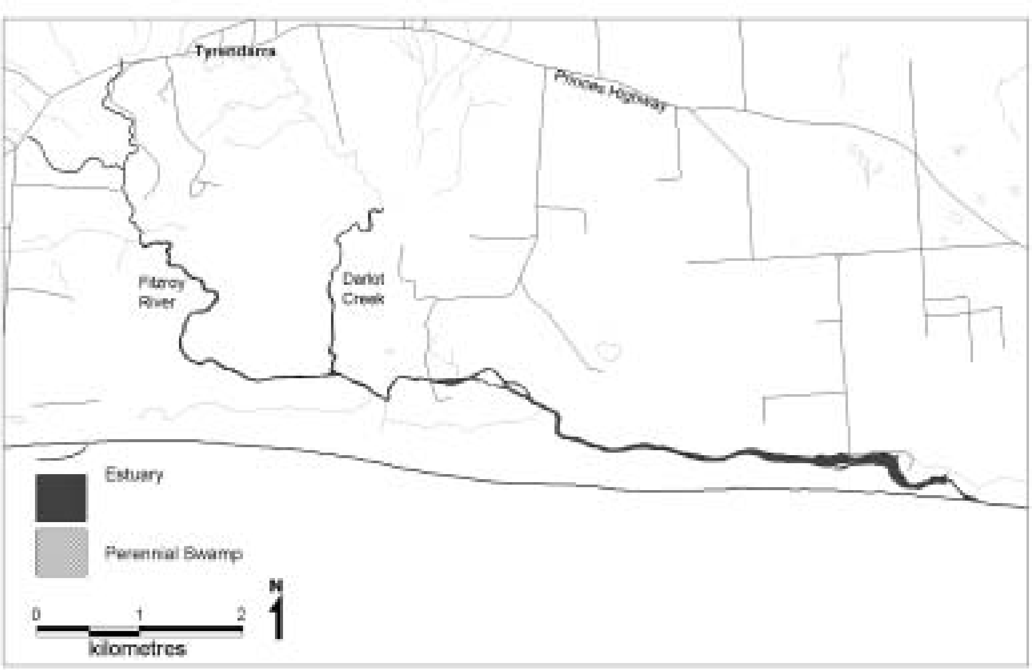


Figure 16. Map of the Fitzroy estuary, and estuary catchment, showing the extent of tidal influence upstream, and the area of estuarine waters and wetlands.

Source: Generated from OSRA (2001).

Figure 17. Aerial photo of the lower Fitzroy estuary, 23/2/00 scale approximately 1:25000.

Source: WCB © QASCO.

Figure 18. Aerial photo of the mouth of the Fitzroy River, 23/2/00.

Source: WCB © QASCO.

There are no major dams in the river catchment. The observed monthly flows into the Fitzroy from 1999 seem relatively unmodified, except for a summer decrease in flows that was substantial (50%) in March (Figures 19 & 20). The flow is highest in winter (6000 ML/month) compared to low summer flows (1000 ML/month).

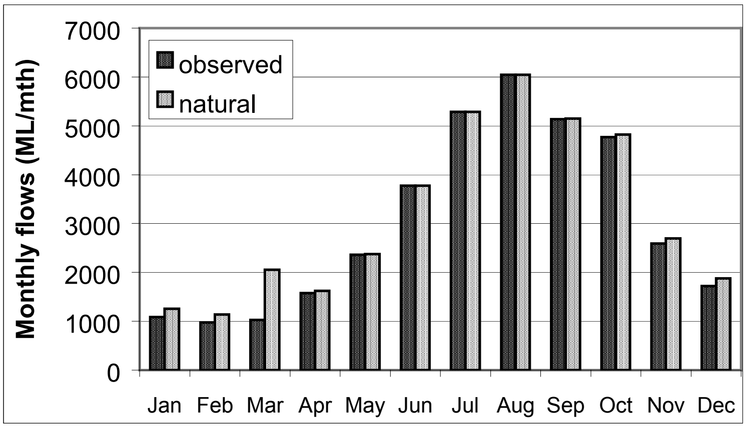


Figure 19. Monthly flows (ML/month) observed for the Fitzroy estuary in 1999 compared to the ISC modelled natural flows.

Source: Victorian Water Resources Data Warehouse (2002).

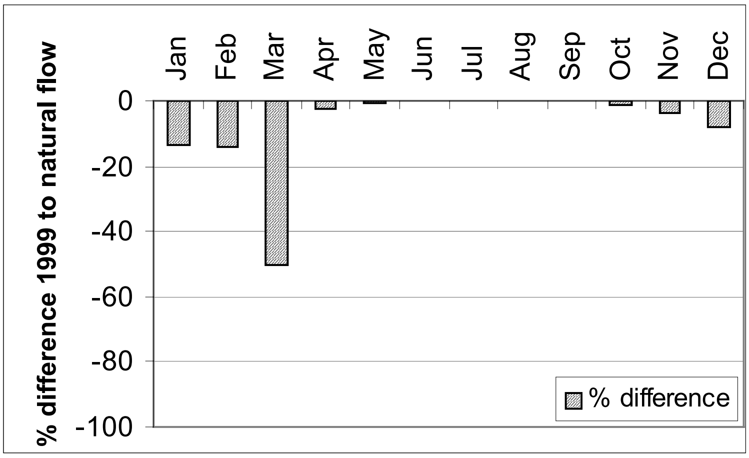


Figure 20. Percent difference of monthly flows (ML/month) for Fitzroy estuary for the observed flows in 1999 compared to the ISC modelled natural flows.

Source: Victorian Water Resources Data Warehouse (2002).

5.2.2 Description of Catchment

The Fitzroy River catchment is at the geological junction of the Normanby Platform and Western District Volcanic Plains (CLS 1981). Its geology consists of Tertiary sediments capped by volcanic lavas. The Tyrendarra lava flow is 19,000 years old and follows an ancestral valley of the Darlot Creek, between Mt. Eccles area and the coast (CLS 1981). The route of the Fitzroy River has been displaced to the western edge of the Tyrendarra lava flow for much of its course, although it subsequently crosses it above the Princes Highway and again below.

The catchment has been extensively cleared (Figure 17) and is used for sheep and cattle grazing.

There is a stream gauge on Darlot Creek at Homerton Bridge (237205) and on the Fitzroy River at Heywood (237202).

5.2.3 Description of Coast Adjacent to Mouth

The Fitzroy River flows to the sea at Portland Bay onto a long sandy beach between the Surrey River and Lake Yambuk (Figure 17). The beach faces southwest and is exposed to westerly winds and waves averaging over 1.5 m (Short 1996). The wave height is slightly reduced by the extensive Julia Reef, which is a part of a lava flow that extends more than 30 km seaward from the coast. The waves interact with the generally fine beach sand to maintain a 250 m wide surf zone. The beach is backed by a 10 to 20 m high, narrow series of foredunes. Farms back the beach and public access is limited to the Fitzroy River Mouth Coastal Reserve, where a 500 m walking track leads from the car park to the beach (Short 1996).

The river mouth is deflected to the east by Holocene dunes before it enters the sea. The Fitzroy River estuary mouth is a site of particular landform interest as it illustrates the interactions of coastal, volcanic and fluvial processes acting at the one site (CLS 1981).

5.2.4 Environmental Values

The fringing wetlands of the Fitzroy estuary run parallel to the coastal dune system. They are not recognised nationally as important (EA 2002), but the junction of the Fitzroy River and Darlots Creek retains a large area of vegetated swamp lands. The fern flora of the catchmentís basalt caves has been recorded as of special scientific interest (CLS 1981).

In the Fitzroy estuary catchment only two plant species with conservation listing in NRE (2001a) occur (Table 9) the Bog Gum and the Lime Fern. The Lime Fern has been recorded from Darlots Creek at Ettrick, and is one of only three such localities in Victoria (CLS 1981).

Fitzroy River has a stand of Swamp (Kangaroo) Paper-bark (*Melaleuca halmaturorum*), this species is usually only found near salt lakes in the Mallee and Wimmera (CLS 1981). However it is not known if the stand occurs naturally or was historically transplanted (A. Pritchard pers. comm. 2002). It is located in semi-saline swamps along the banks of brackish streams as far as the tidal limit (CLS 1981). Woolly Tea-tree and Manna Gum also occur in the area.

Three conservation listed species of fish are recorded from the estuary catchment: the Pouched Lamprey, Yarra Pigmy Perch and Freshwater Blackfish (Table 11). In total 16 species of fish have been recorded in the Fitzroy estuary catchment (Appendix 4).

Fourteen conservation listed birds have been recorded in the Fitzroy estuary catchment (Table 11). These birds are the Great Egret, which is JAMBA and CAMBA listed, the Australasian Bittern, Grey Goshawk, Grey Falcon, Lewinís Rail, Baillonís Crake, Brolga, Australian Bustard, Bush Stone-curlew, Hooded Plover, Little Tern, Red-tailed Black-Cockatoo, Powerful Owl and Rufous Bristlebird.The rush and sedge swamps adjacent to Darlot Creek support very large ibis rookeries in which up to 10,000 ibis may be present at times (CLS 1981).

No conservation listed invertebrates or reptiles have been recorded in the Fitzroy estuary catchment. One conservation listed mammal, the Spot-tailed Quoll has been recorded (Table 11).

There are four licenses for adult eel fisheries in the Fitzroy, two of them are for the lower estuary and two for further upstream (B. Sinott pers. comm. 2002).

5.2.5 Alteration of the Estuary

In the National Estuaries Audit the Fitzroy estuary was classified as modified, based on possible changes to the estuarine ecology due to changes to the catchment hydrology (NLWA 2002). The mid-catchment of the Fitzroy River, above the Princes Highway to near Homerton, was extensively drained and modified around 1945 (Mitchell 1998).

The 1999 ISC assessment of the freshwater reach of the Fitzroy River immediately upstream of the estuary classified it as in marginal condition. Whilst the aquatic life of the river (9/10), the hydrology (10/10), and the physical form (8/10) were all good, the zone was in very poor condition (3/10) (Victorian Water Resources Data Warehouse 2002). Darlot Creek was also assessed as being in marginal condition with a poor riparian zone (5/10), and altered physical form and hydrology (both 7/10). Water quality in Darlot Creek was good (8/10) and aquatic life very good (9/10).

5.2.6 Ecological Understanding

The ecological processes of this estuary are not well understood. There is not even basic survey information for the estuaryís flora and fauna. The extent of estuarine wetlands and tidal influence along Darlot Creek are not known. Moverley and Hirst (1999) sampled estuarine macroinvertebrates in the Fitzroy[a6].

5.2.7 Existing Management Plans

There is no management plan for the Fitzroy River. Surrey River, adjacent to the Fitzroy, does have a management plan (SKM 2000), but is unclear how much of that would be transferable to the Fitzroy.

5.2.8 Past and Present Opening Regimes and Protocols

A trigger level at 0.6 m AHD is marked on the lower jetty. There are no specific mouth opening protocols except the general protocols in the license. The mouth is generally opened with a backhoe towards the western end of its bar (A. Morris pers. comm. 2002). The timing of mouth opening is done so that the channel will be completed on the falling tide. Access to open the mouth once it reaches its trigger level is difficult and has to be made through private land to the west of the mouth (A. Morris pers. comm. 2002). Records of the mouth condition, including artificial opening are sparse. There are records for the mouth being artificially opened in May 1999, sometime in 2000 and in May 2001.

In 2000 the estuary was opened through the centre of the sand bar rather than the western end, this was not successful as the channel rapidly closed up (A. Morris pers. comm. 2002). This different opening position was used mainly because of concerns from eel fishermen (B. Sinott pers. comm. 2002). In May 2001 there was only a very shallow layer of well oxygenated surface water, so the mouth was opened on a rising tide in an effort to prevent overly rapid drainage of the estuary and the associated risk of fish kills (Table 14). An excavator made a 1 m wide channel. After approximately 48 hours the level had dropped to 0.3 m on the boat ramp board and the mouth was 30ñ40 m wide, 1.5 m deep, 20ñ25 m off the eastern dunes and still running (B. Sinott pers. comm. 2002). There were no fish kills, but the mouth did not stay open very long before it closed over, to later open naturally (A. Morris pers. comm. 2002).

Table 14. Risk assessment of Fitzroy Estuary pre artificial openings.

Sample Date	# of sites sampled	Depth of good DO*	Opening Risk+
24/5/01	7	2	medium
17/5/00	11	1	high

*Depth of water having DO ≥ 5 mg/L

+Risk that loss of surface water (1ñ2 m) would cause mortality of estuarine organisms

Source: Deakin Uni Water Quality Laboratory.

5.3 CURDIES ESTUARY

5.3.1 General Physical Description

The Curdies River has a catchment area of 1015 km^2. Its headwaters are fed by Lake Purrumbete, which episodically overflows. The main stem of the River is approximately 117 km long and it has one major tributary, Scotts Creek-Corriemungle Creek. Curdies River enters the coast at Peterborough as Curdies Inlet (Figure 21). The estuarine tidal and seawater influence extends approximately 17 km upstream, as far as A'Becketts Creek, which is 5 km above Curdievale (Figure 21).

The coastline into which the Curdies River enters has very high wave energy from the prevailing southwesterly ocean swell and storm waves arriving through deep water over a narrow section of the Australian continental shelf (Bird 1993). Curdies River follows a slight synclinal depression in the Port Campbell limestone to form a shallow coastal lagoon, in what is otherwise a coast dominated by dramatic limestone cliffs (Figure 22).

The lower 4 km of the estuary occupies a shallow (< 1 m deep), broad V-shaped inlet that decreases steadily in width until it meets the riverine section (Figure 21). The riverine section is much deeper (7ñ8 m). The estuary is a mature barrier type in the final stages of infilling (Roy 1982). A sand dune crosses the entrance from the eastern side leaving a narrow entrance channel on the west (Figure 23).

5.3.2 Description of Catchment

The catchment is primarily developed for dairy farming, having been extensively cleared for soldier settlement after World War 2. Basalts occur in the upper catchment but most of the catchment is underlain by Tertiary marine sediments. Down cutting of the Tertiary sediments is more rapid than the basalts leading to deeply incised valleys immediately downstream of the basalt escarpment.

There are no major dams in the river catchment. A gauging station is located at Curdievale (site code 235203). The River downstream of Curdievale scored 9 out of 10 in the ISC assessment of hydrology, as the observed 1999 flows were not significantly different from modelled natural flows (Figure 24; Victorian Water Resources Data Warehouse 2002). However the flows were over 60% less in summer and autumn than modelled natural flows (Figure 25), and this may have implications for mouth closure frequency.

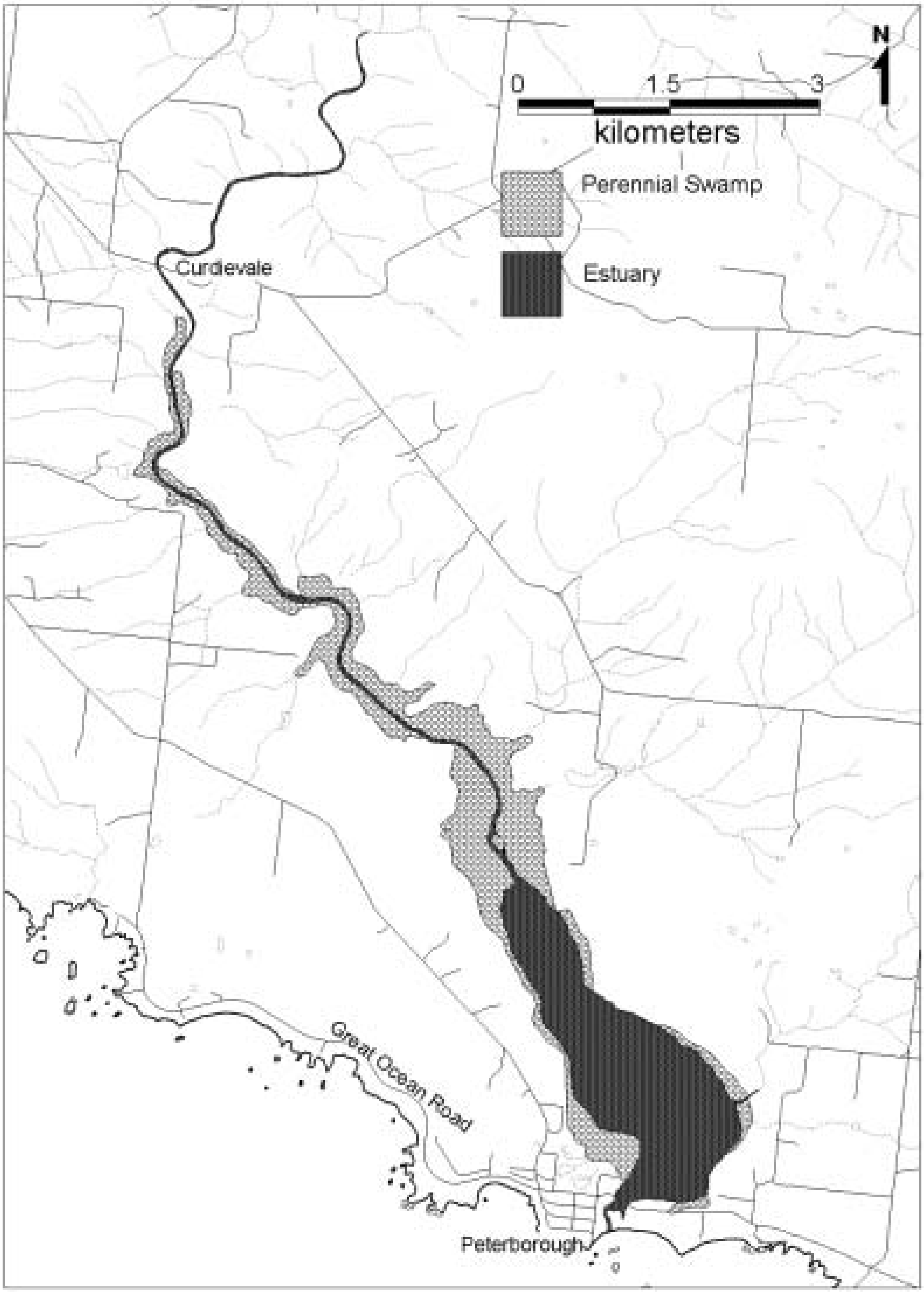


Figure 21. Map of the Curdies Inlet estuary, and estuary catchment, showing the extent of tidal influence upstream, and the area of estuarine waters and wetlands.

Source: Generated from OSRA (2001).

Figure 22. Aerial photo of Curdies Inlet at Peterborough, 23/2/00, scale approx. 1:25000.

Source: WCB © QASCO

Figure 23. Aerial photo of the mouth of Curdies Inlet at Peterborough, 23/2/00.

Source: WCB © QASCO.

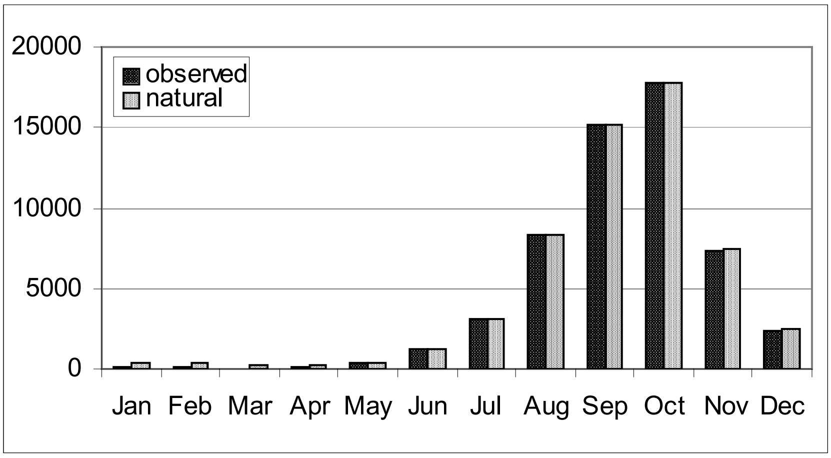


Figure 24. Monthly flows (ML/month) observed for the Curdies Inlet estuary in 1999 compared to the ISC modelled natural flows.

Source: Victorian Water Resources Data Warehouse (2002).

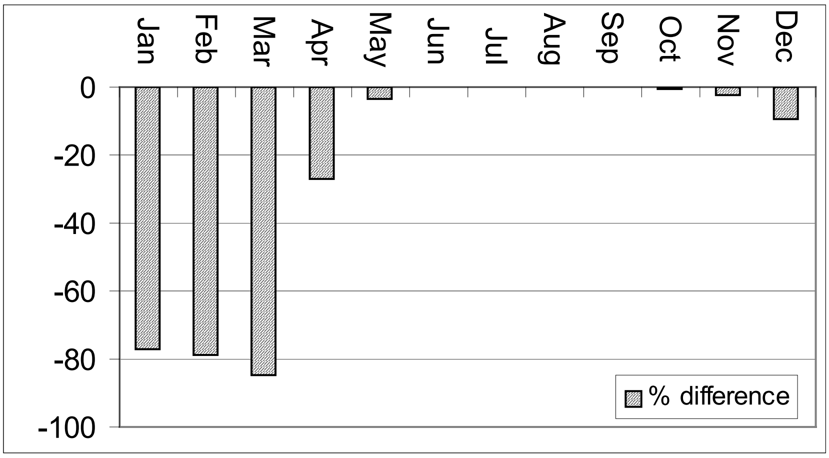


Figure 25. Percent difference of monthly flows (ML/month) for Curdies Inlet for the observed flows in 1999 compared to the ISC modelled natural flows.

Source: Victorian Water Resources Data Warehouse (2002).

5.3.3 Description of Coast Adjacent to Mouth

Waters from Curdies Inlet flow into the sea at Newfield Bay, Peterborough against a rocky headland on its western side (Figure 22). To the east of the mouth is a 1.5 km long, 300ñ 400 m wide sand barrier, consisting of 10ñ20 m high dunes (Short 1996). The mouth of the Curdies has a southerly aspect. It is sheltered by Schomberg Reef and small calcarenite stacks immediately offshore from the mouth (Figure 23). The coast supports crayfish and abalone fisheries.

