RT2: Changing Hydrodynamic Conditions (Impacts of Second Entrance)

DRAFT FINAL REPORT

- Draft A
- 9 September 2005
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# Contents

1. Introduction and Background  

2. A Second Entrance to the Gippsland Lakes  
   2.1 The Concept of a Second Entrance  
   2.2 The Second Entrance and Algal Blooms  
   2.3 The Peel-Harvey Estuary Precedent  
   2.4 Impacts of a Second Entrance to the Gippsland Lakes  

3. The Values of the Gippsland Lakes  
   3.1 Introduction  
   3.2 Environmental  
      3.2.1 Wetlands  
      3.2.2 Estuarine Systems  
   3.3 Socio-Economic  
      3.3.1 Recreation and tourism  
      3.3.2 Aesthetic values  
      3.3.3 Commercial  
      3.3.4 Other values  

4. Existing Hydrodynamic and Water Quality Conditions  
   4.1 Introduction  
   4.2 General Considerations  
   4.3 Hydraulic Parameters  
      4.3.1 Bathymetry  
      4.3.2 Tidal Levels  
      4.3.3 Tidal Range  
      4.3.4 Tidal Velocity  
   4.4 Water Quality  
      4.4.1 Catchment Inputs  
      4.4.2 Algal Blooms  
      4.4.3 Water Quality Modelling  

5. Potential Second Entrance Configurations  

6. Impacts of Second Entrance on Hydrodynamic and Water Quality Conditions  
   6.1 Introduction  
   6.2 General Considerations  
   6.3 Hydraulic Parameters
6.3.1 Bathymetry
6.3.2 Tidal Levels
6.3.3 Tidal Range
6.3.4 Tidal Velocity
6.4 Water Quality
6.4.1 Hydraulic Flushing
6.4.2 Saline Recovery
6.5 Impact of Second Entrance
6.5.1 Overview
6.5.2 Hydraulic Parameters
6.5.3 Water Quality
6.5.4 Discussion
6.5.5 Comparison with CSIRO 2001 Model
6.6 Other Considerations
6.6.1 Gippsland Lakes Flooding
6.6.2 Coastal Processes
6.6.3 Navigation and Dredging
6.7 Impacts of Second Entrance at Rotamah Island or Lake Reeve
6.8 Conclusions

7. Risks of a Second Entrance
7.1 Overview of Risk Assessment Framework
7.2 Ocean Grange
7.2.1 Environmental
7.2.2 Socio-Economic
7.3 Rotamah Island
7.3.1 Environmental
7.3.2 Socio-Economic
7.4 Lake Reeve
7.4.1 Environmental
7.4.2 Socio-Economic
7.5 Summary of Risk Assessment

8. Conclusion

9. References

Appendix A Project Brief
Appendix B Steering Committee
Appendix C Hydrodynamic Modelling
## Document history and status

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date issued</th>
<th>Reviewed by</th>
<th>Approved by</th>
<th>Date approved</th>
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<td>Chris Barry</td>
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1. Introduction and Background

1.1 Project Overview
The Gippsland Research Co-ordination Group (GRCG) has commissioned Sinclair Knight Merz (SKM) to undertake an assessment of the hydrodynamic, environmental, social and economic impacts of a second entrance to the Gippsland Lakes. The project is being undertaken as part of the Group’s Gippsland Lakes Research and Development Program. The information sheet that accompanied the call for research and investigation proposals for the project is attached as Appendix A.

The project is being undertaken under the direction of a Steering Committee, membership of which is listed in Appendix B.

The project was originally intended to be undertaken in two Stages. The first stage was to comprise background reviews, establishment of a risk assessment framework, and assessment of hydrodynamic, environmental, social and economic impacts of both existing conditions, and conditions relating to one second entrance configuration/scenario. The need for a second stage was then to be assessed following the completion of the first stage. The second stage, if it proceeded, was to investigate up to a further two second entrance configurations/scenarios.

A Draft Interim Report documenting Stage 1 investigations was submitted for consideration by the Steering Committee on 13 April 2005. This was then presented to and discussed with the Steering Committee at a meeting on 22 April 2005. It was agreed at the meeting that full hydrodynamic modelling of further second entrance options should not be undertaken. However, it was agreed that a desktop investigation, without additional hydrodynamic modelling, should be undertaken for two variants to the second entrance option investigated in Stage 1.

The project has focussed on assessing the potential risks of a second entrance to the economic, social and environmental values of the Lakes. The Draft Final Report documents the investigations and findings of the Stage 1 second entrance option, and the two variants.