5.3.4 Environmental Values

The coast near Peterborough is of environmental significance due to the rich heathlands that are similar to those of the nearby National Park and the occurrence of four rare plants and remnants of Manna Gum communities (Table 9; Appendix 3). The Leafy Greenhood has been recorded near Peterborough (CLS 1981). The Swamp Greenhood occurs under dense Woolly Tea-tree groves. Currant-wood and Square Raspwort also occur in the estuarine catchment.

The Manna Gum was once very numerous along much of the coast between Princetown and Yambuk, but now only survives near the Fitzroy and Curdies estuaries (CLS 1981). A number of other rare plants occur near Peterborough, they include Dark Swamp Wallaby Grass which is a semi aquatic plant, the Lax Twig-rush, Swamp Diuris, Soft Shield Fern and the Morning-Flag (CLS 1981).

One conservation listed fish has been recorded from the Curdies Inlet estuary, the Yarra Pigmy perch (Table 11). The fish community in the estuary seems to be poorly described, with only seven recreationally important and native species recorded (Appendix 4). Likewise no conservation listed invertebrates, mammals or reptiles have been recorded. One explanation for these low numbers may be the high degree of alteration of the estuary catchment although it may also indicate a low survey effort.

A possible lack of survey effort may also be reflected in the bird species list. Eleven birds have been recorded and all are conservation listed (Table 11). These birds are the Great Egret, which is JAMBA and CAMBA listed, the Australasian Bittern, Little Bittern, Cape Barren Goose, Grey Goshawk, Brolga, Hooded Plover, Fairy Tern, Red-tailed Black Cockatoo, Powerful Owl and Rufous Bristlebird. The Orange Bellied Parrot has been observed on the south west edge of Curdies Inlet among rushes, grass and low scrub (CLS 1981).

The wetlands are valued for recreational duck shooting, and one active eel fishing licence is held for the estuary. Curdies also ranks highly as an estuary perch fishery (McCarraher & Mckenzie 1986).

The coastal lagoon of Curdies Inlet is of particular geomorphological interest due to its formation. It appears to have formed by the water filling a down warped section of the Tertiary limestone. This contrasts with most of the other coastal lagoons in the southwest, which have been formed by stream flow being blocked by dune systems (CLS 1981).

5.3.5 Alteration of the Estuary

The riverine and estuarine catchments of Curdies Inlet have been extensively modified (Figure 22), with large scale clearing and the loss of many EVCs (RFA 2000; see Figure 10 a & b in Section 2). In particular large areas of Damp Heath Scrub have been lost to the west of Curdies Inlet.

Elevated nutrient levels in Curdies Inlet (CCMA 2001; Maher 2001) reflect changes in landuse in the catchment. In the National Estuaries Audit Curdies Inlet condition was classified as modified, based on possible changes to the estuarine ecology due to high nutrient loads entering the estuary (NLWA 2002). The condition of the freshwater environment of the Curdies River, immediately above the estuary is poor. The ISC assessment of this reach of the Curdies indicated that whilst the hydrology of the river was good, water quality (6/10), stream side zone (7/10), and aquatic life (1/10) were poor to very poor (Victorian Water Resources Data Warehouse 2002). Surveys of water quality by Deakin University have also shown that the river is degraded, with high nutrient levels (Maher 2001). Its waters consistently exceed State water quality guidelines.

The Curdies River estuary has had blooms of blue-green algae in recent years. Concern over the possible toxic effects of the algae has seen the estuary closed to recreational activities such as fishing, boating and swimming during autumn in 1991 and again in 1998. The Curdies is the only southwest Victorian estuary to have suffered a blue-green bloom. There may be an increased risk of blue-green algae blooms when the mouth is closed (Maher 2001).

In their draft Water Health Strategy, Corangamite CMA (2001) identifies the lower Curdies River as a medium priority for willow treatment works. All of the lower Curdies is also identified as being a high priority for streamside protection works, which include revegetation and fencing.

5.3.6 Ecological Understanding

The ecological processes of this estuary are not well understood, with the exception of some preliminary understanding of sediment and water nutrient cycling, and phytoplankton communities (Maher 2001).

5.3.7 Existing Management Plans

Historically the manager for the mouth has been unclear, as it is at the junction of three parcels of land: Port Campbell National Park, Curdies Inlet and River Reserve (which came under Parks Victoria management in 1996), and, to the west, a parcel managed by Moyne Shire. Further west, past Peterborough, the coastal land becomes the Bay of Islands Coastal Park. Parks Victoria obtained the the waterway works licence to artificially open the mouth in

1998. There is currently no management plan for the estuary. The local community group Heytesbury District Landcare Network is looking to develop landcare and coast action/coastcare groups for the region.

5.3.8 Past and Present Opening Regimes and Protocols

The mouth has closed at any time throughout the year, but artificial opening usually happens in the summer months, at least once a year (J. Turner pers. comm. 2002). This year (2002) was unusual as during December and January the mouth was still naturally open (J. McInerny pers. comm. 2002). No records are kept of the mouth condition, when it closes or when it naturally opens, and only sparse and incomplete records are available of when it has been artificially opened (Tables 16 and 17). Some records of artificial opening may be held by the mouth opening contractor.

The current trigger height for artificial openings is 1.3 m AHD on a gauge board on the Great Ocean Road bridge. Parks Victoria monitors the gauge height once water starts to lie in the wetland to the east beside the Great Ocean Road. This wetland was once an old opening of the inlet. The time it takes for the water level to reach 1.3 m from when the wetland fills is unpredictable (A. Morris pers. comm. 2002). Relevant stakeholders are phoned and informed of possible artificial mouth opening when the river reaches 1 m. The mouth is usually opened with an excavator because of the volume of sand that needs to be shifted. The same contractor has opened it for the past decade, and opens the mouth at the same spot each year, lining up a telephone pole and the Great Ocean Road bridge. It takes approximately four hours to open the channel.

Boggy Creek Pubís boat landing at Curdievale goes under water before the estuary height reaches the trigger level. This flooding may be one of influences determining the height at which the trigger level is set. One of the primary issues influencing mouth opening is the flooding to private land and houses in Peterborough township. Septic tank overflow in Peterborough may also be an issue. However, plans are underway to sewer the town.

There have been no records of any fish kills in the estuary associated with mouth opening. In August 2001, after a natural opening following a period of strong easterly winds and upper catchment rain, fishermen reported mass mortality of crayfish in the reefs offshore. The reefs became covered with a large deposit of sediment and this seemed to have smothered the crayfish. This incident may not have been caused entirely by the sediment from the mouth opening as major sections of dune were lost to the east of the mouth.

Table 15. Parks Victoria records of Curdies Inlet mouth condition.

Opening date	Artificial or natural	Estuary height (m)	Pre monitoring*	Post monitoring*
9/8/01	natural	1.7	yes	yes
6/6/96	artificial	1.32	no	no

*Pre and Post monitoring refers to surveys of DO levels at sites along the estuary before and after opening

Table 16. Risk assessment of Curdies Estuary pre artificial opening.

Sample Date	# of sites sampled	Depth of good DO*	Opening Risk+
10/8/01	8	4 m	low
7/8/01	7	all	low
22/7/00	9	all	low
8/9/99	4	5 m	low

*Depth of water having DO ≥ 5 mg/L, +Risk that loss of surface water (1ñ2 m) would cause mortality of estuarine organisms

Source: Deakin Uni Water Quality Laboratory.

5.4 GELLIBRAND ESTUARY

5.4.1 General Physical Description

The Gellibrand River headwaters are in the Otway Ranges, draining from the western side of Lavers Hill. The Gellibrand River joins the coast below the township of Princetown. The estuary has only one major tributary, Latrobe (or Serpentine) Creek, which joins the Gellibrand from the west 1.25 km above the mouth (Figure 26 & 27).

The estuary, with its tidal and seawater influence extends approximately 10.7 km upstream (Sherwood 1983). The estuary opens to the east of the high (50 m) cliffs of Pt Ronald, cutting across a sand bar that is approximately 150 m wide, with a typical channel width of 25ñ30 m, and a channel depth of 1ñ1.5 m (Figure 28). Upstream, the channel broadens to up to 50 m wide and 3 m deep, with occasional deeper scour holes at bends, and with wide floodplains. The upper part of the estuary narrows at approximately 3.5 km from the mouth becoming 6ñ 20 m wide and 5ñ7 m deep, and with narrow floodplains, and levee banks beside the channel (Figure 27). It is a mature barrier estuary in the final stages of infilling (Roy 1982).

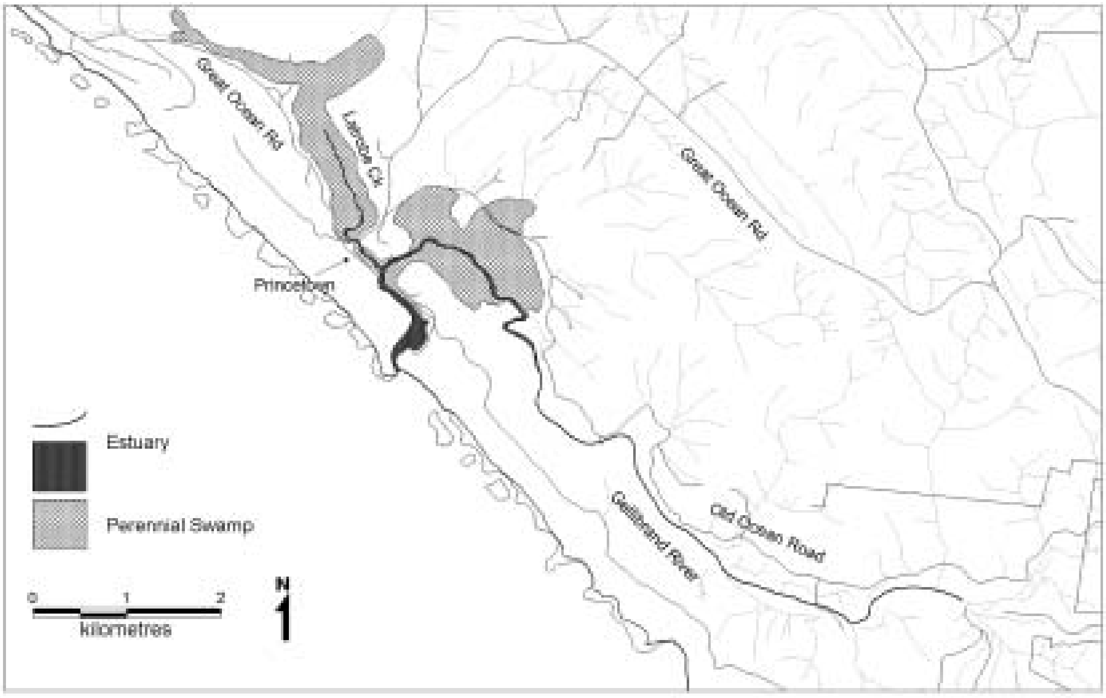


Figure 26. Map of the Gellibrand estuary, and estuary catchment, showing the extent of tidal influence upstream, and the area of estuarine waters and wetlands.

Source: Generated from OSRA (2001).

The upper estuary floodplain is approximately 1 km wide, considerably narrower than that of the lower estuary, and is mostly cleared and drained for dairy pasture. This land is often inundated by floods, which deposit silt. Most of the banks were cleared of vegetation in the early 1900s, to allow horse drawn barges to transport milk and cream to a factory upstream (O'May & Wallace 2001). There has been some regrowth of *Leptospermun* and *Acacia*, but the majority of the floodplain and estuary banks are without major trees (McKay 2000).

Tides in the Gellibrand estuary have been studied on two occasions and are asymmetrical, the flood tide being shorter than the ebb tide (Sherwood 1983). High tide can occur within 30 minutes of the predicted high tide for Portland, but may differ by two hours for low tide.

Latrobe Creek enters the Gellibrand 1.25 km above the mouth, where Gellbrand is 15 m wide. It is a small system, being approximately 2 m deep and navigatable for 2.5 km before it becomes too narrow for a boat. It has a considerable area of wetlands, making up approximately half of the total lower Gellibrand wetland area (Sherwood 1983). The extent of tidal influence up the Latrobe Creek has not been established. The salinity of Latrobe Creek has always been higher than that of the freshwaters of Gellibrand River. Leaching of salts from the adjoining wetlands may be a cause of this (Sherwood 1984).

The Gellibrand is shallower than the Hopkins or Glenelg estuaries, which are set in deep canyons with minimal floodplains. The large area of floodplain in the Gellibrand estuary dissipates freshwater flood energy and limits the amount of flood scour.

A large body of work exists on the Gellibrand River and estuary from the early 1980s (Sherwood 1983 & 1984; Breen 1982; Earl & Bennett 1986; Koehn 1984; Tunbridge & Glenane 1988). This is because of a major investigation by the State Rivers and Water Supply Commission into the environmental consequences of increased water diversion of the Gellibrand to supply southwestern district towns (NREC 1989). There has also been recent research (Kelly 2000; McKay 2000) which formed a basis for the development of an estuary and wetland management plan (O'May & Wallace 2001).

The hydrological study by Sherwood (1983 & 1984) provides valuable information that is often lacking in these small estuarine systems, describing the position of the salt wedge and identification of the freshwater flow needed to flush saline water from the estuary. The toe of the saline bottom waters moves up and down the length of the estuary depending on freshwater flow, tidal flow and storm surges. The upper extent of the estuary is at a section of shallow rapids that prevents the salt wedge migrating further upstream (Sherwood 1983). From cross sections along the length of the estuary Sherwood estimated the total estuary water area to be 20.8 ha and the total estuary volume to be 490 ML (Sherwood 1983).

Increased freshwater flow in the estuary happens 1ñ4 days after rainfall in the upper catchment (Sherwood 1984). Sherwood (1983) estimated that 500 ML/day would flush all saline water from the estuary. Hydrological records show long term average daily flows of 500 ML/day for months during winter and spring, so the estuary in normal rainfall years is likely to be freshwater for months of the year. Peak flows of over 500 ML/day lasted 3ñ5 days during the 1983 study period and flushed the estuary of saline water (Sherwood 1984). Five days after these peak flows, the salt wedge had returned to the estuary, so complete flushing lasted a short time.

In the follow up study of 1983 in which the catchment monthly rainfall was close to the long term averages, and the river discharges were appreciably higher than the previous year, the mouth stayed open during the whole of the study, from May to October (Sherwood 1984). As predicted from the 1982 study, in 1983 the estuary remained fresh through much of winter and autumn because of the high freshwater discharge, and the salt wedge was not measured to penetrate further upstream than 4 km (Sherwood 1984).

Figure 27. Aerial photo of the Gellibrand River estuary at Princetown, 23/2/00, scale approximately 1:25000.

Source: WCB © QASCO.

Figure 28. Aerial photo of the mouth of Gellibrand R. estuary near Princetown, 23/2/00.

Source: WCB © QASCO.

5.4.2 Description of Catchment

The Gellibrandís upper catchment is one of the wettest parts of Victoria, with an average annual rainfall of 2040 mm, as measured at Weeaproinah. The river length is about 125 km and it has a catchment area of 1170 km^2. After flowing through steep terrain covered with eucalypt forests, the river meanders through agricultural land and across extensive flood plains. Throughout agricultural areas, the river is used extensively for irrigation particularly during summer.

There are gauging stations on the river at Bunkers Hill (235227), Carlisle (235208) and Burrupa (235224). At Burrupa the riverís mean annual flow is 315,000 ML; its highest flows are in August (60,000 ML mean monthly flow) and lowest flows are in March (4,855 ML mean monthly flow; Tunbridge & Glenane 1988; Figure 29). The river system is prone to sudden flooding (Koehn 1984).

Gellibrand River water is used by the Colac District Water Board and for the Otway Water Supply System, which supply towns from Camperdown to Warrnambool.

The Gellibrand River was used as a case study to model natural flows for the development of the hydrological index for the Index of Stream Condition (ISC) (Ladson & White 1999). In normal years, the diversions have little effect on the flow in the river but for drought years, water is limited. All indicators suggest the amount of hydrological change in the Gellibrand was much less than for highly regulated streams (Ladson & White 1999). However, as can be seen in Figures 29 and 30, there was a decrease in the observed flow in 1999 compared to the modelled natural flow. This difference was greatest in summer (up to 55%).

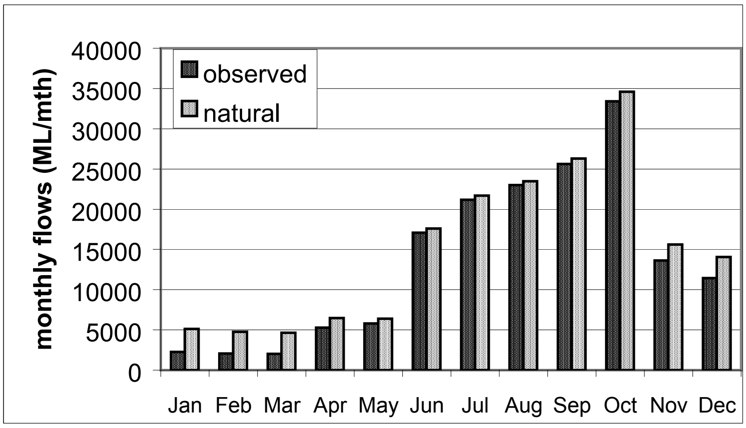


Figure 29. Monthly flows (ML/month) observed for the Gellibrand estuary in 1999 compared to the ISC modelled natural flows.

Source: Victorian Water Resources Data Warehouse (2002).

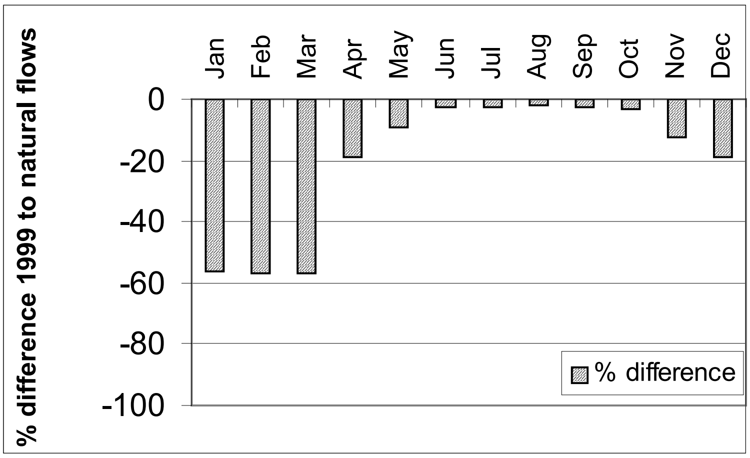


Figure 30. Percent difference of monthly flows (ML/month) for Gellibrand estuary for the observed flows in 1999 compared to the ISC modelled natural flows.

Source: Victorian Water Resources Data Warehouse (2002).

5.4.3 Description of Coast Adjacent to Mouth

The Gellibrand River enters the coast in the Twelve Apostles Marine National Park (NRE 2002). The east bank of the estuary mouth is in the Cape Otway National Park and the west bank is in the Port Campbell National Park. The Gellibrand flows out at the western end of the main beach immediately to the east of Point Ronald (Figures 27 & 28). A continuous surf zone extends for 3 km to the east of Point Ronald, backed by five separate beaches, with calcarenite and limestone bluffs and platforms separating the beaches (Short 1996). The beaches face southwest and receive waves averaging over 1.5 m, which interact with the coarse sand to produce alternating bars and deep rip channels every 300 m. The dune system behind the main beach, to the east of the mouth of the Gellibrand, is well vegetated and extends 1 km inland.

Access to the main Gellibrand beach, also known as Princetown Beach, is by the Princetown Reserve Road (Short 1996). A 500 m walking track runs along the east river bank to the beach and a 4WD vehicle track runs along the National Park boundary to a second beach.

5.4.4 Environmental Values

The Gellibrand River is highly valued for its still largely natural state, especially in its upper catchment (DCE 1993). In its lower reaches the Princetown Wetlands (VIC093) have national recognition in the directory of important Australian wetlands (EA 2002). They were included in the directory because of three characteristics:

1. It is a good example of a wetland type occurring within a biogeographic region in Australia.

2. It is a wetland that plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex.
3. It is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge in adverse conditions such as droughts.

The Princetown Wetlands include both the lower Gellibrand wetlands and Latrobe Creek wetlands. Their major ecological features are their extensive beds of Common Reed, and meadows dominated by Beaded Glasswort that can support large numbers of waterbirds. Significant numbers of the Swamp Greenhood occur in this wetland, growing under dense Woolly Tea-tree groves.

Three conservation listed plants (Table 9) have been recorded in the Gellibrand estuary catchment. These are the Swamp Greenhood, Ruddy Bent and Coast Stackhousia (NRE 2001a). An additional nine species of listed plants, Leafy Greenhood, Green Leek-orchid, Broad-lip orchid, Short Water Starwort, Long Rope-rush, Velvet Correa, Hairy Shepardís Purse, Bog Gum and Coast Pomaderris, have the potential to occur in the estuarine catchment (NRE 1996).

Only one conservation listed fish has been recorded from Gellibrand estuary, the Pouched Lamprey (Table 11). In total twenty species of fish have been recorded in the estuary (Appendix 4). The high number of native fish species that occur in the Gellibrand places it among Victoriaís more important rivers for the conservation of native fish (Smith 1989). Yellow-eye mullet and black bream numbers dominate estuarine recreational fish populations, and blackfish dominate freshwater populations (Koehn 1984). The abundance of other estuarine recreational fish species are thought to be low compared with other estuaries in western Victoria (Tunbridge & Glenane 1988). The Gellibrand River also carries the largest population of blackfish, in both number and size of fish, of any river in Victoria and possibly southeast Australia (Tunbridge & Glenane 1984) and attracts large numbers of people for fishing, camping and other recreation (Koehn, 1984).

Nine species of conservation listed birds have been recorded in the Gellibrand estuary catchment (Table 11). These species are the Great Egret, Little Egret, Australian Bittern, Cape Barren Goose, Blue-billed Duck, Grey Goshawk, Letter-winged Kite, Black Falcon, Powerful Owl and Rufous Bristlebird. The Great Egret is protected under JAMBA and CAMBA.

One conservation listed invertebrate (the Otway Black snail), mammal (Swamp Antechinus) and reptile (Swamp Skink) have been recorded in the Gellibrand estuary catchment (Table 11).

5.4.5 Alteration of the Estuary

The estuary catchment for the Gellibrand has been cleared, drained and is used for grazing resulting in a reduction in the amount and diversity of vegetation types (EVCs; Figure 27). The extraction of flow for domestic and irrigation supply appears to have reduced the amount of water reaching the estuary in summer (Figure 30), and is of some concern (CCMA 2001).

In the National Estuaries Audit, Gellibrand estuary was classified as modified. This was based on possible changes to the estuarine ecology due to changed landuse and forestry (NLWA, 2002). The 1999 ISC assessment of the freshwater reach of the Gellibrand immediately upstream of the estuary indicated that its condition is marginal. Whilst the water quality and aquatic life of the river was good (9/10), the hydrology (7/10) was altered, and the physical form (4/10) and stream-side zone (5/10) were poor (Victorian Water Resources Data Warehouse 2002). This excellent score for water quality contrasts with the high nutrient levels found in other studies (Kelly 2000; McKay 2000).

Stock access to the Gellibrand has been identified as an issue because of the impacts on riparian vegetation and water quality (CCMA 2001; Kelly 2000; McKay 2000; O'May and Wallace 2000).

In its Waterway Health Strategy, Corangamite CMA identified all of the Gellibrand River system including major tributaries as being a high priority for willow treatment works (CCMA 2001).

5.4.6 Ecological Understanding

The hydrology associated with flushing of the estuary after mouth opening is well understood (Kelly 2000; McKay 2000; Sherwood 1983 & 1984). However the natural wetland flooding frequency and duration, natural mouth opening frequency, and basic ecology of the flora and fauna in the estuary are not well understood. The extent of estuarine influence up Latrobe Creek, the quality of the water draining from the Latrobe wetlands when the mouth is opened and the factors that affect that quality are not well known.

5.4.7 Existing Management Plans

A management plan that OíMay and Wallace (2001) developed as recommended by Harty (2001a), including extensive stakeholder consultation, has been finalised. The plan proposes that ongoing management directions be supported by the formation of the Gellibrand River Estuary and Wetlands Advisory Committee (GREWAC) to manage mouth openings and associated procedures.

The plan identified the following strategic directions that directly relate to mouth opening:

- a flooding cycle for the river that is as close as practicable to natural, with occasional mouth openings managed by the relevant government authorities (CCMA and PV) and the community, and
- wetland ecosystems that are healthy and diverse, and management practices on both public and private land that contribute to its continuing health.

The management directions identified to help achieve the strategies involved:

- establishing an interim river mouth opening protocol that attempts to maintain a flooding regime that is close to natural and protects both the health of the ecosystem and community,
- establishing an ongoing research, monitoring and review program that provides a basis to improve management of the flood regime, and
- ensuring that the local community that has the most direct interest in flooding is closely involved in management and review of the river mouth opening process.

A Parliamentary inquiry into southwest region water management decided that no further diversions should occur on the Gellibrand River and that additional water for Geelong be sourced from groundwater (NREC 1989). The Gellibrand River is considered a priority environmental flow stream by NRE and it is one of the first in Victoria to have a draft stream flow management plan developed (SRW 1998).

5.4.8 Past and Present Opening Regimes and Protocols

The trigger level for considering artificial opening of the mouth is at 1.136 AHD on the Latrobe Creek Bridge (O'May & Wallace 2001). The mouth predominantly closes during times of low freshwater flow. During 1982, the mouth was recorded as closed at least seven times, for periods of up to several weeks (Sherwood 1983). Drought conditions influenced the number and duration of mouth closures. Farm land, formerly natural wetlands, may be inundated as far as 10 km upstream, and the Old Ocean Road is subject to flooding (O'May & Wallace 2001). On 15 September 1982 the old Great Ocean Road had to be closed because of flood waters from mouth closure, with water levels 1.5ñ2 m higher than normal (Sherwood 1983).

The flooding associated with mouth closure has long been considered a problem, and engineering solutions were tried in the early 1900s to prevent mouth closure and decrease flooding (O'May & Wallace 2001). Most spectacularly, a tunnel was dug through Pt Ronald, and fitted with a gate so that flood waters could be released. However, the tunnel silted up soon after construction and the scheme was abandoned. A wooden wall near the mouth was built at approximately 45° to the entrance channel to stop sand from filling the river channel. This apparently worked quite well until large floods washed away the wall, the remaining pylons can still be seen at the mouth.

From measurements of the surface areas of the estuary and wetlands, and river flow rate, the time it would take for the water levels to rise 1 m after mouth closure has been estimated for different flow rates (Table 17; Sherwood 1983).

Table 17. Estimated time, once the mouth is closed, for the water level to rise 1 m under different river flows.

River discharge (ML/day)	Flooding time (days)
50	36
100	18
200	9
500	3.6

Gellibrand, of all the southwest estuaries, probably has the most detailed licence conditions for artificial opening (O'May & Wallace 2001):

- the amount of rainfall in the upper catchment in the previous 7 days must be more than 60 mm, or
- the streamflows below the North Otway Pipeline must be 100 ML/day, or
- there is no less than 1 m depth of water of more than 5 mg/L DO in the Gellibrand and Latrobe rivers and specified wetland monitoring points.

As well as specifying a trigger height, the estuary may be opened if the river mouth has been closed for more than 60 days. It also specifies avoiding spring tides (new or full moon) and the three weeks before the opening of duck hunting season. Monitoring, both pre- and post-opening, at specified sites must be carried out, and public safety warning signs erected.

The implications of artificial mouth opening to the Gellibrand have been the focus of recent research (Kelly 2000; McKay 2000; Walker 2001). Fish kills have been observed to accompany mouth openings. In April 2000 large numbers of spawning Common Galaxias, adult smelt and gudgeon were killed when deoxygenated waters filled the main channel from fringing wetlands (Kelly 2000).

Another study was based around an opening event on 29 March 2001. It included pre- and post-opening sampling of water quality in the estuary and diurnal surveys of DO (Walker 2001). DO levels in surface waters pre- and post-opening were within the requirements of the management plan (DO > 5 mg/L) (O'May & Wallace 2001). This study concluded that the Princetown Wetlands, particularly the Latrobe Creek Wetlands, may be the most important factor in the health, as measured by DO, of the lower estuary during a mouth opening event. The highest risk area for adverse affects from low DO water was identified as the reach from the mouth to 1 km past Campground Bridge. This work supported the findings by previous studies (Kelly 2000; McKay 2000) and endorsed the management plan (O'May & Wallace 2001).

The diurnal DO survey measured a decrease in dissolved oxygen amongst wetland vegetation at night (Walker 2001). It was suggested that this had implications for mouth opening, as most openings occur in the morning, when DO levels would still be low. However, the lowest concentrations recorded during the decrease in DO overnight were still above those recommended for safe opening (O'May & Wallace 2001). More understanding of the factors controlling DO concentrations in the wetlands is necessary to evaluate potential risks of mouth opening.

Corangamite CMA has raised concerns about the risk associated with artificial opening, in particular the affect of the manipulation of wetland water levels by artificial opening and altering the natural flooding regimes of the wetlands (CCMA 2001).

5.5 AIRE ESTUARY

5.5.1 General Physical Description

The Aire River drains the western side of the southern Otway ranges. South of the Great Ocean Road (GOR), between the townships of Glenaire and Horden Vale, it runs into a large coastal floodplain and is joined by its two major tributaries, the Ford and Calder Rivers. Three lakes, Costin, Craven and Horden, also occur in this alluvial basin. In total the Aire estuary wetland is approximately 1500 ha in area, being 6 km wide and extending 4 km inland from the coast (Figures 33 & 34).

The Aire basin illustrates a Tertiary depositional sequence that differs from that of the major part of the Otway basin to the west (Rosengren 1984). Several important stratigraphic sections of Tertiary strata occur on the coast near the Aire mouth and in cliffs fringing the floodplain. Quaternary sediments in the Aire basin are complex and include shallow marine, estuarine, lagoonal and tidal sands, muds and shells, floodplain and lacustrine deposits, and windblown sand (Rosengren 1984).

The extent of tidal influence is thought to reach at least the GOR bridge over the Aire River (G. Summers pers. comm. 2002), but is unknown for the Ford and Calder Rivers. The flow of the Aire River to the estuary, as assessed by ISC (1999), is essentially natural (Figure 31), with little difference between observed flow and modelled natural flow for any month of the year (Figure 32). Unlicensed stock and domestic extraction occurs around Horden Vale (NRE 1997).

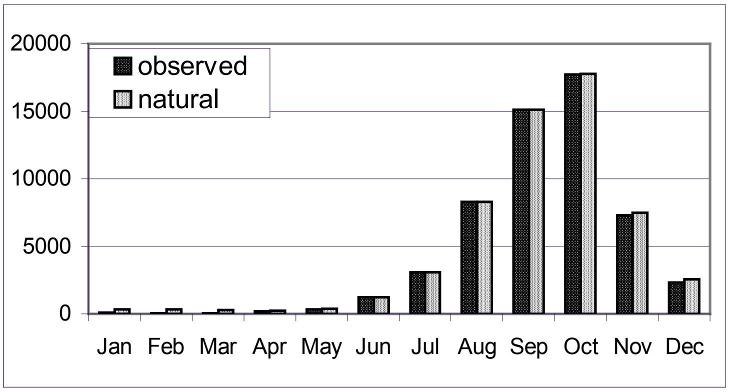


Figure 31. Monthly flows (ML/month) observed for the Aire estuary in 1999 compared to the ISC modelled natural flows.

Source: Victorian Water Resources Data Warehouse (2002).

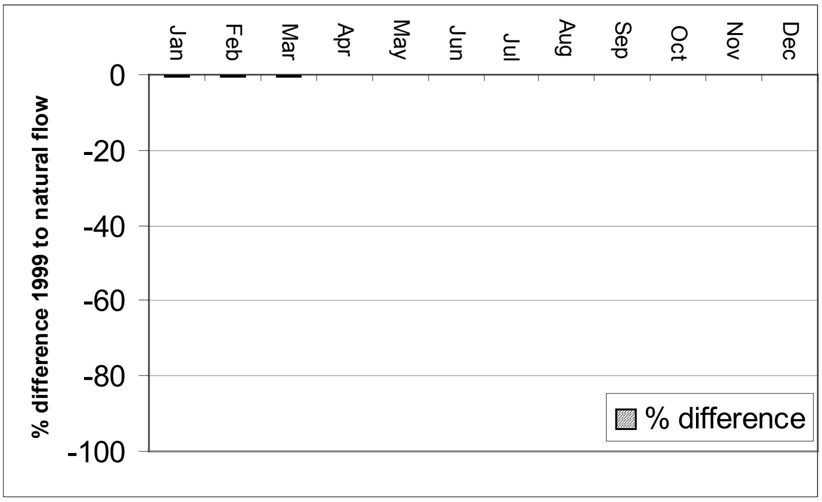


Figure 32. Percent difference of mean monthly flows (ML/month) for the Aire estuary for the observed flows in 1999 compared to the ISC modelled natural flows.

Source: Victorian Water Resources Data Warehouse (2002).

5.5.5 Description of Catchment

The Aire River does not have any major impoundments and has a relatively undeveloped catchment and as such is recognised as a Heritage River (NRE 1997). It will have no major extraction developments until at least 2030.

The three rivers entering the estuary drain a catchment of approximately 12,000 ha (Parr-Smith *et al.* 1993). Catchment elevation rises to 600 m. There is a gauging station in the upper catchment at Wyelangata (site code 235219). The mean annual flow is 82,200 ML, with peak flows in August, and minimum flows in February (Figure 31). High rainfall in the catchment causes frequent flooding flows (NRE 1997).

Grazing and potato farming occur at the head of its catchment around Beech Forest and Weeaproinah, and grazing occurs on the slopes close to the estuary. The remainder of the catchment is State Forest, or softwood plantations. To the west, Ford River flows from Lavers Hill. Land uses in its catchment include hardwood timber production, grazing and potato farming (Parr-Smith *et al.* 1993). The Calder River has its headwaters entirely within the Otway National Park. Its lower reaches drain hilly grazing land, as does Duck Creek, a smaller stream that drains the back of the coastal dunes to the east of the estuary, flowing into Lake Costin.

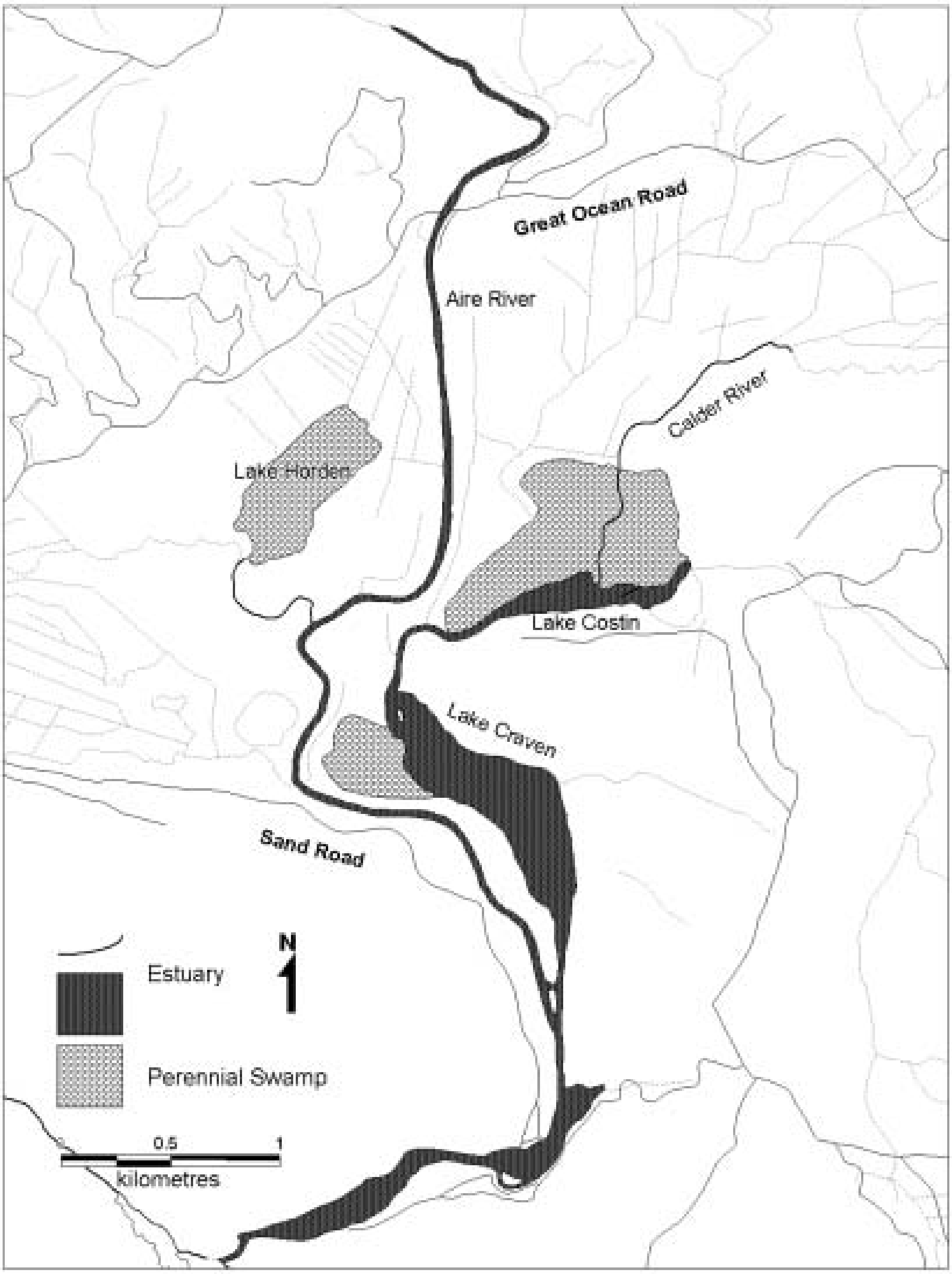


Figure 33. Map of the Aire estuary, and estuary catchment, showing the extent of tidal influence upstream, and the area of estuarine waters and wetlands.

Source: Generated from OSRA (2001).

Figure 34. Aerial photo of the Aire River estuary at Glenaire, 23/2/00, scale approximately 1:25000.

Source: WCB © QASCO.

Figure 35. Aerial photo of the mouth of Aire River estuary near Glenaire, 23/2/00.

Source: WCB © QASCO.

5.5.3 Description of Coast Adjacent to Mouth

The coastline at the Aire River mouth has very high wave energy from prevailing southwesterly ocean swell and storm waves arriving through deep water over a narrow section of the Australian continental shelf (Bird 1993). The Aire River enters the sea at Glenaire Beach (Figure 35). It flows through a 500 m wide gap in the dune calcarenite that has been piled up on either side by strong westerly winds (Short 1996). The now lithified dunes date back several hundred thousand years. The mouth and the beach onto which it opens have a southwesterly aspect.

Access to the Glenaire Beach is via the road to the Parks Victoriaís riverside camping area, and a 2 km 4WD/walking track leads from the camping area along the east shore of the estuary (Figure 35; Short 1996).

5.5.4 Environmental Values

Both the Lower Aire River Wetlands (VIC091) and the entire Aire River (VIC158) have been recognised in the directory of nationally important wetlands (EA 2002). They were included in the directory because of three characteristics:

- They are a good example of a wetland type occurring within a biogeographic region in Australia.
- They are wetlands that play an important ecological or hydrological role in the natural functioning of a major wetland system/complex.
- They are wetlands that are important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge in adverse conditions such as droughts.

The Lower Aire River Wetlands (VIC091) include Lakes Hordern, Craven and Costin and cover 84 ha. Their important ecological features are extensive beds of Common Reed and groves of Woolly Tea-tree.

Aire River is also listed as a heritage river under the *Heritage Rivers Act 1992* (Vic). Values identified for protection are the habitats of Australian Grayling, Freshwater Blackfish and Australian Mudfish (NRE 1997). There is an eel fishery license on the Aire River (G. Summers pers. comm. 2002).

A vegetation survey has been conducted of the estuarine catchment (Head & Stuart 1980), but it probably lacks enough detail to be useful for management plan design (Parr-Smith *et al.* 1993). Vegetation types in the estuary catchment are determined by the hydrology of the estuary, the level of the estuary surface in relation to flooding, and by clearing (Parr-Smith *et al.* 1993). No detailed mapping has been undertaken, but differences in land surface level, although small (10s of cm), can be readily seen, particularly from the different vegetation types they support (Figure 34; Appendix 3; Parr-Smith *et al.* 1993). The vegetation communities found in the estuary catchment represent a sequence from brackish estuarine vegetation with salt marsh components through to non-saline swamp scrub vegetation (Parr-Smith *et al.* 1993). Although extensively cleared it still retains high quality remnants of what are now extremely rare vegetation types.

There are 13 conservation listed plants recorded from the Aire River estuary catchment (Table 9). Theses include three orchids, the Leafy Greenhood, Swamp Greenhood and Broad-lipped Leek orchid. Other plants are the Short Water Starwort, Ruddy Bent, Long Rope-rush, Velvet Correa, Hairy Shepherdís Purse, Glistening Saltbush, Bog Gum, Compact Bedstraw, Coast Ballarat and Coast Stackhousia.

Six species of fish that have conservation status listed occur in the Aire River estuary catchment (Table 11). These are the Pouched Lamprey, Australian Mudfish, Spotted Galaxias, Australian Grayling, Yarra Pygmy Perch and Freshwater Blackfish. One conservation listed fish, the Mountain Galaxias occurs above the estuary. The Tasmanian Mudfish is particularly rare in Victoria. It is also known from the Wye River in the Otways and Wilsonís Promontory and has a marine migration as part of its life history (Koehn & Raadik 1991). In all 20 fish have been recorded from the Aire River estuary catchment (Appendix 4).

Native fish such as Blackfish, Grayling, Tupong, Common and Spotted galaxias are found in the lower sections of the Aire River (Smith 1989). It is also one of only 28 streams/rivers in the state where Broad-finned, Spotted and Common galaxias occur together (Smith 1989). The high number of native species that occur in the Aire River place it among Victoriaís more important rivers for the conservation of native fish (Smith 1989). The Aire River is also considered to have the highest population density of Platypus in Victoria (Parr-Smith *et al.* 1993).

Seventeen species of conservation listed birds have been recorded from the Aire River estuary catchment (Table 11). These include the Black-faced Shag, Pied Cormorant, Great Egret, Intermediate Egret, Little Egret, Royal Spoonbill, Australasian Bittern, Cape Barren Goose, Lewinís Rail, Lathamís Snipe, Pacific Gull, Caspian Tern, Ground Parrot, Powerful Owl, Rainbow Bee-eater, Southern Emu Wren and Rufous Bristlebird.

Five species of conservation listed mammals occur in the Aire River estuary catchment, the Heath Mouse, Smoke Mouse, Swamp Antechinus, Broad-toothed Rat and Tiger Quoll (Table 11).

Rosengren noted six sites of geomorphological significance in the lower Aire River (Rosengren 1984).

5.5.5 Alteration of the Estuary

The estuary catchment has been cleared extensively (Figure 34). European settlement in the estuarine catchment dates from 1846 (Parr-Smith *et al.* 1993). Major changes in the catchment occurred after World War I when drainage channels were dug in the river system (Head & Stuart 1980). A channel 6 m deep, for example, was dug a short way upstream from the Aire River mouth (Head & Stuart 1980). Wooden pylons remain at the mouth from an early attempt to prevent the eastern sand dunes closing the river mouth (Head & Stuart 1980). The dunes used to have extensive she-oak woodlands and were stabilized by the planting of Marram Grass (Head & Stuart 1980).

In the National Estuaries Audit, Aire estuary was classified as modified based on possible changes to the estuarine ecology due to changed landuse and forestry (NLWA 2002). Forest activity in the Aire River catchment is thought to have caused siltation in the river (Smith 1989). The 1999 ISC assessment of the freshwater reach of the Aire River immediately upstream of the estuary was incomplete as only the hydrology (10/10) and aquatic life index (8/10) were assessed.

A large amount of woody debris in the Aire River channel was removed in the belief that it would help relieve flooding. The Ford River was channelised for this same reason (John Turner pers. comm. 2002). Dunes traditionally had cattle grazing on them over winter (J. Turner pers. comm. 2002), but the instability this caused has been reversed over the past 70 years by Marram Grass planting and the removal of grazing (Parr-Smith *et al.* 1993).