1.2 Draft Final Report
The concept of a second entrance is introduced in Chapter 2. The economic, social and environmental values of the Lakes that could potentially be impacted upon by a second entrance are outlined in Chapter 3. The risk assessment has been based where possible on the expected impacts of a second entrance on relevant Lake parameters, particularly water level regime, velocities and salinities. Expected changes to these parameters have then been used to infer the likely impacts of a second entrance on the frequency and severity of algal blooms in the Lakes. Existing hydrodynamic and water quality conditions in the Lakes are summarised in Chapter 4.
The three potential second entrance configurations investigated during the project, and the rationale for these, are outlined in Chapter 5. The impacts of each configuration on hydrodynamic and water quality conditions, including inferred impacts on frequency and severity of algal blooms, are detailed in Chapter 6. The risk assessment is then presented in Chapter 7, and conclusions presented in Chapter 8.
2. A Second Entrance to the Gippsland Lakes

2.1 The Concept of a Second Entrance
The Gippsland Lakes are one of Australia’s largest coastal lagoon systems. They represent a unique aquatic ecosystem with a range of environmental values that support a number of beneficial uses that include recreational boating, tourism and commercial fishing. Most of the lakes and lagoons also form part of the Gippsland Lakes Ramsar site and therefore support significant numbers of waders and seabirds.

Like most coastal embayments around Australia, the pressures of coastal development and catchment degradation on the Gippsland Lakes has resulted in substantial changes to the ecosystem. There has been a well-documented impact on water quality that includes the regular occurrence of blue green algal blooms and extended periods of deoxygenation in bottom waters and sediments of the lower lakes.

In response to the need to investigate strategies for ameliorating the environmental problems of the Gippsland Lakes, and following recommendations from the Gippsland Lakes Environmental Audit (Harris et al. 1998), the CSIRO initiated the Gippsland Lakes Environmental Study (GLES), which assessed the various options available for improving water quality and ecological function of the Gippsland Lakes.

One suggested option was to consider the feasibility of a second entrance near Ocean Grange (Webster et al. 2001).

2.2 The Second Entrance and Algal Blooms
The Gippsland Lakes are susceptible to eutrophication because of a number of factors including poor flushing, high nutrient loads per unit volume of receiving water, and vertical salinity stratification. Algal blooms have the potential to occur all year round, but tend to occur in autumn/late summer when long, dry periods with low river flows during winter are followed by calm conditions conducive to stratification. Blooms sometimes also follow major rain events and floods in spring which are accompanied by high nutrient loads from the catchments. Large scale blooms of the toxic, blue-green alga *Nodularia spumigenia*, have occurred about every 10 years, although blooms of unspecified algal species including dinoflagellates and diatoms occur more often. Most *Nodularia* blooms have been recorded from Lake King.

High concentrations of nutrients in the water and sediments of the Lakes together with elevated temperature and low salinity, provide the conditions conducive to the formation of algal blooms.

Further discussion of the causes, and spatial and temporal distribution of algal blooms in the Gippsland Lakes is included in Chapter 4.
2.3 The Peel-Harvey Estuary Precedent

The Peel-Harvey estuary in southwest Australia was subject to similar environmental stresses as the Gippsland Lakes. Historically, the estuary suffered from increases in sediment and nutrient inputs from severely modified river systems. Seasonal blooms of the blue green alga *Nodularia* were a common occurrence as tidal flushing was reduced through a single shallow entrance at Mandurah. In an effort to permanently improve water quality in the inlet, a second entrance was excavated at Dawesville in 1994. The channel was cut to flush nutrients from the estuarine basins and increase salinities to levels that inhibit growth of the toxic estuarine blue-green algae, *Nodularia*.

Interestingly, the construction of the second entrance has considerably improved water quality in the estuary although blooms of *Nodularia* and other phytoplankton species continue to occur in the lower tidal reaches of the inflowing rivers. Water quality in the estuary basins improved due to an increase in mixing and decrease in residence times. Other notable changes were the absence of *Nodularia* blooms since the opening of the channel, an increase in water clarity, a change in substrate from mud to sand and a significant change in biota with an increase in diversity and abundance of fish with marine affinities. An increase in mosquito numbers was noted that was attributed to increased micro-flooding caused by increased tides and some shoreline erosion was observed in sections of the estuary. More importantly, some problems continue to persist, as there has been little change in the inflows of nutrients from the catchment (Turner *et al.* 2004).