The Heritage River management plan recognised that the impact of artificial mouth opening on the environment of the Aire River and wetlands is not known. There have been drainage works in the lowland grazing area around Horden Vale and cattle have unrestricted access to the banks and wetlands, with associated trampling and erosion (NRE 1997).

The lower Ford River, before its junction with the Aire, has a high priority for bed stabilisation works as well as willow treatment works (CCMA 2001). All of the Aire River system, including major tributaries, is also identified as being a high priority for streamside protection works such as revegetation and fencing.

5.5.6 Ecological Understanding

The ecological processes are not well understood for this estuary. The extent of the estuarine influence upstream along the Aire, Ford and Calder rivers is not known. The natural frequency of mouth opening is not known, nor the relationship between mouth closure and inundation of the estuarine catchment and wetlands, nor the relationship between inundation and ecologically meaningful effects. Moverley and Hirst (1999) sampled estuarine macroinvertebrates in the Aire in 1997.

5.5.7 Existing Management Plans

A very comprehensive draft management plan exists for the Aire River estuary (Parr-Smith *et al.* 1993). This plan has not undergone extensive public consultation, but provides a good summary of management issues in the estuary and fully identifies land tenure, and hence land management responsibility. This is further reinforced in the draft management plans for the Aire as a Heritage River (NRE 1997). The land around the mouth of the estuary, on both banks, is part of the Otway National Park and management of the land is guided by the Park Management Plan (NRE 1996).

5.5.8 Past and Present Opening Regimes and Protocols

Aire River mouth closes at least 6ñ8 times a year (G. Summers, pers. comm., 2002). It naturally opens 2ñ4 times per year and is artificially opened up to 6ñ8 times a year. It is opened with a tractor, and the position of opening varies. It has been opened artificially since the 1920s (NRE 1997). The impetus to open it typically comes from farmers affected by flooding of freehold pasture.

There is a gauge on the bridge at the end of Sand Road, near the camp grounds. The trigger level for opening is 1.9 m on that gauge (Parr-Smith *et al.* 1993).

The mouth has been observed to close up very quickly, within as little as three days after opening (Parr-Smith *et al.* 1993). The bar can build to a height of 2 m above the level of the estuary, which can then exceed sea level. High seas on a southwesterly wind and high tides can drive sea water across the bar, causing the estuarine water near the mouth to become more saline and water levels to continue to rise.

With low rainfall and a high sand bar the estuary may remain blocked for some months (Parr-Smith *et al.* 1993). Heavy rainfall and a destructive sea pattern, which cuts the fore dune and bar away, eventually causes the estuary mouth to open. If the water levels are high when this happens, there is a massive flow to the sea and water levels in the estuary can drop up to 1 m in a few hours (Parr-Smith *et al.* 1993). The flow can continue for some days, providing the sea does not rapidly reblock the mouth. Flow out of the system is not uniform, with flow from Lake Horden and the swamps behind it lagging some days behind the opening of the mouth.

A key recommendation of the Draft Management Plan for Aire River as a Heritage River was to develop trigger level heights for the opening of the river mouth to protect natural values, as well as adjoining properties (NRE 1997).

The Aire River Drainage Committee opened the mouth of the river until mid 2000. The opening was historically an event for the community, where families would gather on the beach to fish the opened channel (John Turner pers. comm. 2002). Parks Victoria now holds the license for opening the estuary under the Water Act, and Corangamite CMA issues the licence. Recently, specific requirements were developed for the licence. These have to be met before the mouth can be opened (D. May pers. comm. 2002). These conditions differ from the standard licence conditions (see Section 3) in that (authorsí emphasis):

1. *Unless subject to condition 13* works (to open the mouth artificially) should not proceed if:
   2. a) a Met bureau Station in the catchment has recorded less than 10mm of rainfall in the 7 day period prior to opening, and
   3. b) the tide and prevailing wind conditions will result in the rapid re-closure of the Estuary mouth.
   4. Ö

12. The Permit holder must maintain and make available upon request a record of River *height* for a minimum of three days from the time the sand bar is breached and conduct water quality monitoring both prior to and *after* works. The monitoring program must be approved by Corangamite Catchment Management Authority.
13. Permission will only be granted under exceptional circumstances if works are proposed to be undertaken during:
    a) summer school holidays,
    b) the two weeks prior to Easter Monday, or
    c) the two weeks prior to the proclaimed duck season opening.

There have been fish kills associated with artificial opening in the past. There are no quantitative records of these events but the fish killed were mainly mullet, small salmon and bream. There are no physico-chemical measurements of the estuary water pre-artificial opening, but surveys by EPA and Deakin University have shown that it stratifies (EPA unpublished data; J. Mondon pers. comm. 2002).

6 Conclusion

The five southwest Victorian estuaries for which Parks Victoria has management responsibilities are highly stratified, ìsalt wedgeî estuaries. They follow an annual hydrodynamic cycle during which floods in winter and spring may flush all salt water from the estuary for weeks at a time. As flows recede well-oxygenated seawater re-enters the estuary, acting as a trigger for breeding in many estuarine organisms. Over summer and autumn, as flows decrease further, coastal long shore drift brings sand into the estuary entrance and tidal exchange is greatly reduced. Total closure of the estuary entrance is common and may persist for months. During this time water levels rise due to both freshwater inflow and overtopping of the entrance sand bar by waves. In estuaries with fringing wetlands such as those of the Aire, Curdies and Gellibrand Rivers the flooded wetlands create valuable habitat ñ acting as drought refuges for water birds driven from inland wetlands as these dry up. At the same time, depletion of dissolved oxygen in deeper saline water layers may lead them to become anoxic.

Autumn flooding can cause inconvenience to humans as jetties, boat ramps and roads become submerged. On some estuaries (*e.g.*, Glenelg) buildings may also be flooded. Farmland can be inundated for lengthy periods leading to agricultural production losses. Historically, ìartificialî opening of estuary entrances was timed to reduce the impacts of flooding on human activities ñ with no concern for the estuarine ecosystem. In extreme cases, loss of the surface oxygenated water on opening can leave only the bottom deoxygenated (anoxic) salt water ñ leading to mass mortality of estuarine organisms. Current management protocols require measurement of dissolved oxygen concentrations as part of a risk assessment process before estuary entrances are manually opened. There are still significant gaps in our understanding of optimum timing and conditions for artificial opening.

The estuaries support diverse biological communities, including 20 plants and 56 animals (mostly birds) that are conservation listed. The species are adapted to the estuarine hydrodynamic cycle ñ including seasonal flooding under both high and low flows. The challenge for estuarine management is to understand these inter-relationships and then to ensure human intervention in the cycle does not threaten these communities.

References

Adam P. (1998) Australian saltmarshes: a review, In *Wetlands for the future* (Eds A. J. McComb & J. A. Davis) pp. 287ñ295. Gleneagle, Adelaide.

Allanson B. & Baird D. (1999) *Estuaries of South Africa*. Cambridge University Press, Cambridge.

ANZECC (Australian and New Zealand Environment and Conservation Council). (1999) *Australian and New Zealand Guidelines for Fresh water and Marine Water Quality*. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australian and New Zealand.

Baird D. & Ulanowicz R. E. (1993) Comparative study on the trophic structure, cycling and ecosystem properties of four tidal estuaries. *Marine Ecology - Progress Series*. **99**, 221ñ237.

Ball D. & Patterson E. (1998) *Surf Coast coastal resource atlas, descriptive report*. Marine and Freshwater Resources Institute, Queenscliffe.

Bantow J., Rashleigh M. & Sherwood J. (1995) *'Tuuram': the Hopkins Estuary and Coastal Environs*. Australia Felix Press, Warrnambool.

Beckett R., Easton A. K., Hart B. T. & McKelvie I. D. (1982) Water movement and salinity in the Yarra and Maribyrnong estuaries. *Australian Journal of Marine and Freshwater Research*. **33**, 401ñ415.

Beer T. (1983) *Environmental Oceanography: An Introduction to the Behaviour of Coastal Waters*. Pergamon Press, Oxford.

Bird E. C. F. (1993) *The coast of Victoria. The shaping of scenery*. Melbourne University Press Melbourne.

Black R. E., Lukatelich R. J., McComb A. J. & Rosher J. E. (1981) Exchange of water, salt, nutrients and phytoplankton between Peel Inlet, Western Australia and the Indian Ocean. *Australian Journal of Marine and Freshwater Research*. **32**, 709ñ720.

Breen C. M. & McKenzie M. (2001) *Managing estuaries in South Africa: An introduction*. Institute of Natural Resources, Pietermaritzburg.

Breen P. (1982) *Gellibrand River Riparian and Aquatic Vegetation Survey*. Arthur Rylah Institute for Environmental Research, Heidelberg.

Bucher D. & Saenger P. (1991) An inventory of Australian estuaries and enclosed marine waters: an overview of results. *Australian Geographical Studies*. **29**, 370ñ381.

Burrell D. C. (1988) Carbon Flow in Fjords. *Oceanography and Marine Biology - Annual Reviews.* **26**, 161ñ163.

Butler E. C. V. & Smith J. D. (1985) Iodine and arsenic redox species in oxygen-deficient estuarine waters. *Australian Journal of Marine and Freshwater Research*. **36**, 301ñ309.

Cadwallader P. L. & Backhouse G. N. (1983) *A guide to the freshwater fish of Victoria*. Victorian Government Printing Office, Melbourne.

CAMBA. (1986) *China-Australia Migratory Birds Agreement*. Agreement between the Government of Australia and the Government of the Peopleís Republic of China for the protection of migratory birds and their environment.

Cawthray G. (1991) *Anoxic Conditions in the Deep Holes of the Hopkins Estuary*. Honours Thesis, Deakin University, Warrnambool.

CCMA (Corangamite Catchment Management Authority). (2001) *Draft Waterway Health Strategy*. Corangamite Catchment Management Authority, Colac.

Chan T. U. & Hamilton D. P. (2001) Effect of freshwater flow on the succession and biomass of phytoplankton in a seasonal estuary. *Marine and Freshwater Research*. **52**, 869ñ884.

CLS (Crown Lands and Survey). (1981) *Western Coastal Study. 1. Resource Document*. Department of Crown Lands and Survey, Melbourne.

Codispoti L. A., Friederich G. E., Murray J. W. & Sakamoto, C. M. (1991) Chemical variability in the Black Sea: implications of continuous vertical profiles that penetrate the oxic/anoxic interface. *Deep-sea Research*. **38**(Suppl. 2), 691ñ710.

Cooper J. A. G., Harrison T. D., Ramm A. E. L. & Singh R. A. (1993) *Refinement, enhancement and application of the Estuarine Health Index to Natal's Estuaries, Tugela-Mtamvuna*. Executive Report No. EFP.05.930402. Department of Environment Affairs, Pretoria.

Craig A. & Pritchard, A. (2001*) Draft recovery plans for three species of orchid in South-East South Australia and South-West Victoria: Caladenia richardsiorum (Little Dip Spider-orchid), Caladenia calcicola (Limestone Spider-orchid), Pterostylis tenuissima (Swamp Greenhood) for 2001ñ2005.* National Parks and Wildlife South Australia, Adelaide.

Curdie D. (1866) Exploration: a journey through the scrub. *The Australasian*, Saturday, Mar 17, p. 11.

Deeley D. M. & Paling E. I. (1998) Assessing the ecological health of estuaries in southwest Australia, in *Wetlands for the future* (Eds A. J. McComb & J. A. Davis) pp. 257ñ271. Gleneagles, Adelaide.

Deeley D. M. & Paling E. I. (1999) *Assessing the ecological health of estuaries in Australia*. National River Health Program, Urban Sub Program, Canberra.

Digby M.J., Saenger P., Whelan M.B., McConchie M., Eyre B., Holmes N. & Bucher D. (1999) *A physical classification of Australian estuaries*. LWRRDC Occasional Paper 16/99. National River Health Program, Urban Sub Program, Canberra.

Douglas M. H. & OíBrien L. eds (1971) *The Natural History of Western Victoria Symposium Proceedings*. Australian Institute of Agricultural Science, Horsham.

Deuser W. G. (1975) Reducing Environments, in *Chemical Oceanography*, eds Riley, J. P. and Skirrow, G., Vol. 3. Academic Press, London (pp.12ñ37).

EA (Environment Australia, now Department of Environment and Heritage). (2002) *Inland Waters: Australian Wetlands Database*. URL:
http://www.ea.gov.au/water/wetlands/database/

Earl G. E. & Bennett A. F. (1986) *A survey of the flora and fauna in four catchments of the Gellibrand River Basin, Otway Ranges, Victoria*. Arthur Rylah Institute for Environmental Research, Department of Conservation, Forests and Lands, Heidelberg.

Edgar G. J., Barrett N. S. & Graddon D. J. (1998) *A classification of Tasmanian estuaries and assessment of their conservation significance: an analysis using ecological and physical attributes, population and land use*. Parks and Wildlife Service, Department of Environment & Land Management, Hobart.

Emerson S., Cranston R. E. & Liss P. S. (1979) Redox species in a reducing fjord: equilibrium and kinetic considerations. *Deep-sea Research*. **26A**, 859ñ878.

Fairweather P. G. (1990) Ecological changes due to our use of the coast: research needs versus effort. *Proceedings of the Ecological Society of Australia*. **16**, 71ñ77.

Flemer D. A., Mackierman G. B., Nehlsen W. & Tippie V. K. (1983) *Chesapeake Bay: A profile of environmental change*. US Environmental Protection Agency, Washington.

Geddes M. C. & Butler A. J. (1984) Physico-chemical and biological studies on the Coorong lagoons, South Australia, and the effect of salinity on the distribution of the macrobenthos. *Transactions of the Royal Society of South Australia*. **108**, 51ñ62.

Gill E. D. (1985) *Coastal Processes and the Sanding of Warrnambool Harbour, Victoria, Australia*. Warrnambool Institute Press, Warrnambool. pp. 51ñ55.

Gill E. D. & Lane, L. N. (1985) Sea levels and aboriginal oyster midden at Lake Connewarre, Victoria, Australia. *Proceedings of the Royal Society of Victoria*. **97**, 95ñ100.

Haas L. W. (1977) The effect of the spring-neap tidal cycle on the vertical salinity structure of the James, York and Rappahannock Rivers, Virginia, USA. *Estuarine and Coastal Marine Science*. **5**, 485ñ496.

Haas L. W., Holden, F. J. & Welch, C. S. (1981) Short term changes in the vertical salinity distribution of the York River estuary associated with the neap-spring tidal cycle, In *Estuaries and Nutrients*, (Eds B. J. Neilson & L. E. Cronin) pp. 585ñ596. Humana Press, New Jersey.

Hamon B. V. (1966) Continental shelf waves and the effects of atmospheric pressure and wind stress on sea level. *Journal of Geophysical Research*. **71**, 2883ñ2893.

Harty C. (2001a) *South West Estuaries Coastal Action Plan*. Western Coastal Board, Coasts & Clean Seas, Natural Heritage Trust, Warrnambool.

Harty C. (2001b) *Draft South West Victorian regional Coastal Action Plan*. Western Coastal Board, Camperdown.

Head L. & Stuart, I. F. (1980) *Change in the Aire; Palaeocology and prehistory in the Aire Basin, southwestern Victoria*. Department of Geography, Monash University, Melbourne.

Herman P. M. J., Middleburg, J. J., Van de Koppel, J. & Heip, C. H. R. (1999) Ecology of estuarine macrobenthos, In *Estuaries*, vol. 29 (Eds D. B. Nedwelland & D. G.Raffaelli) pp. 195ñ240. Academic Press, London.

Heron S. (1989) *Conservation values of wetlands and estuaries in South-East Victoria*. Report No. 52. Department of Water Resources, Melbourne.

Heydorn A. E. F. (1984) The South African coastline, its estuaries and manís impact upon them, in *Estuarine Environments of the Southern Hemisphere* (Ed E. Hodgkin) pp. 5ñ22. Bulletin No.161 Department of Conservation and Environment, Western Australia.

Hodgkin E. P. & Lenanton R. C. (1981) Estuaries and coastal lagoons of South Western Australia, in *Estuaries and Nutrients* (Eds B. J. Neilson & L. E.Cronin) pp. 307ñ321. Humana Press, New Jersey.

Hodgkin E. P. (1994) Estuaries and coastal lagoons, in *Marine Biology* (Eds L. S. Hammond & R. N. Synnot) pp. 315ñ332. Langmon Cheshire, Melbourne.

Hodgkin E. P. & Hesp P. (1998) Estuaries to salt lakes: Holocene transformation of the estuarine ecosystem of south-west Australia. *Marine & Freshwater Research.* **49**, 183ñ201.

Holmes J. H. (1986) Population, in *Australia: A Geography, Volume 2: Space and Society*, (Ed D. N. Jeans) pp. 24ñ48. Sydney University Press, Sydney.

HRC (Healthy Rivers Commission). (1999) *Independent inquiry into the Shoalhaven River system*. Healthy Rivers Commission, Sydney.

HRC (Healthy Rivers Commission). (2000a) *Securing healthy coastal rivers; A strategic perspective*. Healthy Rivers Commission, Sydney.

HRC (Healthy Rivers Commission). (2000b) *Independent inquiry into the Bega River system*. Healthy Rivers Commission, Sydney.

Imberger J. & Agnew H. (1974) Gravitational currents in the Blackwood River estuary, In *Proceedings of the Fifth Australasian Conference of Hydraulics and Fluid Mechanics*, Christchurch, New Zealand.

JAMBA. (1974) *Japan-Australia Migratory Birds Agreement*. Agreement between the Government of Australia and the Government of Japan for the protection of migratory birds and birds in danger of extinction and their environment.

Keddy P. A. (2000) *Wetland Ecology: Principles and Conservation*. Cambridge University Press, Cambridge.

Kelly L. M. (2000) *The management of ecological impacts of nutrients, vegetation and river mouth opening processes in the Gellibrand River Estuary and Wetlands*. Honours Thesis, Deakin University, Warrnambool.

Koehn J. D. (1984*) Survey of angling and recreational use of the Gellibrand River, south-western Victoria*. Arthur Rylah Institute, Department of Conservation and Lands, Heidelberg.

Koehn J. D. & Raadik T. A. (1991) The Tasmanian Mudfish, Galaxias cleaveri Scott, 1934, in Victoria. *Proceedings of the Royal Society of Victoria*. **103**, 77ñ86.

Kuo A. Y. & Neilson B. J. (1987) Hypoxia and salinity in Virginia estuaries. *Estuaries*. **10**(4), 277ñ283.

Kuo A. Y., Park K. & Moustafa M. Z. (1991) Spatial and temporal variabilities of hypoxia in the Rappahannock River, Virginia. *Estuaries*. **14**(2), 113ñ121.

Ladson A. R. & White L. J. (1999) *An index of stream condition: Reference manual*. Victorian Government, Melbourne.

Lane, B. A. (1987) *Shorebirds in Australia*. Nelson, Melbourne.

Largier J. L. & Taljaard S. (1991) The dynamics of tidal intrusion, retention and removal of seawater in a bar-built estuary. *Estuarine, Coastal and Shelf Science*. **33**, 325ñ338.

LCC (Land Conservation Council). (1991) *Rivers and streams. Special Investigation. Final recommendations*. Land Conservation Council, Melbourne.

Lukatelich R. J. & McComb A. J. (1986) Nutrient levels and the development of diatom blooms in a shallow Australian estuary. *Journal of Plankton Research*. **8**, 597ñ618.

Maher P. (2001) *Nutrients and Phytoplankton of the Curdies River, Southwest Victoria*. Honours Thesis, Deakin University, Warrnambool, Victoria.

Mackay C. F. & Cyrus D. P. (2001) Is freshwater quality adequately defined by physico-chemical components? Results from two drought-affected estuaries on the east coast of South Africa. *Marine and Freshwater Research*. **52**, 267ñ281.

Matthews T. (2001) *Population Dynamics of the Estuarine Bivalve Solatellina alba*. PhD Thesis, Deakin University, Warrnambool.

McCarraher D. B. (1986a) *Distribution and abundance of sport fish populations in selected Victorian estuaries, inlets, coastal streams and lakes. 4. Portland Region.* Conservation Forests and Lands, Fisheries Division, Victoria, Melbourne.

McCarraher D. B. (1986b*) Distribution and abundance of sport fish populations in selected Victorian estuaries, inlets, coastal streams and lakes. 3. Otway and Geelong Regions.* Conservation Forest and Lands, Fisheries Division, Victoria, Melbourne.

McCarraher D. B. (1986c) *Distribution and abundance of sport fish populations in selected Victorian estuaries, inlets, coastal streams and lakes. 2. Gippsland Region.* Conservation Forest and Lands, Fisheries Division, Victoria, Melbourne.

McCarraher D. B. (1986d) *Distribution and abundance of sport fish populations in selected Victorian estuaries, inlets, coastal streams and lakes. 1. Orbost Region.* Conservation Forests and Lands, Fisheries Division, Victoria, Melbourne.

McCarraher D. B. & Mckenzie J. A. (1986) *Observations on the distribution, growth, spawning and diet of estuary perch (Macquaria colonorum) in Victorian waters*. Arthur Rylah Institute, Department of Conservation, Forests and Lands, Heidelberg.

McClusky C. F. (2001) Dispersal of estuarine fauna, using genetic markers. Honours Thesis, Deakin University, Warrnambool.

McComb A. J. & Humphries R. (1992) Loss of nutrients from catchments and their ecological impacts in the Peel-Harvey estuarine system, Western Australia. *Estuaries*, **15**, 529ñ537.

McComb A. J. & Lukatelich R. J. (1990) Inter-relations between biological and physico-chemical factors in a data base for a shallow estuarine system. *Environmental Monitoring and Assessment*. **14**, 223ñ238.

McKay S. F. (2000) *The ecology and management of the Gellibrand River estuary and wetlands*. Honours Thesis, Deakin University, Warrnambool.

Millero F. J. & Sohn M. L. (1992) *Chemical Oceanography*, CRC Press, Florida (pp. 486ñ 508).

Mitchell B. D. (1998) *Assessment of proposal for "stream clearing" on the Fitzroy River ñ Homerton Parish* (Melway Map 88 D/4). Deakin University, Warrnambool.

Morrow R. A. (1984) The movement of pressure systems across Bass Strait. *Bass Bulletin*, No.5, May, 6ñ7.

Moverley J. & Hirst A. (1999) *Estuarine health assessment using benthic macrofauna*. Land and Water Resources Research and Development Corporation, Canberra.

Murray-Wallace C. V., Beu A. G., Kendrick G. W., Brown L. J., Belperio A. P. & Sherwood J, E. (2000) Palaeoclimatic Implications of the occurrence of the arcoid bivalve *Anadara trapezia* (Deshayes,1840) in the Quaternary of Australia. *Quaternary Science Reviews*. **19**(6), 559ñ590.

National Land and Water Resources Audit (2002) *Australian Catchment, River and Estuary Assessment 2002*. Land & Water Australia, Canberra.

Newton G. M. (1996) Estuarine icthyoplankton ecology in relation to hydrology and zooplankton dynamics in a salt-wedge estuary. *Marine & Freshwater Research*. **47**, 99ñ111.

Newton G. M. P. (1994) *Estuarine zooplankton ecology in relation to the hydrological cycles of a salt-wedge estuary (Parts I and II).* PhD Thesis, Deakin University, Warrnambool.

Nelson R. C. & Keats A. J. (1981) Design sea levels for the Victorian Otway coast, in *Fifth Australian Conference on Coastal and Ocean Engineering, Proceedings*. Perth (pp. 252ñ 257).

NRE (Natural Resources and Environment). (1996) *Otway National Park Management Plan*. Department of Natural Resources and Environment, East Melbourne.

NRE (Natural Resources and Environment). (1997) *Heritage rivers and natural catchment areas*. Department of Natural Resources and Environment, East Melbourne.

NRE (Natural Resources and Environment). (2001a) *Flora Information System* (database). Department of Natural Resources and Environment, Victoria.

NRE (Natural Resources and Environment). (2001b) *Atlas of Victorian Wildlife* (database). Department of Natural Resources and Environment, Victoria.

NRE (Natural Resources and Environment). (2002) *Victoriaís Marine Parks*. URL: http://www.nre.vic.gov.au/

NRE (Natural Resources and Environment). (2002) Victorian Water Resources Data Warehouse: Index of stream condition data. http://www.vicwaterdata.net/

NREC (Natural Resources and Environment Committee). (1989) *Inquiry into water resources management in Victoria: South-Western region management strategy*. Natural Resources and Environment Committee, Melbourne.

NSWF (New South Wales Fisheries). (1993) *Why do we depend on estuaries? An environmental education report*. NSW Fisheries, Pyrmont.

Officer C. B. (1976) *Physical Oceanography of Estuaries and Associated Coastal Waters*. John Wiley and Sons, New York.

O'May J. & Wallace G. (2001) *Gellibrand River estuary and wetland management plan*. Centre for Environmental Management, University of Ballarat, in association with Ecoscape, Ballarat.

Parr-Smith G., Sullivan C., Yorke S. & DuGuesclin P. (1993) *Aire River and Milangil Wetlands preliminary management plans*. Department of Conservation and Natural Resources, Colac.

Paterson D. M. & Black K. S. (1999) Water flow, sediment dynamics and benthic biology, In *Estuaries*, vol. 29 (Eds D. B. Nedwell & D. G. Raffaelli) pp. 155ñ194. London, Academic Press.

Perryman S. (1995) *Sulphur Speciation in an Anoxic Basin in the Hopkins River*. Honours Thesis, Deakin University, Warrnambool.

Pethick, J. (1984) *An Introduction to Coastal Geomorphology*. Arnold, London.

Platell M. E. & Potter I. C. (1996) Influence of water depth, season, habitat and estuary location on the macrobenthic fauna of a seasonally closed estuary. *Journal of the Marine Biological Association, U.K.* **76**, 1ñ21.

PV (Parks Victoria). (1998) *Discovery Bay Parks*. Parks Victoria, East Melbourne.

Reilly P. (1998) Waterbirds on a small estuarine wetland ñ a six year study. *Corella*. **22**, 17ñ 23.

RFA (Regional Forest Agreement). (2000) *West Victoria Comprehensive Regional Assessment; Biodiversity Assessment*. Commonwealth and Victorian Regional Forest Agreement Steering Committee, East Melbourne.

Richards F. A. (1975) The Cariaco Basin (Trench). *Oceanography and Marine Biology*, **13**, 11ñ67.

Riggert T. L. (1978) *The Swan River Estuary: development, management and preservation*. Frontispiece, Perth.

Rosengren N. (1984) *Sites of geological and geomorphological significance in the Shire of Otway*. Department of Conservation, Forests and Lands, Melbourne.

Rouse A. (1988) *Annual phytoplankton and nutrient fluctuations in the Hopkins Estuary*. PhD Thesis, Deakin University, Warrnambool.

Roy P. S. (1982) Evolution of NSW Estuary Types, in *Symposium on Management of Estuaries*. Water Research Foundation of Australia Ltd, Sydney.

Roy P. S., Williams R. J., Jones A. R., Yassini I., Gibbs P. J., Coates B., West R. J., Scanes P. R., Hudson J. P. & Nichol S. (2001) Structure and function of South-eastern Australian estuaries. *Estuarine, Coastal and Shelf Science*. **53**, 351ñ384.

RWC (Rural Water Commission). (1990) *Victorian Surface Water Information to 1987, Volume 2*. Rural Water Commission of Victoria, Armadale, Victoria

Saywell C. (1992) *Redox Chemistry of Deep Basins in the Hopkins Estuary*. Honours Thesis, Deakin University, Warrnambool.

Scharler U. M. & Baird, D. (2000) The effects of a single freshwater release into the Kromme estuary. 1: General description of the study area and physico-chemical responses. *Water SA* **26**, 291ñ300.

Schlacher T. A. & Wooldridge T. H. (1996) Ecological responses to reductions in freshwater supply and quality in South Africaís estuaries: lessons for management and conservation, *Journal of Coastal Conservation*. **2**, 115ñ130.

Seliger H. H., Boggs J. A. & Biggley, J. A. (1985) Catastrophic anoxia in the Chesapeake Bay in 1984. *Science*. **228**, 70ñ73.

Sherwood J. (1983) *Hydrodynamics of the Gellibrand River estuary*. Report to Victorian SRWS Commission, Warrnambool.

Sherwood J. (1984) *Hydrodynamics of the Gellibrand River estuary: Part 2*. Report to the Victorian SRWS Commission, Warrnambool.

Sherwood J. E. (1985) *Hydrodynamics of South West Victorian Estuaries*. Faculty of Applied Science and Technology, WIAE, Research Report 85ñ1.

Sherwood J. E. (1988) The likely impact of climate change on south-west Victorian estuaries, In *Greenhouse: Planning for Climate Change*, Pearman, G.I. ed. CSIRO, Melbourne (pp. 456ñ72).

Sherwood J. E. (1992) Otwayís water: whose resource? In *The Otways: Flora, Fauna, Conservation, Management* (Eds M. Westbrooke, B. Wilson & S. Laidlaw) pp. 2ñ11. Deakin University, Geelong.

Sherwood J. E. & Backhouse G. N. (1982) *Hydrodynamics of salt wedge estuaries: Implications for successful spawning in black bream (Acanthopagrus butcheri).* Warrnambool Institute of Advanced Education, Warrnambool.

Sherwood J., Mitchell B., Magilton C., Walsh C. & Newton, G. (1987) *A study of the Barwon Estuary Complex*. Report 87ñ2. Faculty of Applied Science and Technology, Warrnambool Institute of Advanced Education.

Sherwood J., Barbetti M., Ditchburn R., Kimber R., McCabe W., Murray-Wallace C., Prescott, J. & Whitehead N. (1994) A comparative study of Quaternary dating techniques applied to sedimentary deposits in southwest Victoria, Australia. *Quaternary Geochronology*. **13**, 95ñ110.

Sherwood J. & Rouse A. (1997) Estuarine chemistry ñ primordial soup Down Under! *Chemistry in Australia*. August 1997, 19ñ22.

Sherwood J., Magilton C. & Rouse A. (1998*) The Glenelg River: Nutrients and estuarine hydrodynamics*. Deakin University, Warrnambool.

Short A. D. (1996) *Beaches of the Victorian Coast & Port Phillip Bay; a guide to their nature, characteristics, surf and safety*. Surf Life Saving Australia Ltd, Sydney.

SKM (Sinclair Knight Merz). (2000) *Surrey River restoration plan*. Sinclair, Knight, & Merz, Melbourne.

Skei J. M. (1988) Framvaren ñ Environmental Setting. *Marine Chemistry*. **23**, 209ñ18.

Skinner B.J. & Porter S.C. (1995) *The Blue Planet*. J. Wiley and Sons, New York (pp. 14ñ17).

Smith I. (1989) *Management of fish resources in the Otway Forest as part of the Otway Forest Management Plan*. Department of Conservation Forests and Lands, Colac.

SOMER (State of the Marine Environment Report). (1995) *Our sea, our future: major findings of the state of the marine environment report for Australia*. Ocean Rescue 2000 program, Department of the Environment, Sport and Territories, Canberra.

Stephens R. & Imberger J. (1996) Dynamics of the Swan River estuary: the seasonal variability. *Marine and Freshwater Research*. **47**, 517ñ529.

Tunbridge B. R. & Glenane T. G. (1984*) Fisheries value and classification of fresh and estuarine waters in Victoria*. Arthur Rylah Institute, Fisheries and Wildlife Division, Melbourne.

Tunbridge B. R. & Glenane T. J. (1988) *A study of the environmental flows necessary to maintain fish populations in the Gellibrand River and estuary*. Department of Conservation, Forests and Lands, Heidelberg.

Turner R. E., Schroeder W. W. & Wiseman W. J. (1987) The role of stratification in the deoxygenation of Mobile Bay and adjacent shelf bottom waters. *Estuaries*. **10**(1), 13ñ19.

Underwood G. J. C. & Kromkamp J. (1999) Primary production by phytoplankton and microphytobenthos in estuaries, in *Estuaries*. vol. 29 (Eds D. B. Nedwel & D. G. Raffaelli) pp. 93ñ154. Academic Press, London.

VCC (Victorian Coastal Council). (2002) *Victorian Coastal Strategy*. Victorian Coastal Council and State Government of Victoria, Melbourne.

Walker M. (2001) *Implications of river mouth opening at the Gellibrand River Estuary, Victoria*. Deakin University, Warrnambool.

Walsh C. J. (1994) *Ecology of epifaunal caridean shrimps in the Hopkins River estuary, and the role of estuaries in the life history of the atyid* Paratya autraliensis *(Kemp, 1917) in south-eastern Australia*. PhD Thesis, Deakin University, Warrnambool.

Warner R. F. (1986) Hydrology, in *Australia: A Geography, Volume 1: The Natural Environment* (Ed D. N. Jeans) pp. 49ñ79. Sydney University Press, Sydney.

Wong V., Richardson A. M. M. & Swain R. (1993*) The crustaceans and molluscs of Tasmanian saltmarshes*. Zoology Department, University of Tasmania, Hobart.

Wortmann J., Hearne J. W. and Adams J. B. (1998) Evaluating the effects of freshwater inflow on the distribution of estuarine macrophytes. *Ecological Modelling*. **106**, 213ñ232.

Yugovic J., Mueck S., Frood D. & Todd J. (1999) *Ecological vegetation classes of far South-West Victoria*. Biosis Research Pty. Ltd for Department of Natural Resources and Environment, Victoria, Port Melbourne.

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Appendix 1

ACRONYMS

AHD	Australian Height Datum
AROTS	Australian Rare or Threatened Species
AVW	Atlas of Victorian Wildlife
CAP	Coastal Action Plan
CAMBA	China Australia Migrating Bird Agreement
CCMA	Corangamite Catchment Management Authority
CMA	Catchment Management Authority
DO	Dissolved oxygen
EPA	Environment Protection Authority, Victoria
EVC	Ecological Vegetation Class
GHCMA	Glenelg Hopkins Catchment Management Authority
GOR	Great Ocean Road
ISC	Index of Stream Condition
JAMBA	Japanese Australia Migrating Bird Agreement
ML	Megalitres (= 10^6 litres)
NLWA	National Land and Water Audit
NRE	Department of Natural Resources, Victoria (now Sustainability and Environment)
OSRA	Oil Spill Response Atlas
ppm	parts per million
PV	Parks Victoria
ROTAPS	Rare or Threatened Australian Plant Species
SRW	Southern Rural Water
WCB	Western Coastal Board
VCC	Victorian Coastal Council
VFIS	Victorian Flora Information System
VROTS	Victorian Rare or Threatened Species

GLOSSARY OF TERMS

Anoxia:	Absence of oxygen. In aquatic environments often associated with bacterial production of hydrogen sulphide, ammonia and methane.
Hypoxia:	Low dissolved oxygen conditions, less than 1ñ2 mg/L.
Halocline:	Region of rapid salinity change in water column.
Oxycline:	Region of rapid change in dissolved oxygen concentration in a water column.
Thermocline:	Region of rapid change in temperature in a water column.

Appendix 2

FLORA OF THE FIVE ESTUARY CATCHMENTS

ROTAP	VROT 98	Scientific name	Common name	Gl	F	C	Ge	A
1: Mosses								
Amblystegiaceae								
		Leptodictyum riparium	Moss				X	
Bryaceae								
		Rosulabryum billardierei	Bryum Bill			X		
		Rosulabryum torquescens	Moss			X		
Fabroniaceae								
		Ischyrodon lepturus	Moss		X			
Hedwigiaceae								
		Hedwigia ciliata	Moss		X			
Hypnaceae								
		Hypnum cupressiforme	Common Hypnum		X			
Lembophyllaceae								
		Lembophyllum divulsum	Moss		X			
Plagiotheciaceae								
		Catagonium nitens ssp. nitens	Feather-tail Moss				X	
Pottiaceae								
		Barbula calycina	Moss			X		
3: Lichens								
Cladiaceae								
		Cladia aggregata	Common Coral-lichen			X		
6: Ferns and Fern-like Plants								
Blechnaceae								
		Blechnum cartilagineum	Gristle Fern					X
		Blechnum minus	Soft Water-fern				X	
		Blechnum wattsii	Hard Water-fern				X	
Culcitaceae								
		Calochlaena dubia	Common Ground-fern				X	

ROTAP	VROT 98	Scientific name	Common name	GI	F	C	Ge	A
Cyatheaceae								
		Cyathea australis	Rough Tree-fern				X	
Dennstaedtiaceae								
		Hypolepis rugosula	Ruddy Ground-fern				X	
		Pteridium esculentum	Austral Bracken	X			X	X
Dryopteridaceae								
		Polystichum proliferum	Mother Shield-fern				X	
Gleicheniaceae								
		Gleichenia dicarpa	Pouched Coral-fern				X	
		Gleichenia microphylla	Scrambling Coral-fern				X	
Lindsaeaceae								
		Lindsaea linearis	Screw Fern				X	
Osmundaceae								
		Todea barbara	Austral King-fern				X	
Pteridaceae								
		Pteris tremula	Tender Brake			X		
Thelypteridaceae								
	e	*Pneumatopteris pennigera*	Lime Fern			X		
8: Monocotyledons								
Araceae								
		**Zantedeschia aethiopica*	White Arum Lily				X	
Colchicaceae								
		Burchardia umbellata	Milkmaids				X	
Cyperaceae								
		Baumea articulata	Jointed Twig-sedge				X	
		Baumea juncea	Bare Twig-sedge		X	X	X	
		Baumea rubiginosa s.l.	Soft Twig-rush	X				X
		Baumea tetragona	Square Twig-sedge				X	
		Baumea spp.	Twig Sedge	X				
		Bolboschoenus spp.	Club Sedge					X
		Carex appressa	Tall Sedge				X	X
		**Carex divulsa ssp. divulsa*	Grey Sedge			X		
		Carex spp.	Sedge	X				

ROTAP	VROT 98	Scientific name	Common name	Gl	F	C	Ge	A
		Eleocharis acuta	Common Spike-sedge	X	X		X	X
		Eleocharis spp.	Spike Sedge					X
		Gahnia clarkei	Tall Saw-sedge	X				
		Gahnia filum	Chaffy Saw-sedge	X		X		
		Gahnia sieberiana	Red-fruit Saw-sedge				X	X
		Gahnia trifida	Coast Saw-sedge	X		X	X	
		Isolepis cernua	Nodding Club-sedge	X				X
		Isolepis inundata	Swamp Club-sedge				X	
		Isolepis nodosa	Knobby Club-sedge	X		X	X	X
		Isolepis platycarpa	Broad-fruit Club-sedge		X			
		Isolepis spp.	Club Sedge	X				
		Lepidosperma concavum	Sandhill Sword-sedge				X	
		Lepidosperma elatius	Tall Sword-sedge				X	X
		Lepidosperma filiforme	Common Rapier-sedge				X	
		Lepidosperma gladiatum	Coast Sword-sedge	X			X	X
		Schoenoplectus pungens	Sharp Club-sedge	X	X			
		Schoenoplectus tabernaemontani	River Club-sedge					X
		Schoenus nitens	Shiny Bog-sedge		X		X	
		Scirpus spp. (s.l.)	Club Sedge	X			X	
		Tetraria capillaris	Hair Sedge	X				
Juncaceae								
		Juncus caespiticius	Grassy Rush	X				
		Juncus gregiflorus	Green Rush					X
		Juncus kraussii ssp. australiensis	Sea Rush	X	X	X	X	X
		Juncus procerus	Tall Rush					X
		Juncus spp.	Rush				X	X
		Luzula meridionalis	Common Woodrush					X
Juncaginaceae								
		Triglochin nanum	Dwarf Arrowgrass					X
		Triglochin procerum s.l.	Water Ribbons				X	X
		Triglochin striatum	Streaked Arrowgrass	X	X		X	X
Luzuriagaceae								
		Drymophila cyanocarpa	Turquoise Berry				X	

ROTAP	VROT 98	Scientific name	Common name	GI	F	C	Ge	A
Orchidaceae								
		Corybas spp.	Helmet Orchid	**X**				
		Microtis unifolia	Common Onion-orchid				**X**	
V	**v**	*Pterostylis cucullata*	Leafy Greenhood	**X**				
		Pterostylis longifolia s.l.	Tall Greenhood				**X**	
		Pterostylis pedunculata	Maroonhood				**X**	
V	**v**	*Pterostylis tenuissima*	Swamp Greenhood	**X**			**X**	
		Pterostylis spp.	Greenhood	**X**				**X**
Phormiaceae								
		Dianella revoluta s.l.	Black-anther Flax-lily	**X**		**X**	**X**	
		Dianella tasmanica	Tasman Flax-lily				**X**	
Poaceae								
		**Aira praecox*	Early Hair-grass			**X**		
		Agrostis avenacea	Common Blown-grass	**X**				
		Agrostis avenacea var. avenacea	Common Blown-grass	**X**				
		Agrostis billardierei	Coast Blown-grass	**X**				
	r	*Agrostis rudis*	Ruddy Bent				**X**	**X**
		**Agrostis stolonifera*	Creeping Bent					**X**
		**Aira caryophyllea*	Silvery Hair-grass					**X**
		**Ammophila arenaria*	Marram Grass			**X**	**X**	
		Amphibromus neesii	Southern Swamp Wallaby-grass		**X**	**X**		
		Amphibromus recurvatus	Dark Swamp Wallaby-grass		**X**			
		Austrostipa flavescens	Coast Spear-grass	**X**				
	r	*Austrostipa mundula*	Neat Spear-grass	**X**				
		Austrostipa pubinodis	Tall Spear-grass				**X**	
		**Briza minor*	Lesser Quaking-grass				**X**	
		**Bromus diandrus*	Great Brome				**X**	
		Bromus spp.	Brome				**X**	
		**Catapodium rigidum*	Fern Grass					**X**
		**Critesion marinum*	Sea Barley-grass	**X**				
		Cynodon dactylon	Couch				**X**	**X**

ROTAP	VROT 98	Scientific name	Common name	Gl	F	C	Ge	A
		**Dactylis glomerata*	Cocksfoot				X	X
		Danthonia s.l. spp.	Wallaby Grass				X	X
		Deyeuxia quadriseta	Reed Bent-grass				X	
		Dichelachne crinita	Long-hair Plume-grass	X				
		Distichlis distichophylla	Australian Salt-grass	X		X	X	
		**Festuca arundinacea*	Tall Fescue					X
		Festuca spp.	Fescue					X
		Hemarthria uncinata var. uncinata	Mat Grass			X		
		**Holcus lanatus*	Yorkshire Fog	X			X	
		Imperata cylindrica	Blady Grass					X
		Isachne globosa	Swamp Millet				X	X
		**Lolium perenne*	Perennial Rye-grass	X				
		Microlaena stipoides var. stipoides	Weeping Grass				X	
		Notodanthonia semiannularis	Wetland Wallaby-grass			X		
		**Parapholis incurva*	Coast Barb-grass	X				
		**Parapholis strigosa*	Slender Barb-grass	X				
		**Phalaris arundinacea*	Reed Canary-grass	X				
		**Phalaris aquatica*	Toowoomba Canary-grass				X	
		**Phleum pratense*	Timothy Grass					X
		Phragmites australis	Common Reed	X	X		X	X
		Poa labillardierei	Common Tussock-grass	X			X	X
		Poa poiformis	Coast Tussock-grass	X		X	X	
		Poa sieberiana	Grey Tussock-grass				X	
		Poa spp.	Tussock Grass				X	X
		Poa tenera	Slender Tussock-grass	X			X	
		Poaceae spp.	an undetermined grass				X	
		**Polypogon monspeliensis*	Annual Beard-grass		X			
		**Polypogon viridis*	Water Bent					X
		**Stenotaphrum secundatum*	Buffalo Grass				X	
		Tetrarrhena distichophylla	Hairy Rice-grass			X		
		Tetrarrhena juncea	Forest Wire-grass				X	X
		Themeda triandra	Kangaroo Grass	X				
		Zoysia macrantha	Prickly Couch				X	

ROTAP	VROT 98	Scientific name	Common name	Gl	F	C	Ge	A
Restionaceae								
		Apodasmia brownii	Coarse Twine-rush	X		X		
		Empodisma minus	Spreading Rope-rush				X	X
		Hypolaena fastigiata	Tassel Rope-rush				X	
		Leptocarpus tenax	Slender Twine-rush		X			
Typhaceae								
		Typha domingensis	Cumbungi					X
Xanthorrhoeaceae								
		Lomandra longifolia	Spiny-headed Mat-rush				X	X
		Xanthorrhoea australis	Austral Grass-tree				X	X
Xyridaceae								
		Xyris operculata	Tall Yellow-eye				X	
9: Dicotyledons								
Aizoaceae								
		Carpobrotus rossii	Karkalla	X		X	X	X
		Tetragonia implexicoma	Bower Spinach	X			X	
Amaranthaceae								
		Hemichroa pentandra	Trailing Hemichroa	X				
Apiaceae								
		Apiaceae spp.	No Common Name				X	
		Apium prostratum ssp. prostratum	Sea Celery	X			X	X
		Apium prostratum ssp. prostratum var. filiforme	Sea Celery	X				
		Centella cordifolia	Centella				X	
		**Conium maculatum*	Hemlock				X	
		Daucus glochidiatus	Austral Carrot					X
		Eryngium vesiculosum	Prickfoot			X		
		Hydrocotyle hirta	Hairy Pennywort				X	
		Hydrocotyle laxiflora	Stinking Pennywort			X	X	X
		Hydrocotyle pterocarpa	Wing Pennywort				X	X
		Hydrocotyle sibthorpioides	Shining Pennywort	X				

ROTAP	VROT 98	Scientific name	Common name	Gl	F	C	Ge	A
		Hydrocotyle spp.	Pennywort				X	X
Apocynaceae								
		Alyxia buxifolia	Sea Box				X	X
		**Vinca major*	Blue Periwinkle			X		
Asteraceae								
		Actites megalocarpa	Dune Thistle			X		
		Angianthus preissianus	Salt Angianthus	X				
		Aster subulatus	Aster-weed	X				X
		Asteraceae spp.	No Common Name				X	
		Brachyscome graminea	Grass Daisy	X			X	
		Brachyscome parvula	Coast Daisy				X	
		**Carduus pycnocephalus*	Slender Thistle		X	X		
		**Carduus pycnocephalus/tenuiflorus spp. agg.*	Slender Thistle species agg.			X		
		**Cirsium vulgare*	Spear Thistle	X			X	X
		**Conyza bonariensis*	Flaxleaf Fleabane				X	
		**Cotula coronopifolia*	Water Buttons	X	X		X	X
		**Hypochoeris glabra*	Smooth Cat's-ear			X		
		**Hypochoeris radicata*	Cat's Ear	X			X	X
		Lagenophora stipitata	Common Bottle-daisy	X				
		**Leontodon taraxacoides ssp. Taraxacoides*	Hairy Hawkbit	X				X
		Leptinella reptans s.l.	Creeping Cotula	X				X
		Leptorhynchos squamatus s.l.	Scaly Buttons			X		
		Leptorhynchos tenuifolius	Wiry Buttons			X		
		**Leucanthemum vulgare*	Ox-eye Daisy			X		
		Leucophyta brownii	Cushion Bush					X
		Olearia axillaris	Coast Daisy-Bush				X	X
		Olearia lirata	Snowy Daisy-bush					X
		Olearia phlogopappa	Dusty Daisy-bush				X	
		Olearia ramulosa	Twiggy Daisy-bush	X				
		Ozothamnus ferrugineus	Tree Everlasting	X			X	X
		Ozothamnus turbinatus	Coast Everlasting					X
		Picris spp.	Picris	X				

ROTAP	VROT 98	Scientific name	Common name	Gl	F	C	Ge	A
		Senecio glomeratus	Annual Fireweed	X				
		**Senecio jacobaea*	Ragwort			X	X	X
		Senecio linearifolius	Fireweed Groundsel				X	
		Senecio odoratus var. odoratus	Scented Groundsel				X	X
		Senecio spathulatus s.l.	Dune Groundsel			X	X	X
		Senecio spp.	Groundsel	X			X	
		**Silybum marianum*	Variegated Thistle			X		
		**Sonchus asper s.l.*	Rough Sow-thistle	X				
		**Sonchus oleraceus*	Common Sow-thistle	X			X	
		Sonchus spp.	Sow Thistle				X	
		Taraxacum spp.	Dandelion	X				
Boraginaceae								
		Cynoglossum australe	Australian Hound's-tongue	X				
		**Myosotis discolor*	Yellow-and-blue Forget-me-not					X
Brassicaceae								
		**Cakile maritima ssp. maritima*	Sea Rocket	X	X			
		Cardamine paucijuga s.l.	Annual Bitter-cress					X
K	v	*Microlepidium pilosulum*	Hairy Shepherd's Purse					X
		**Rorippa nasturtium-aquaticum*	Two-row Water-cress				X	
Campanulaceae								
		Isotoma fluviatilis ssp. australis	Swamp Isotome				X	
		Lobelia anceps	Angled Lobelia	X				X
		Lobelia irrigua	Salt Pratia		X			X
		Wahlenbergia spp.	No Common Name					X
Caryophyllaceae								
		**Cerastium glomeratum s.l.*	Common Mouse-ear Chickweed					X
		**Cerastium vulgare*	Common Mouse-ear Chickweed				X	
		**Minuartia mediterranea*	Fine-leaved Sandwort					X
		**Petrorhagia velutina*	Velvety Pink					X
		**Polycarpon tetraphyllum*	Four-leaved Allseed					X

ROTAP	VROT 98	Scientific name	Common name	GI	F	C	Ge	A
		**Silene nocturna*	Mediterranean Catchfly					X
		Stellaria angustifolia	Swamp Starwort	X				X
Casuarinaceae								
		Allocasuarina paludosa	Scrub Sheoak				X	
		Allocasuarina verticillata	Drooping Sheoak				X	X
Chenopodiaceae								
	v	*Atriplex billardierei*	Glistening Saltbush					X
		**Atriplex prostrata*	Hastate Orache	X				X
		Rhagodia candolleana ssp. *candolleana*	Seaberry Saltbush	X			X	
		Sarcocornia quinqueflora	Beaded Glasswort			X		
		Suaeda australis	Austral Seablite	X				
Clusiaceae								
		**Hypericum androsaemum*	Tutsan			X		
		Hypericum gramineum	Small St John's Wort			X		
Convolvulaceae								
		Calystegia sepium	Large Bindweed			X		X
		Dichondra repens	Kidney-weed	X				X
Crassulaceae								
		Crassula helmsii	Swamp Crassula		X			
		Crassula sieberiana	Sieber Crassula			X		
Cunoniaceae								
		Bauera rubioides	Wiry Bauera				X	
Dilleniaceae								
		Hibbertia appressa	Southern Guinea-flower				X	
		Hibbertia fasciculata var. prostrata	Bundled Guinea-flower				X	
		Hibbertia sericea s.l.	Silky Guinea-flower	X			X	X
Droseraceae								
		Drosera peltata ssp. peltata	Pale Sundew				X	
Epacridaceae								
		Acrotriche affinis	Ridged Ground-berry	X				
		Acrotriche serrulata	Honey-pots				X	
		Epacris impressa	Common Heath				X	
		Leucopogon australis	Spike Beard-heath				X	X

ROTAP	VROT 98	Scientific name	Common name	Gl	F	C	Ge	A
		Leucopogon lanceolatus var. lanceolatus	Lance Beard-heath			X		
		Leucopogon parviflorus	Coast Beard-heath	X		X	X	X
	r	*Monotoca glauca*	Currant-wood			X		
Euphorbiaceae								
		Amperea xiphoclada var. xiphoclada	Broom Spurge				X	X
		Beyeria lechenaultii	Pale Turpentine Bush	X				
		**Euphorbia paralias*	Sea Spurge		X			
		Poranthera microphylla	Small Poranthera				X	
Fabaceae								
		Bossiaea cinerea	Showy Bossiaea				X	
		Bossiaea prostrata	Creeping Bossiaea					X
		Cullen microcephalum	Dusky Scurf-pea			X		
		Desmodium gunnii	Southern Tick-trefoil					X
		Dillwynia glaberrima	Smooth Parrot-pea				X	
		Dillwynia sericea	Showy Parrot-pea				X	
	k	*Lotus australis*	Austral Trefoil	X				
		**Lotus corniculatus var. tenuifolius*	Narrow Bird's-foot Trefoil				X	
		**Lotus suaveolens*	Hairy Bird's-foot Trefoil				X	
		**Lotus uliginosus*	Greater Bird's-foot Trefoil					X
		**Medicago lupulina*	Black Medic	X				X
		**Medicago spp.*	Medic					X
		**Melilotus indicus*	Sweet Melilot	X				
		Platylobium obtusangulum	Common Flat-pea				X	
		Pultenaea daphnoides	Large-leaf Bush-pea					X
		Swainsona lessertiifolia	Coast Swainson-pea				X	
		**Vicia hirsuta*	Tiny Vetch				X	
Gentianaceae								
		**Centaurium erythraea*	Common Centaury			X	X	
		Sebaea albidiflora	White Sebaea		X			
Geraniaceae								
		**Erodium cicutarium*	Common Heron's-bill			X	X	
		**Geranium molle var. molle*	Dovesfoot					X

ROTAP	VROT 98	Scientific name	Common name	Gl	F	C	Ge	A
		Geranium potentilloides	Cinquefoil Cranesbill				X	
		Geranium solanderi s.l.	Austral Cranesbill	X				X
		Geranium spp.	Crane's Bill				X	
Goodeniaceae								
		Goodenia humilis	Swamp Goodenia				X	
		Goodenia lanata	Trailing Goodenia				X	X
		Goodenia ovata	Hop Goodenia				X	X
		Scaevola albida	Pale Fan-flower	X				
		Selliera radicans	Shiny Swamp-mat	X	X		X	X
Haloragaceae								
		Gonocarpus humilis	Shade Raspwort				X	
		Gonocarpus tetragynus	Common Raspwort				X	X
		Haloragis brownii	Swamp Raspwort	X				
V	v	*Haloragis exalata ssp. exalata var. exalata*	Square Raspwort			X		
Lamiaceae								
		Ajuga australis	Austral Bugle	X				
		Lycopus australis	Australian Gipsywort					X
		Mentha diemenica	Slender Mint	X				
		Mentha diemenica var. serpyllifolia	Slender Mint	X				
		Prostanthera lasianthos	Victorian Christmas-bush				X	
		**Prunella vulgaris*	Self-heal					X
Lauraceae								
		Cassytha glabella	Slender Dodder-laurel	X			X	
Lythraceae								
		Lythrum salicaria	Purple Loosestrife					X
Malvaceae								
		**Malva dendromorpha*	Tree Mallow			X		
Menyanthaceae								
		Villarsia umbricola	Lax Marsh-flower	X				
		Villarsia spp.	No Common Name		X			

ROTAP	VROT 98	Scientific name	Common name	Gl	F	C	Ge	A
Mimosaceae								
		Acacia genistifolia	Spreading Wattle				X	
		**Acacia longifolia var. longifolia*	Sallow Wattle				X	X
		Acacia melanoxylon	Blackwood			X	X	X
		Acacia mucronata var. longifolia	Narrow-leaf Wattle				X	
		Acacia pycnantha	Golden Wattle	X				
		Acacia stricta	Hop Wattle			X	X	X
		Acacia verticillata	Prickly Moses				X	X
Myrtaceae								
		Eucalyptus baxteri s.l.	Brown Stringybark				X	X
R	r	*Eucalyptus kitsoniana*	Bog Gum		X			
		Eucalyptus obliqua	Messmate Stringybark				X	X
		Eucalyptus ovata	Swamp Gum					X
		Eucalyptus radiata s.l.	Narrow-leaf Peppermint				X	
		Eucalyptus viminalis	Manna Gum				X	
		Eucalyptus viminalis ssp. Cygnetensis	Rough-barked Manna-gum			X		
		Leptospermum continentale	Prickly Tea-tree				X	X
		Leptospermum lanigerum	Woolly Tea-tree	X			X	X
		Leptospermum myrsinoides	Heath Tea-tree			X	X	
		Melaleuca lanceolata ssp. Lanceolata	Moonah	X				
		Melaleuca squarrosa	Scented Paperbark	X			X	X
Onagraceae								
		Epilobium billardierianum	Variable Willow-herb	X				X
		Epilobium billardierianum ssp. Billardierianum	Smooth Willow-herb	X				X
Oxalidaceae								
		Oxalis corniculata s.l.	Yellow Wood-sorrel				X	X
		Oxalis spp.	Wood-sorrel	X				
Pittosporaceae								
		Billardiera scandens	Common Apple-berry				X	
		Bursaria spinosa ssp. spinosa	Sweet Bursaria	X			X	X
Plantaginaceae								
		**Plantago coronopus*	Buck's-horn Plantain	X				X

ROTAP	VROT 98	Scientific name	Common name	Gl	F	C	Ge	A
		**Plantago lanceolata*	Ribwort	X			X	X
		Plantago spp.	Plantain				X	
Polygalaceae								
		Comesperma calymega	Blue-spike Milkwort					X
		Comesperma volubile	Love Creeper	X				X
Polygonaceae								
		Persicaria decipiens	Slender Knotweed				X	X
		Persicaria praetermissa	Spotted Knotweed					X
		**Rumex crispus*	Curled Dock				X	X
Primulaceae								
		**Anagallis arvensis*	Pimpernel	X			X	
		Samolus repens	Creeping Brookweed	X	X	X	X	X
Proteaceae								
		Banksia marginata	Silver Banksia				X	
Ranunculaceae								
		Clematis microphylla	Small-leaved Clematis	X			X	X
		Ranunculus amphitrichus	Small River Buttercup				X	X
		**Ranunculus repens*	Creeping Buttercup					X
		Ranunculus spp.	Buttercup		X			X
Rhamnaceae								
		Pomaderris paniculosa ssp. paralia	Coast Pomaderris	X				
		Spyridium parvifolium	Dusty Miller				X	
Rosaceae								
		Acaena echinata	Sheep's Burr	X			X	
		Acaena novae-zelandiae	Bidgee-widgee	X			X	X
		**Rubus fruticosus spp. agg.*	Blackberry			X		X
		Rubus parvifolius	Small-leaf Bramble				X	X
Rubiaceae								
R	**k**	*Asperula charophyton*	Elongate Woodruff	X				
		Asperula conferta	Common Woodruff					
		Coprosma quadrifida	Prickly Currant-bush				X	X
		Coprosma reptans	Dwarf Nertera		X			X
	r	*Galium compactum*	Compact Bedstraw					X

ROTAP	VROT 98	Scientific name	Common name	Gl	F	C	Ge	A
		Galium spp.	No Common Name					X
Rutaceae								
		Correa alba	White Correa				X	
		Correa reflexa	Common Correa	X			X	
Santalaceae								
	r	*Exocarpos syrticola*	Coast Ballart					X
Scrophulariaceae								
		Gratiola peruviana	Austral Brooklime			X		X
		Mimulus repens	Creeping Monkey-flower					X
		**Parentucellia viscosa*	Yellow Bartsia				X	
		Veronica calycina	Hairy Speedwell	X				
		Veronica gracilis	Slender Speedwell	X			X	
Solanaceae								
		**Lycium ferocissimum*	African Box-thorn				X	
Stackhousiaceae								
	k	*Stackhousia spathulata*	Coast Stackhousia				X	X
Thymelaeaceae								
		Pimelea glauca	Smooth Rice-flower	X				X
Tremandraceae								
		Tetratheca ciliata	Pink-bells				X	
Tropaeolaceae								
		**Tropaeolum majus*	Nasturtium				X	
Urticaceae								
		Parietaria debilis s.l.	Shade Pellitory				X	X
		Urtica incisa	Scrub Nettle	X		X	X	
Violaceae								
		Viola hederacea s.l.	Ivy-leaf Violet	X			X	

from NRE, 2001a.

ROTAP, Rare or Threatened Australian Plant, V = vulnerable, R = rare, K = poorly known

VROTS98, Victorian Rare or Threatened Species 1998, e = endangered, v = vulnerable, r = rare, k = poorly known

* indicates the plant is a weed species

Appendix 3

DESCRIPTION OF ECOLOGICAL VEGETATION CLASSES ASSOCIATED WITH SOUTHWEST VICTORIAN ESTUARINE WETLANDS

(Yugovic et. al. 1999; RFA 2000).

Coastal Dune Scrub Mosaic (EVC 1)

This occurs on exposed foredunes or on more protected secondary dunes of all five estuaries. Wind-blown calcareous sands form the dune system behind the rocky headland. The average altitude is 10ñ30 asl and average annual rainfall is 900 mm. In the Port Campbell region, it is predominately treeless with the occasional Swamp Gum *Eucalyptus ovata* or Messmate *E. Obliqua*. The shrub layer may be dense or patchy and is characterised by Coast Beard-heath *Leucopogon parviflorus* with Coast Daisy-bush *Olearia axillaris,* Seaberry Saltbush *Rhagodia candolleana* spp. *Candolleana*, and the rare *Exocarpus syticola*, the rare Velvet *Correa backhousiana* and the scrambling Bower Spinach *Tetragonia implexa*. The dominant life forms are tussock forming graminoids and forbs. Blue Tussock-grass *Poa poiformis* and Knobby Club-sedge *Isolepis nodosa* dominate this layer, with Coast Sword-sedge Lepidosperma gladiatum and Black-anther Flax lily Dianella *brevicaulis/reoluta* s.l. often interspersed. On the fore dune the tussock-dominated grassland is often dominated by the introduced Marram Grass * *Ammophila arenaria* which replaces the native sand-binding grass Hairy Spinifex *Spinifex sericeus*. Forbs are common and include Yellow Wood-sorrel *Oxalis corniculata* ssp. agg., Pimpernel Groundsel *Senecio spathulatus*, Ivy-leaf Violet *Viola hederacea* and the introduced Branched Centuary **Cnetaurium tenuiflorum* and Catís Ear * *Hypochoeris radicata*. This floristic alliance is easily disturbed due to the proximity to beaches and subsequently a large proportion of weed species are present.

Damp Sands Herb-rich Woodland (EVC 3)

This is mapped in the Glenelg, Fitzroy, Gellibrand and Aire estuarine wetlands. It cccurs on deep sandy loams, usually associated with adjacent creeks or seasonal lakes or swamps. In the Otway region it occurs on public land only near the coast with an average altitude of 70 m asl. It does occur further inland, but mostly on private land. It grows in areas with average to high rainfall. Effective rainfall is increased by the shallow water-tables associated with the creeks which provide adequate moisture to support a rich ground layer of forbs and grasses, including many weed species. Weed species are exacerbated by the long history and continuing land clearance and disturbance, and proximity to farmland. Invasion by Coast/Shallow Wattle *Acacia longifolia*, primarily due to lack of fire, is a major management issue in southern areas including Lower Glenelg National Park.

The over storey is dominated by Manna Gum, *Eucalyptus viminalis*, in association with Messmate *E. obliqua* and Swamp Gum *E. ovata*. A few scattered shrubs may be present including Coast Beard-heath *Leucopogan parviflorus*, Prickly Moses *Acacia verticillata*, Sweet Bursaria *Bursaria spinosa*, Prickly Tea-tree *Leptospermum continetale*, Tree Everlasting *Ozothamnus ferrugineu*, Small-leaf Bramble *Rubus parvifolius*, Matted Rice-flower *Pimelia biflora* and Coast *Pomaderris oraria* ssp. *oraria* and Large-leafed Bush-pea *Pultenaea daphnoides*.

The ground is dominated by a dense layer of Austral Bracken *Pteridium escullentum* over a diverse layer of forbs, grasses and other graminoids. Common forbs include Bidgee-Widgee *Acaena novae-zelandiae*, Austral Cranesbill *Geranium solanderi*, Common Raspwort *Gonocarpus tetragynus*, Kidney-weed *Dichondra repens*, Yellow Wood-sorrel *Oxalis coniculata* spp. agg. Grassland Wood-sorrel *Oxalis pernnans*, Prickly Starwort *Stellaria pungens*, and Grass Trigger-plant *Stylidium graminifolium*, Common Lagenifera *Langenifera stipitata*, Hairy Pennywort *Hydrocotyle hirta*, Ivy-leaf Violet *Viola hederaceas*, Hairy Speedwell *Veronica calycina*, and Greenhoods *Pterosylis spp.*. along with the introduced weeds Catís Ears **Hypochoeris radicata*, Common Centuary **Centuarium erythraea*, and Pimpernel **Anagallis arvensis*. Common graminoids include Weeping Grass *Microlaena stipoidesl*, Common Tussock-grass *Poa labillardieri*, , Spiny headed Mat-rush *Lomandra longifolia* and Black-anther Flax-lily s.l. *Dianella brevicaulis/revoluta* and the introduced Hareís Tail **Lagurus ovatus.*

Estuarine Wetland (EVC 10)

This EVC receives saline water from tidal movements and freshwater flows from inland. The inundating waters are usually salty, sometimes brackish and occasionally fresh over the period of a year depending upon river flooding regimes. Soils are anaerobic peat-rich muds. Rainfall is between 800ñ1000 mm/annum. Elevation is 0ñ2 m.

This EVC occurs in all five estuaries. Pre-1750 there were large stands within Curdies Inlet and extending many kilometres inland beside Curdies River. This also occurred in association with other large rivers in the SW. Now it is greatly reduced due to clearing and drainage for agriculture, however the remnant stands at Curdies Inlet are still one of the largest in south-east Australia.

Estuarine Wetland is dominated by the Common Reed *Phragmites australis*, Creeping Monkey-flower *Mimulus repens*, , Streaked arrow grass *Triglochin striatum*, Club Sedge *Bolboschoenus* spp. Shiny Swamp-mat *Selliera radicans*, and introduced Water Buttons **Cotula coronopifolia*.

Coastal saltmarsh complex (EVC 52)

This EVC is clearly mapped in the Aire, but probably occurs in the other four estuaries but in too small an area to be clearly distinguishable on the 1:100,000 scale of the maps. Occurs with in Port Campbell National Park, at or just above sea level and has an average annual rainfall range of 600ñ780 mm. Fertile clay loam soils and disturbance from recreational activities combine to encourage a high proportion of weeds. Species diversity is low, reflecting the saline nature of the estuarine environment. A good example of this complex occurs in the Aire, approximately 1km south from its intersection with the Old Great Ocean Road.

This EVC is treeless with rushes, sedges, forbs and aquatic plants dominating. Creeping Brookweed *Samolus repens*, Sea Rush *Juncus kraussii* are dominant, along with grasses such as Australian Salt-grass *Distichlis distichophylla*, Blue Tussock-grass *Poa poiformis*, Annual beard-grass *Polypogon mospliensis* growing on the fringe of the estuary. Shiny Swamp-mat *Selliera radicans*, Beaded Glasswort *Sarcocornia quinqueflora*, Smooth Willow-herb *Epilobium billardierianum* spp. *Billardieruanum*, and the introduced species Aster-weed* *Aster subulatus*, Water Buttons * *Cotula coronopifolia*, and Buckís-horn Plantain* *Plantago cronopus* also occur on the margins of this complex. Nodding Club-sedge *Isolepis cernua* and Knobby Club-sedge *Isolepis nodosa* are the most common sedges.

Swamp scrub (EVC 53)

Swamp Scrub occurs close to the coast and has affinities with Shallow Freshwater Marsh. Both occupy similar habitats. However, Swamp Scrub occurs on slight rises where the soil is deeper and better drained. It is largely confined to alluvial deposits along streams or paludal deposits in basins. Previously extensive but now almost entirely cleared and drained. Moleside Creek contains a typical example, in the Lower Glenelg National Park. Craven, Costin and Hordern Lakes which are on the broad swampy flats of the lower reaches of the Aire River also contain other examples. Flooded Reedbed occurs in the slightly deeper areas of inundation of these flats, the remainder of the flats were mapped as Swamp Scrub. It also occurs in the other three estuaries.

This EVC lacks an overstorey and is dominated by tall Woolly Tea-tree *Leptospermun lanigerum* which forms dense impenetrable thickets, out competing other species. Coast Saw-Sedge *Gahnia trifida* and Common Reed *Phragmites australis* are also common.

Damp Heath Scrub (EVC 165)

Damp Heath Scrub occurs on flat to gently sloping terrain, on or near coastal sites near Port Campbell, and a number of other locations. During the pre-1750 vegetation mapping exercise, this EVC was modelled on an extensive flat near the coast between the Port

Campbell National Park and the Cooriemungle public land block. This extends its description from the valley type environments it commonly occupies in the extant examples on public land. From the map it is difficult to tell where it occurs, but most likely Gellibrand and Curdies Inlet. High rainfall and lack of drainage retaining high levels of moisture throughout the year are important.

Floristically this EVC carries influences of Wet Heath. The overstorey is generally sparse and includes Swamp Gum *Eucalyptus ovata* and less commonly Brown Stringybark *E. baxteri*. The shrub layer is very dense and includes Prickly Tea-tree *Leptospermum continentale*, Silver Banksia *Banksia marginata*, Prickly Moses *Acacia verticillata*, Scrub Sheoke *Allocausarina paludosa*, Common Heath *Epacris impressa*, Scented paperbark *Melaleuca squarrosa*, Dusty Miller *Spyridium parvifolium* and Honey-pots *Acrotriche serrulata*.

Other common species are Austral Grass-tree *Xanthorrhoea australis*, Spreading Rope-rush *Empodisma minus*, Slender Dodder-laurel *Cassytha glabella*, Common Rapier-sedge *Lepidosperma filiforme*, Screw-fern *Lindsea linearis* and Honey Cone-bush *Isopogen ceratophyllus*.

Shallow Freshwater Marsh (EVC 200)

These are wetlands which, while still shallow, are more deeply inundated and for longer periods than Freshwater Meadows (EVC 680). While this hydrological regime delimits a range of possible wetland EVCs, only on a very local scale does it imply a particular EVC with any certainty. On the volcanic plains and more fertile Tertiary soils, shallow freshwater marsh is usually indicative of Plains Sedgy Wetland, or poorly characterised species-poor variant so Plains Grassy Wetland in drier areas. It can also refer to sites supporting Swamp Scrub along impeded drainage lines in higher rainfall areas of plains. On floodplains Shallow Freshwater Marsh has typically been treated as part of Floodplain Riparian Woodland (Floodplain Wetland). This EVC is mapped in the the Glenelg estuarine wetland.

Floodplain reedbed (EVC 863)

A good example of this EVC is at Craven, Costin and Hordern Lakes which are on the broad swampy flats of the lower reaches of the Aire River. It occurs in the slightly deeper areas of inundation of these flats. The remainder of the flats were mapped as Swamp Scrub. Soils are Quaternary swamp and lagoonal deposits of clays, silts and peat. Altitude is just above sea level (less than 5 m). Rainfall is greater than 1000 mm/annum.

Floodplain reedbed is dominated by a dense sward of Common Reed *Phragmites australis* to 2m tall. Other species recorded include Sea Rush *Juncus kraussii*, Creeping Monkey-flower *Mimulus repens*, Australian Gipsywort *Lycopus asutralis*, Water Riboons *Triglochin porcerum* and introducedWater Buttons **Cotula coronopifolia*.

Appendix 4

FAUNA OF THE FIVE ESTUARY CATCHMENTS

Family	Common Name	Latin Name	Occurance in Estuary					Ref
			Gl	F	C	Ge	A	
Fish								
Geotriidae	Pouched lamprey	*Geotria australis*		H		H	H	10
Anguillidae	Short finned eel	*Anguilla australis*	H	H	H	H	H	1, 3, 9
Galaxiidae	Australian mudfish	*Galaxias cleveri*					H	10
	Common galaxias	*Galaxias maculatus*	H	H		H	H	4, 5
	Mountain Galaxias	*Galaxias olidus*					H	10
	Spotted Galaxias	*Galaxias truttaceus*	H				H	10
Retropinnidae	Australian smelt	*Retropinna semoni*	H			H	H	1, 4, 5, 9
Prototrocidae	Australian Grayling	*Prototroctes maraena*					H	10
Atherinidae	Small mouthed hardyhead	*Atherinosoma microstoma*	H	H		H		3, 4, 5, 9
Sparidae	Black Bream	*Acanthopagrus butcheri*	H	H	H	H		1, 3, 8, 9
Ambassidae	Estuary Perch	*Macquaria colonorum*	H	H	H	H	H	4, 5, 8
Kuhliidae	Yarra Pigmy Perch	Edelia obscura	H	H	H		H	10
	Pigmy perch	*Nannoperca australis*	H					4
	Variegated Pygmy Perch	*Nannoperca variegata*	H				H	7, 10
Gapopsidae	Freshwater Blackfish	*Gadopsis marmoratus*	H	H			H	10
Mugilidae	Yellow eye mullet	*Aldrichetta forsteri*	H	H	H	H	H	4, 5, 8
	Sea mullet	*Mugil cephalus*	Gl	F	C	Ge	A	3, 4, 9
Bovichthyidae	Tupong	*Pseudaphritis urvilli*				H	H	5
Eleotridae	Flathead gudgeon	*Philypnodon grandiceps*		H		H		3 4, 5, 9
Gobiidae	Bridled goby	*Arenigobius bifrenatus*	H					1, 4

Family	Common Name	Latin Name	Occurance in Estuary					Ref
			Gl	F	C	Ge	A	
	Tamar goby	*Favonigobius tamarensis*	H				H	4, 5
	Blue-spot goby	*Pseudogobius olorum*	H	H	H	H	H	1
Salmonidae	Brown trout	*Salmo trutta*					H	3, 5, 9
Engraulididae	Southern anchovy	*Engraulis australis*	H					4
Arripidae	Tommy ruff	*Arripis georgianus*	H	H		H		3, 4, 5, 9
	Australian salmon	*Arripis spp*	H	H	H	H	H	4, 5, 8
Sciaenidae	Mulloway	*Sciaena antarctica*	H			H	H	3, 4, 5
Pleuronectidae	Long-nosed flounder	*Ammotretis rostratus*	H	H		H	H	3, 4, 5, 9
Scorpaenidae	South Australian cobbler	*Gymnapistes marmoratus*		H		H		3, 4
Tetraodontidae	Smooth toadfish	*Torquigener glaber*	H	H		H		3, 4
Girellidae	Luderick	*Girella tricuspidata*	H			H		4, 9
Pomatomidae	Tailor	*Pomatomus saltator*	H					4
Hemiramphidae	Sea garfish	*Hyporhamphus melanochir*	H					4
Sillanginidae	King George Whiting	*Sillaginodes punctatus*	H					4
Cheilodactylidae	Blue morwong	*Nemadactylus douglasii*	H					4
	Dusky morwong	*Dactylophora nigricans*	H					4
Monacanthidae	Tooth-brush leather jacket	*Acanthaluteres vittiger*	H					4
Triglidae	Red gurnard	*Chelidonichthys kumu*	H					4
Carangidae	Trevally	*Pseudocaranx dentex*	H			H		4, 9
Invertebrates								
	Glenelg Spiny Cray	*Euastacus bispinosus*	H					10

Family	Common Name	Latin Name	Occurance in Estuary					Ref
			Gl	F	C	Ge	A	
	Southern Victorian Spiny Cray		H					10
	Glenelg Freshwater Mussel	*Hyridella glenelgensis*	H					10
	Otway Black Snail	*Victaphanta compacta*					H	10
	Butterfly	*Heteronympha cordace wilsoni*	H					10
Birds								10
Pelecanidae	Australian Pelican	*Pelecanus conspicillatus*					H	2
Phalacrocoracidae	Black-faced shag	*Leucocarbo fuscenscens*					H	2
	Pied Cormorant	*Phalocrocorax varius*					H	2
Arideidae	Great Egret	*Ardea alba*	H	H	H	H	H	10
	Intermediate Egret	*Ardea intermedia*	H				H	10
	Australasian Bittern	*Botaurus poiciloptilus*	H	H	H	H		10
	Little Bittern	*Ixobrychus minutus*	H		H			10
Anatidae	Cape Barren Goose	*Cereopsis novaehollandiae*	H		H	H	H	10
	Blue-billed Duck	*Oxyura australis*	H			H		10
Accipitridae	Grey Goshawk	*Accipiter novaehollandiae*	H	H	H	H		10
	Letter-winged Kite	*Elanus scriptus*				H		10
	White-bellied Sea-Eagle	*Haliaeetus leucogaster*	H					10
Falconidae	Grey Falcon	*Falco hypoleucos*		H				10
	Peregrine falcon	*Falco peregrinus*					H	2
	Black Falcon	*Falco subniger*				H		10
Rallidae	Baillon's Crake	*Porzana pusilla*		H				10
	Lewin's Rail	*Rallus pectoralis*	H	H			H	10
Gruidae	Brolga	*Grus rubicunda*	H	H	H			10
Otididae	Australian Bustard	*Ardeotis australis*		H				10
Burhinidae	Bush Stone-curlew	*Burhinus grallarius*		H				10

Family	Common Name	Latin Name	Occurance in Estuary					Ref
			Gl	F	C	Ge	A	
Charadriidae	Hooded Plover	*Thinornis rubricollis*	H	H	H			10
Scolopacidae	Eastern Curlew	*Numenius madagascariensis*	H	H				10
Laridae	Pacific gull	*Larus pacificus*					H	2
	Little Tern	Sterna albifrons	H	H				10
	Caspian Tern	*Sterna bergii*					H	2
	Fairy Tern	*Sterna nereis*	H		H			10
Cacatuinae	Red-tailed Black-Cockatoo	*Calyptorhynchus banksii graptogyne*	H	H	H			10
Platycercinae	Orange-bellied Parrot	*Neophema chrysogaster*	H					10
	Swift Parrot	*Lathamus discolor*	H					10
Strigidae	Powerful Owl	*Ninox strenua*	H	H	H	H	H	10
Meropidae	Rainbow bee-eater	*Merops ornatus*					H	2
Maluridae	Southern Emu Wren	*Stipiturus malachurus*					H	2
Acanthizidae	Rufous Bristlebird	*Dasyornis broadbenti*	H	H	H	H	H	10
Ploceidae	Beautiful firetail	*Emblema bella*					H	2
Mammals								
	Heath mouse	*Pseudomys shortridgei*	H					10
	Swamp Antechinus	*Antechinus minimus*	H			H	H	10
	Broad-toothed rat	*Mastacomys fuscus*				H		10
	Spot-tailed Quoll	*Dasyurus maculatus*		H		H		10
	Large-footed Myotis	*Myotis adversus*	H					10
	Common Bent-wing bat	*Miniopterus schreibersii*	H					10
Reptiles								
	Swamp skink	*Egernia corentryi*	H				H	7

References; (1 = Cadwallader and Backhouse, 1983; 2 = CNR, 1994; 3 = Kohen, 1984; 4 = McCarraher, 1986a; 5 = McCarraher, 1986b; 6 = McCarraher and McKenzie, 1986; 7 = NRE, 1997; 8 = Tunbridge and Glenane, 1988; 9 = VWA, 2002)

Appendix 5

DEAKIN UNIVERSITY ESTUARINE RESEARCH

Honours

Arundel A. (1995) Movement of Amphipods within a shallow lagoon at Port Fairy, Victoria.

Barnett E. (2001) Critical tests of zonation pattern on local sandy beaches, saltmarshes and rocky shores.

Baumgartner L. (1998) Utilisation of temperate mangrove habitat by small and juvenile fish.

Beckman D. (1999) Effects of salinity on hatchability, and early development of Estuary Perch, *Macquaria colonorum*.

Booth M. (1995) The importance of seagrass *Amphibolis antarctica* to the survival of Sabellid polychaetes at Killarney Beach.

Cawthray G. (1991) Anoxic Conditions in the Deep Holes of the Hopkins Estuary.

Dyson K. M. (1998) Photosynthetic bacteria of the oxic/anoxic interface.

Farrington L. (1996) Allozyme and morphological variation in the black bream *Acanthopagrus butcheri*, (Munro) (Perciformes:Sparidae) in Southeastern Australia.

Hamilton S. (1997) Aluminium Speciation in the Hopkins and Glenelg Estuaries.

Harney T. (1996) Nutrient composition and metabolism of *Zostera muelleri* (Irmisch ex Ascher) in the Hopkins Estuary

Howells T. (1999) Diet and growth of Estuary Perch (*Macqaria colonorum*) in the Hopkins River.

Ierodiaconou D. (2000) Development of a spatial database using GIS and GPS technologies for the analysis of seagrasss in the Hopkins River Estuary.

Kelly L. (2000) The management of ecological impacts of nutrients, vegetation and river mouth opening processes in the Gellibrand River Estuary and Wetlands.

Kenny S. (1998) Estimating Spatial Variation in Estuarine benthic Communities: Effects of decisions made before, during and after sample processing

Lazzarotto E. (1999) The Effect of Propeller Scars on Seagrass & its associated Macro-infauna in Shallow Inlet Marine & Coastal Park, Australia

Lonza D. (1999) Monitoring change in macroinvertebrate community structure over time in the Curdies River estuary.

Maher P. (2001) Nutrients and phytoplankton of the Curdies River, Southwest Victoria.

Matthews R. (1999) Community Structure of Macroscopic Flora & Fauna in the Saltmarshes of south-west Victoria

Matthews T. (1995) The effect of flooding on estuarine bivalve populations near the mouth of the Hopkins River.

McGregor J. (1995) An Environmental Audit of the Merri River.

McKay S. (1999) The ecology and management of the Gellibrand River estuary and wetlands

Meyer L. (1997) Aspects of the growth and recrutiment of *Ficopomatus enigmaticus* (Polychaete: Serpulidae), near the mouth of the Hopkins River estuary, Victoria, Australia.

Mills K. (1999) Bait/food Harvesting of *Katelysia* spp. & *Anapella cycladea* in Shallow Inlet Marine & Coastal Park

Perryman S. (1995) Sulphur Speciation in an Anoxic Basin of the Hopkins Estuary.

Rouse, A. (1992) An aid to the chemist ñ marine plants as sentinel accumulators for estuarine copper.

Rowlings J. (1996) A study of the population structure of the Yelloweye Mullet, *Aldrichetta forsteri* (Cov. and Val.), in Victoria, using allozyme electrophoresis.

Saywell C. (1992) Redox Chemistry in Deep Holes of the Hopkins Estuary.

Tyndall J. (2001) Species composition and diet of fish found in vegetated and unvegetated littoral habitats of Yambuk estuary, in South-west Victoria.

Unthank S. (1998) Determination of the fine layering of anaerobic ciliates in a deep saline hole of the Hopkins River Estuary, South-west Victoria.

Masters and PhD research

Newton G. M. (1994) Estuarine zooplankton ecology in relation to the hydrological cycles of a salt-wedge estuary (Parts I and II**)**.(PhD).

Matthews T. (2001) Population Dynamics of the Estuarine Bivalve *Solatellina alba* (PhD)

McBurnie J. (1998) The Development and Evaluation of an Information Base for Environmental Management of Aireyís Inlet**.** (MSc)

Parreira P. (2000) Spatial and Temporal Variation of Infauna in an Australian Estuary (MSc)

Rouse A. (1998) Annual phytoplankton and nutrient fluctuations in the Hopkins Estuary. (PhD)

Walsh C. J.. (1994) Ecology of epifaunal caridean shrimps in the Hopkins River estuary, and the role of estuaries in the life history of the atyid *Paratya autraliensis* (Kemp, 1917) in south-eastern Australia. (PhD).

Work currently in progress

H. Arundel Larval Dynamics in Intermittent Estuaries (PhD)

J. Barton Indicators of estuarine health (PhD) (transferred to Flinders University)

K. Bishop Fish use of the inundated margins of Lake Yambuk (PhD)

B. Maddington. Dynamics of estuary mouth opening (PhD).

J. Gwyther Meiofauna of Phytal Habitats in the Barwon Estuary (PhD)

J. Mondon Western Victorian Estuaries-Classification and Management Guidelines (Coast and Clean Seas Project)

M Truong Genetics of SE populations of estuary perch (PhD)

A. Pope Physico-chemical factors influencing seagrass dynamics in intermittently open estuaries (PhD)

Publications

Walsh C. J. (1993) Larval development of *Paratya australiensis* Kemp, 1917 (Decapoda: Caridea: Atyidae), reared in the laboratory, with comparisons of fecundity and egg and larval size between estuarine and riverine environments. *Journal of Crustacean Biology*. **13**, 456ñ 480.

Walsh C. J. & Mitchell B. D. (1995) The freshwater shrimp *Paratya australiensis* (Kemp. 1917) (Decapoda: Atyidae) in estuaries of south-western Victoria, Australia. *Marine and Freshwater Research*. **46**, 959ñ969.

Walsh C. & Mitchell B. D. (1998) Factors associated with variations in abundance of epifaunal caridean shrimps between and within estuarine seagrass meadows. *Marine and Freshwater Science*. **49**, 769ñ777.

Willis S., Laurenson L., Mitchell B.D. & Harrington D. (1999) Diet of larval and juvenile black bream, *Acanthopagrus butcheri*, in the Hopkins River estuary, Victoria, Australia. *Proceedings of the Royal Society of Victoria*. **111,** 283ñ295.

Gwyther J. (2000) Meiofauna in phytal and sedimentary habitats of a temperate mangrove ecosystem - a preliminary report. *Proc. Roy. Soc. Victoria*., in press.

Constable A. J. & Fairweather P. G. (1997) Conservation of Victorian Estuaries: Integrating ecology into management. Victorian Coastal Conference: Caring for the Coast, Geelong, November 20ñ21 1997, *Proceedings*, pp. 79ñ81.

Murray-Wallace C. V., Beu A. G., Kendrick G. W., Brown L. J., Belperio A. P. & Sherwood J. E. (2000) Palaeoclimatic Implications of the occurrence of the arcoid bivalve *Anadara trapezia* (Deshayes,1840) in the Quaternary of Australia *Quaternary Science Reviews*. **19**(6), 559ñ590.

Denney S., Sherwood J. and Leyden J. (1999) In-situ measurements of labile Cu,Cd and Mn in river waters using DGT *Science of the Total Environment*. **239**, 71ñ80.

Sherwood J., Barbetti, M., Ditchburn, R., Kimber,R., McCabe, W., Murray-Wallace, C., Prescott, J. & Whitehead, N. (1994) A comparative study of Quaternary dating techniques applied to sedimentary deposits in southwest Victoria, Australia. *Quaternary Geochronology*. **13**, 95ñ110.

Gill E. D., Sherwood J. E., Cann J. H., Coutts P. J. & Magilton C. J. (1991) Pleistocene shell beds of the Hopkins River, Warrnambool, Victoria : estuarine sediments or Aboriginal middens? In *The Cainozoic in Australia : a Reappraisal of the Evidence* (Eds M. A. J. Williams, P. DeDeckker & A. Kershaw), Geological Society of Australia, Special Publication **18**, 321ñ338.

Sherwood J. E. (1988) The likely impact of climate change on southwest Victorian estuaries" In *Greenhouse: Planning for Climate Change* (Ed G. I. Pearman) C.S.I.R.O. Melbourne, 456ñ472.

Consultant Reports and Other Publications

Sherwood J., Magilton C. & Rouse A. (1998) *The Glenelg River: Nutrients and Estuarine Hydrodynamics*, Prepared for the Department of Natural Resources and Environment, Victoria (65pp).

Sherwood J. & Rouse A. (1997) Estuarine chemistry ñ primordial soup Down Under! *Chemistry in Australia*. August 1997,19ñ22.

Bantow J., Rashleigh M. & Sherwood J. (1995) *'Tuuram': the Hopkins Estuary and Coastal Environs*. Australia Felix Press, Warrnambool (96pp).

Sherwood J. E. (1992) Otways' Water: whose resource? In *The Otways: Flora, Fauna, Conservation, Management.* (Eds M. Westbrooke, B. Wilson & S. Laidlaw) Proceedings of a conference held at Deakin University, Geelong, 4ñ5 July 1990, 2ñ11.

Sherwood J. E., Mitchell B. D., Magilton C. J., Walsh C. J. & Newton G. M. (1988) Victoria's Barwon Estuary ñ a test of adaptability. In *Silver Jubilee Conference Commemorative Volume* (Ed D. Wilkinson), Australian Marine Sciences Association, Sydney University, Sydney, 125ñ130.

Prescott J. R. and Sherwood J. E. (1988) Thermoluminescence ages for an unusual shell deposit at Point Ritchie, Warrnambool, Australia. In Archaeometry : Australasian Studies 1988 (Ed J. R. Prescott), University of Adelaide, Adelaide, 61ñ69.

Sherwood J. E., Mitchell B. D., Magilton C. J., Walsh C. J. & Newton G.M. (1987) *A Study of the Barwon Estuary Complex*. Report 87ñ2, Centre for Aquatic Science, WIAE. Prepared for the South-West Regional Water Resources Task Force (147pp).

Sherwood J. E. (1985) *Hydrodynamics of South West Victorian Estuaries*. Faculty of Applied Science and Technology, WIAE, Research Report 85ñ1 (27pp).

Sherwood J. E. (1984) *Hydrodynamics of the Gellibrand River Estuary (Part 2)*. Faculty of Applied Science and Technology, WIAE. Research Report 84ñ1, April, 1984. Prepared for the Rural Water Commission, Victoria (84pp).

Sherwood J. E. (1983) *Hydrodynamics of the Gellibrand River Estuary*. Faculty of Applied Science and Technology, WIAE. Research Report 83ñ1. Prepared for the Rural Water Commission, Victoria (102pp).

Sherwood J. E. (1982) *An Anglerís Map of the Hopkins River Estuary*, WIAE Press, Warrnambool.

Sherwood J. E. & Backhouse G. (1982) *Hydrodynamics of Salt Wedge Estuaries ñ Implication for Successful Spawning in Black Bream (*Acanthopagrus butcheri*)*. Faculty of Applied Science and Technology, WIAE, Research Report 82ñ3, September, 1982 (16pp).

Appendix 6

METADATA SPECIFICATIONS FOR MAPS

Road, hydrology and coastline information in the maps provided has been directly derived from the respective layers of the Victorian Oil Spill Response Atlas CD-ROM.

The datasets "swamp" and "estuary" have been created from the "hydrology" layer of the Victorian Oil Spill Response Atlas CD-ROM.

The areas in "swamp" have been directly derived from areas of perennial swamp associated with the 5 estuaries.

Areas in "estuary" have been derived from areas deemed to be estuarine based on literature cited in this report and personal experience.

DATASET

Name:	VCST_25G
Title:	Victorian coastline (mean high water mark) at 1:25,000
Custodian:	Land Victoria ñ Department of Natural Resources and Environment
Jurisdiction:	Victoria

Description

Abstract

This layer contains the Victorian coastline (mean high water mark) only and was extracted from the statewide layer SHORE25. SHORE25 also contains other coastal and marine related features represented by points and lines (eg. rock platforms) and these features will be utilised in the Shoreline (Intertidal) OSRA layer. Shoreline features including piers, jetties and seawalls will be represented in a separate layer.

The coastline has been coded according to the Australian Standard Geographic Information Systems ñ Geographic Data ñ Interchange of feature-coded digital mapping data AS2482 ñ 1989.

Data has been derived from Land Victoriaís State Digital Map Base ñ Topographic data and converted from Microstation .DGN format to ArcInfo format.

Spatial Extent

Victoria

Dataset Currency

Data Collection

Beginning Date:	Early 1970s
Ending Date:	Present

Dataset Status

Progress:	Active
Maintenance & Update Freq:	As required

Dataset Access

Stored Data Format(s):	Digital Arc/Info Revision 7 & ArcView Shapefile
Available Format Type(s):	Digital ñ all major formats available
Projection:	Geographic, datum AGD

Access constraints:	Subject to Data Exchange and License conditions specified by LandVictoria.

Data Quality

Map input scale:	1:25,000

Data Set Origin

Originality:	Primary
Data Collection Method:	Maps

Data Set Source

Land Victoria 1:25,000 State Digital Map Base ñ Topographic

Data Set Processing Details

The data was received in an ArcInfo format in a single file containing all features as described on a published 1:25,000 map, including annotation and symbology defined as arcs. Prior to insertion in the library the data underwent the following processes:

- Line features separated into individual covers based on AS2482
- Line covers then unsplit on AS2482
- Line, point and annotation then sorted into appropriate layers

Positional Accuracy

Geospatial Information SDMB-T Metadata (1998) states:

> The planimetric accuracy attainable will be the sum of errors from three sources:
>
> - the positional accuracy of the source material
> - errors due to the conversion process
> - errors due to the manipulation process

Precision

Source Data

1:25,000 topographic maps

Horizontal accuracy:	90% of well defined points will fall within ± 12.5 m of true position
Vertical accuracy:	90% of elevations will fall within ± 0.5 of a contour interval that is at 10 or 20 m

Digital Data

Any departure between the digital and source material (measured between centrelines) will not exceed 0.5 mm at map scale (*i.e.*, 12.5m at 1:25,000) with a root mean square of 0.12 mm for any random sample.

Determination

Survey controlled with 8 points per mapsheet with a residual error less than 10 m at ground scale

Attribute Accuracy

Coding on all features has been validated by Land Victoria during the creation of the State Digital Map Base ñ Topographic from scanned repromats of published 1:25,000 maps. Geospatial Information SDMB-T Metadata (1998) states:

> The allowable error in attribute accuracy ranges between a 1% allowable error to 5% error. For this product attribute accuracy ranges between a 1% to 5% error. For this

product attribute accuracy is a measure of the degree to which features and attribute values of spatial objects agree with the information on the source material.

Logical Consistency

All coverages go through a checking procedure that includes (Geospatial Information SDMB-T Metadata 1998):

Item validation

The allowable error in attribute accuracy ranges between 1% to 5% error. Logical consistency is a measure of the degree to which data complies with the technical specification. The test procedures are a mixture of scripts, Microstation MGE program and on-screen visual checks.

Completeness

All of the State is covered by data in the DNRE Corporate Geospatial Data Library with the exception of information currently held by NSW Land Information Centre as per the cross border agreement 1997. Geospatial Information SDMB-T Metadata (1998) states:

The completeness of the data is tested by visual comparison to the source material. This test may be either on-screen visual checks or overlay symbolised plots compared to the source material. The SDMB-T is still being produced to complete capture stage that will reflect the information levels contained on a printed 1:25 000 topographic map. At present there is a number of different capture data sets:

- freeways, highways, roads, and tracks
- rivers, creeks and hydrographic features
- contours at 10 and 20 m intervals
- railway line

The data set produced by digital stereo capture covering 20% of the State contains all levels of information except for text and information relating to administrative boundaries. Other data sets have varying degrees of data capture beyond the mandatory requirements. The remaining data set required to complete the data capture over the whole of the State is currently being captured by private contractors.

Further Information

Supporting Documentation

Natural Resources & Environments 1:25,000 Topographical Base Datasets ñ Phil King ñ NRS (May 1997)

SDMB-T in the Corporate Geospatial Library ñ Phil King, Sandro Condurso ñ NRS (1998)

Tolerances

Precision:	Double
Features:	Line, Annotation
Spatial Index:	ALL
Anno Subclasses:	SHORE25
Tolerances:	Dangle: 12.5
	Fuzzy: 1
	Grain: 2
	WeEd 2
	Tic Match: 0
	Edit: 40
	Node snap: 20
	Snap: 20

Data Content

Attributes

VCST_25G ARC ATTRIBUTE TABLE (VCST_25G.AAT)

Item Full Name	Class	Coln	Item Name	Item Width	Out Width	Item Type	Notes
Version	O	33	VER-SION	4	5	B	Data revision number applied to modified features
Microstation level number	O	37	IGDS_ LEVEL	2	5	I	GDV-Microstation level number
Microstation colour number	O	39	IGDS_ COLOR	3	3	I	GDV-Microstation colour number
AS2482	O	42	AS2482	2	4	B	Australian Standard AS2482 ñ 1989
AS2482 Description	O	44	AS2482_ DESC	50	50	C	Australian Standard AS2482 ñ 1989
Occur	O	94	OCCUR	4	11	B	Item containing spot height and contour values
Entity	R	98	ENTITY	2	4	B	Redefined item for AS2482

VCST_25G ANNOTATION ATTRIBUTE TABLE (VCST_25G)

Item Full Name	Class	Coln	Item Name	Item Width	Out Width	Item Type	Notes
Level	O	9	LEVEL	4	5	B	ArcEdit annotation level number
Symbol	O	13	SYMBOL	4	4	I	Symbol value for CMYK7 symbol sets
Text	O	17	TEXT	80	80	C	Point text that reflects annotation
Rotation	O	97	ROT	4	12	F	Rotation angle for feature symbol
Justify	O	101	JUSTIFY	2	2	C	Displays original $JUSTIFY values for annotation.
AS2482	O	103	AS2482	4	5	B	Australian Standard AS2482 ñ 1989
AS2482 Description	O	107	AS2482_ DESC	50	50	C	Australian Standard AS2482 ñ 1989
Occur	O	157	OCCUR	4	5	B	GDV-Microstation text style number
Version	O	161	VER-SION	4	5	B	Data revision number applied to modified features

DATASET

Name: VHYDRO_25G

Title: Victorian coastal hydrological features at a scale of 1:25,000

Custodian: Land Victoria, Department of Natural Resources and Environment

Jurisdiction: Victoria

Description

Abstract

This layer contains line and point features delineating hydrology in the Victorian coastal region at a scale of 1:25,000. The layer was extracted from HYDRO25 which covers the entire State of Victoria

NOTE: This layer has perennial waterbody features added such as, AS2482 4401 (Perennial Area Feature ñ Lake, Dam) and 4414 (Swamp) to allow for stream connectivity.

All features are identified and coded according to the Australian Standard Geographic Information Systems ñ Geographic Data ñ Interchange of feature-coded digital mapping data AS2482 ñ 1989

Data has been derived from Land Victoriaís State Digital Map Base ñ Topographic data and converted from Microstation .DGN format to ArcInfo format.

Geographic Extent

Victoria

Dataset Currency

Data Collection

Beginning Date: Early 1970s

Ending Date:	Present

Dataset Status

Progress:	Active
Maintenance & Update Freq:	As required

Dataset Access

Stored Data Format(s):	Digital Arc/Info Revision 7 & ArcView Shapefile
Available Format Type(s):	Digital ñ all major formats available
Projection:	Geographic, datum AGD
Access constraints:	Subject to Data Exchange and License conditions specified by LandVictoria.

Data Quality

Map input scale:	1:25,000

Data Set Origin

Originality:	Primary
Data Collection Method:	Maps

Data Set Processing Details

Data Set Source

Land Victoria 1:25,000 State Digital Map Base ñ Topographic

Positional Accuracy:

Geospatial Information SDMB-T Metadata (1998) states:

> The planimetric accuracy attainable will be the sum of errors from three sources:
>
> - the positional accuracy of the source material
> - errors due to the conversion process
> - errors due to the manipulation process

Precision

Source Data

1:25,000 topographic maps

Horizontal accuracy:	90% of well defined points will fall within ± 12.5 m of true position
Vertical accuracy:	90% of elevations will fall within ± 0.5 of a contour interval that is at 10 or 20 m

Digital Data

Any departure between the digital and source material (measured between centrelines) will not exceed 0.5 mm at map scale (*i.e.*, 12.5 m at 1:25,000) with a root mean square of 0.12 mm for any random sample.

Determination

Survey controlled with 8 points per mapsheet with a residual error less than 10m at ground scale.

Attribute Accuracy

Coding on all features has been validated by Land Victoria during the creation of the State Digital Map Base ñ Topographic from scanned repromats of published 1:25,000 maps. Geospatial Information SDMB-T Metadata (1998) states:

> The allowable error in attribute accuracy ranges between a 1% allowable error to 5% error. For this product attribute accuracy ranges between a 1% to 5% error. For this product attribute accuracy is a measure of the degree to which features and attribute values of spatial objects agree with the information on the source material.

Logical Consistency

All coverages go through a checking procedure that includes (Geospatial Information SDMB-T Metadata 1998):

> Item validation
>
> The allowable error in attribute accuracy ranges between 1% to 5% error. Logical consistency is a measure of the degree to which data complies with the technical specification. The test procedures are a mixture of scripts, Microstation MGE program and on-screen visual checks.

Completeness

All of the State is covered by data in the DNRE Corporate Geospatial Data Library with the exception of information currently held by NSW Land Information Centre as per the cross border agreement 1997. Geospatial Information SDMB-T Metadata (1998) states:

> The completeness of the data is tested by visual comparison to the source material. This test may be either on-screen visual checks or overlay symbolised plots compared to the source material. The SDMB-T is still being produced to complete capture stage that will reflect the information levels contained on a printed 1:25,000 topographic map. At present there is [sic] a number of different capture data sets.
>
> - freeways, highways, roads, and tracks
> - rivers, creeks and hydrographic features
> - contours at 10 and 20 m intervals
> - railway lines
>
> The data set produced by digital stereo capture covering 20% of the State contains all levels of information except for text and information relating to administrative boundaries. Other data sets have varying degrees of data capture beyond the mandatory requirements. The remaining data set required to complete the data capture over the whole of the State is currently being captured by private contractors.

Further Information

Tolerances

Precision: Double

Features: Line, Point, Annotation

Spatial Index: ALL

Anno Subclasses: HYDRO25

Tolerances: Dangle: 12.5

Fuzzy: 1

Grain: 2

WeEd 2

Tic Match: 0

Edit: 40

Node snap: 20

Snap: 20

Data Content

Attributes

VHYDRO_25G ARC ATTRIBUTE TABLE (VHYDRO_25G.AAT)

Item Full Name	Class	Coln	Item Name	Item Width	Out Width	Item Type	Notes
Version	O	33	VERSION	4	5	B	Data revision number applied to modified features
Microstation level number	O	37	IGDS_ LEVEL	2	5	I	GDV-Microstation level number
Microstation colour number	O	39	IGDS_ COLOR	3	3	I	GDV-Microstation colour number
AS2482	O	42	AS2482	2	4	B	Australian Standard AS2482 ñ 1989
AS2482_ DESC		44	AS2482 Feature description	25	25	C	Item added to replace LUT in Hydro25 layer
Occur	O	69	OCCUR	4	11	B	Item containing spot height and contour values
Entity	R	73	ENTITY	2	4	B	Redefined item for AS2482

VHYDRO_25G POINT ATTRIBUTE TABLE (VHYDRO_25G.PAT)

Item Full Name	Class	Coln	Item Name	Item Width	Out Width	Item Type	Notes
Symbol	O	25	SYMBOL	4	5	B	Symbol value for CMYK7 symbol sets
Version	O	29	VERSION	4	5	B	Data revision number applied to modified features
Rotation	O	33	ROT	4	5	B	Rotation angle for feature symbol
Microstation level number	O	37	IGDS_ LEVEL	2	2	I	GDV-Microstation level number
Microstation colour number	O	39	IGDS_ COLOR	3	3	I	GDV-Microstation colour number
AS2482	O	42	AS2482	4	4	I	Australian Standard AS2482 ñ 1989
AS2482_ DESC		46	AS2482 Feature description	25	25	C	Item added to replace LUT in Hydro25 layer
Occur	O	71	OCCUR	4	11	B	Item containing spot height and contour values
Entity	R	75	ENTITY	2	4	B	Redefined item for AS2482

VHYDRO_25G ANNOTATION ATTRIBUTE TABLE (VHYDRO_25G)

Item Full Name	Class	Coln	Item Name	Item Width	Out Width	Item Type	Notes
Level	O	9	LEVEL	4	5	B	ArcEdit annotation level number
Symbol	O	13	SYMBOL	4	4	I	Symbol value for CMYK7 symbol sets
Text	O	17	TEXT	80	80	C	Point text that reflects annotation
Rotation	O	97	ROT	4	12	F	Rotation angle for feature symbol
Justify	O	101	JUSTIFY	2	2	C	Displays original $JUSTIFY values for annotation.
AS2482	O	103	AS2482	4	5	B	Australian Standard AS2482 ñ 1989
AS2482_DESC		107	AS2482 Feature description	25	25	C	Item added to replace LUT in Hydro25 layer
Occur	O	132	OCCUR	4	5	B	GDV-Microstation text style number
Version	O	136	VER-SION	4	5	B	Data revision number applied to modified features

DATASET

Name: VROAD_25G

Title: Road features at 1:25,000 in the Victorian coastal region

Custodian: Land Victoria ñ Department of Natural Resources and Environment

Jurisdiction: Victoria

Description

Abstract

This layer contains line features delineating roads and related features.

All features are identified and coded according to the Australian Standard Geographic Information Systems ñ Geographic Data ñ Interchange of feature-coded digital mapping data AS2482 ñ 1989.

Data has been derived from Land Victoriaís State Digital Map Base ñ Topographic data and converted from Microstation .DGN format to ArcInfo format.

Geographic Extent

Victoria

Dataset Currency

Data Collection

Beginning Date: Early 1970s

Ending Date: Present

Dataset Status

Progress: Active

Maintenance & Update Freq: As required

Dataset Access

Stored Data Format(s):	Digital Arc/Info Revision 7 & ArcView Shapefile
Available Format Type(s):	Digital ñ all major formats available
Projection:	Geographic, datum AGD
Access constraints:	Subject to Data Exchange and License conditions specified by Land Victoria.

Data Quality

Map input scale:	1:25,000

Data Set Origin

Originality:	Primary
Data Collection Method:	Maps

Data Set Processing Details

Data Set Source

Land Victoria 1:25,000 State Digital Map Base ñ Topographic

Positional Accuracy

Geospatial Information SDMB-T Metadata (1998) states:

> The planimetric accuracy attainable will be the sum of errors from three sources:
>
> - the positional accuracy of the source material
> - errors due to the conversion process
> - errors due to the manipulation process

Precision

Source Data:

1:25 000 topographic maps

Horizontal accuracy:	90% of well defined points will fall within ± 12.5 m of true position
Vertical accuracy:	90% of elevations will fall within ± 0.5 of a contour interval that is at 10 or 20 m.

Digital Data

Any departure between the digital and source material (measured between centrelines) will not exceed 0.5 mm at map scale (*i.e.*, 12.5 m at 1:25,000) with a root mean square of 0.12 mm for any random sample.

Determination

Survey controlled with 8 points per mapsheet with a residual error less than 10 m at ground scale.

Attribute Accuracy

Coding on all features has been validated by Land Victoria during the creation of the State Digital Map Base ñ Topographic from scanned repromats of published 1:25,000 maps. Geospatial Information SDMB-T Metadata (1998) states:

> The allowable error in attribute accuracy ranges between a 1% allowable error to 5% error. For this product attribute accuracy ranges between a 1% to 5% error. For this product attribute accuracy is a measure of the degree to which features and attribute values of spatial objects agree with the information on the source material.

Logical Consistency

All coverages go through a checking procedure that includes (Geospatial Information SDMB-T Metadata 1998):

> Item validation
>
> The allowable error in attribute accuracy ranges between 1% to 5% error. Logical consistency is a measure of the degree to which data complies with the technical specification. The test procedures are a mixture of scripts, Microstation MGE program and on-screen visual checks.

Completeness

All of the State is covered by data in the DNRE Corporate Geospatial Data Library with the exception of information currently held by NSW Land Information Centre as per the cross border agreement 1997. Geospatial Information SDMB-T Metadata (1998) states:

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>
> - freeways, highways, roads, and tracks
> - rivers, creeks and hydrographic features
> - contours at 10 and 20 m intervals
> - railway lines
>
> The data set produced by digital stereo capture covering 20% of the State contains all levels of information except for text and information relating to administrative boundaries. Other data sets have varying degrees of data capture beyond the mandatory requirements. The remaining data set required to complete the data capture over the whole of the State is currently being captured by private contractors.

Further Information

Supporting Documentation

Natural Resources & Environments 1:25,000 Topographical Base Datasets ñ Phil King ñ NRS (May 1997)

SDMB-T in the Corporate Geospatial Library ñ Phil King, Sandro Condurso ñ NRS (1998)

Tolerances

Precision:	Double
Features:	Line, Annotation
Spatial Index:	ALL
Anno Subclasses:	ROAD25
Tolerances:	Dangle: 12.5
	Fuzzy: 1
	Grain: 2
	WeEd 2
	Tic Match: 0
	Edit: 40
	Node snap; 20
	Snap: 20

Data Content

VROAD_25G ARC ATTRIBUTE TABLE (VROAD_25G.AAT)

Item Full Name	Class	Coln	Item Name	Item Width	Out Width	Item Type	Notes
Version	O	33	VERSION	4	5	B	Data revision number applied to modified features
Microstation level number	O	37	IGDS_ LEVEL	2	5	I	GDV-Microstation level number
Microstation colour number	O	39	IGDS_ COLOR	3	3	I	GDV-Microstation colour number
AS2482	O	42	AS2482	2	4	B	Australian Standard AS2482 ñ 1989
AS2482 Description	O	44	AS2482_ DESC	50	50	C	Australian Standard AS2482 ñ 1989
Occur	O	94	OCCUR	4	11	B	Item containing spot height and contour values
Entity	R	98	ENTITY	2	4	B	Redefined item for AS2482

VROAD_25G ANNOTATION ATTRIBUTE TABLE (VROAD_25G)

Item Full Name	Class	Coln	Item Name	Item Width	Out Width	Item Type	Notes
Level	O	9	LEVEL	4	5	B	ArcEdit annotation level number
Symbol	O	13	SYMBOL	4	4	I	Symbol value for CMYK7 symbol sets
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Rotation	O	97	ROT	4	12	F	Rotation angle for feature symbol
Justify	O	101	JUSTIFY	2	2	C	Displays original $JUSTIFY values for annotation.
AS2482	O	103	AS2482	4	5	B	Australian Standard AS2482 ñ 1989
AS2482 Description	O	107	AS2482_ DESC	50	50	C	Australian Standard AS2482 ñ 1989
Occur	O	157	OCCUR	4	5	B	GDV-Microstation text style number
Version	O	161	VER-SION	4	5	B	Data revision number applied to modified features

Parks Victoria is responsible for managing the Victorian protected area network, which ranges from wilderness areas to metropolitan parks and includes both marine and terrestrial components.

Our role is to protect the natural and cultural values of the parks and other assets we manage, while providing a great range of outdoor opportunities for all Victorians and visitors.

A broad range of environmental research and monitoring activities supported by Parks Victoria provides information to enhance park management decisions. This Technical Series highlights some of the environmental research and monitoring activities done within Victoria's protected area network.

Healthy Parks Healthy People

For more information contact the **Parks Victoria Information Centre** on **13 1963**, or visit **www.parkweb.vic.gov.au**

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