2.4 Impacts of a Second Entrance to the Gippsland Lakes

Some clues to the possible environmental impacts of a second entrance into the Gippsland Lakes can be gleaned from the above, however these relate to environmental effects only. In reality, a second entrance into Gippsland Lakes would need to consider a suite of other potential issues such as socio-economic impacts and the impact on coastal processes.

Potential benefits of a second entrance may include:

- improved oxygenation of waters by increased mixing,
- increased flushing of nutrient rich water,
- reduced stratification,
- inhibition of algal blooms (specific to *Nodularia*) due to elevated salinity,
- an increase in seagrass cover

Potential impacts of a second entrance could include:

- a change in salinity that may affect spawning of fish that rely on a particular range of salinity to spawn successfully eg bream
an increase in species with marine affinities at the expense of brackish and estuarine species,

- an increase in tidal range and current strength could reduce access to popular recreational boating areas such as Bunga Arm, and result in erosion of the shoreline and low lying islands in the immediate vicinity of the entrance.

In recognising the potential benefits of a second entrance in reducing the frequency and severity of algal blooms, the GLES also recognised the potential associated risks, costs and limitations:

“Although the second entrance appears to be superficially attractive in terms of water quality indicators in Lakes Victoria and King, it would have little or no beneficial effect on L. Wellington, would involve a very substantial capital outlay, and probably considerable ongoing expenditure to maintain dredged channels. ... Due consideration would need to be applied to all other major environmental consequences of a likely increased salinity regime in the Lakes and conjunctive waterways including the potential impacts on the flora, invertebrates, fish and birds. Similarly, turning the Lakes fresh would cause major ecological changes .... (which) would need to be evaluated by the affected communities and environmental managers very carefully if this strategy were to be considered” The Study also acknowledged uncertainties surrounding the salinity tolerance of *Nodularia*, and the limitations of the modelling undertaken as part of the Study, particularly of vertical mixing.

Further investigation of the benefits, impacts and risks of a second entrance is the focus of the current study, and is discussed further in subsequent chapters.
3. **The Values of the Gippsland Lakes**

3.1 **Introduction**
An overview of the existing environmental, social and economic values of the Gippsland Lakes (refer Figure 3-1) is presented in the following sections.

3.2 **Environmental**

3.2.1 **Wetlands**
In addition to the estuarine lagoons, the Gippsland Lakes have a number of fringing freshwater wetlands, salt marshes, river deltas and embayments, which have been classified as nationally significant Ramsar sites (DSE 2003). These areas provide a diversity of habitats for many fauna species and in particular, waterbirds, which are one of the most important components of a Ramsar wetland ecosystem (Parks Victoria 1998).

Nearly one-third of the bird species found in the region are totally or partially dependent on these wetlands (DPUG and DCE 1990) and the Gippsland Lakes support an estimated 4% of Victoria’s shorebird population (DSE, 2003).

The estuary and fringing wetlands that make up the Gippsland Lakes are productive ecosystems. These areas contain important remnants of original vegetation which are important for the conservation of native fauna, particularly waterbirds and fish. The wetlands also contain sites of State and Regional geological and geomorphological significance and the National Trust of Australia classifies the Gippsland Lakes as a significant regional landscape.

Wetlands provide foraging and nursery habitat for many fish, crustaceans and molluscs, including species of commercial and recreational value. Not only are wetlands critical to Australia's fishing industries but they are also important feeding, breeding and roosting areas for waterbirds, including migratory species, and provide refuge for inland species in times of drought.

Additional values provided by wetlands and estuaries include: groundwater recharge; water storage and flood mitigation; water purification (including denitrification); shoreline stabilisation and storm protection; nutrient and sediment retention and export; and tourism and recreational amenity (DCNR 1995).
The wetlands and freshwater marshes of the Gippsland Lakes contain significant and varied vegetation communities. A number of projects are currently being undertaken in the wetlands including wetlands fringing Lake Wellington. These include vegetation surveys and mapping, development of an Index of Wetland Condition and assessment of the ecological condition of Dowd’s Morass.

3.2.2 Estuarine Systems

Prior to the creation of a permanent entrance at Lakes Entrance in 1889, the Gippsland Lakes were an intermittently open system of brackish lakes. The permanent entrance resulted in an increase in salinity, particularly in the lower lakes and a reduction in water levels and annual water fluctuations. The increase in salinity has led to a loss of freshwater reed beds and melaleuca
swamps and an expansion of mangrove areas, which are intruding, into areas of saltmarsh (Turner et al 2004).

The changes in salinity, oxygen and temperature levels have resulted in a change of faunal species composition and in the presence and distribution of aquatic flora, including seagrass and reeds (Bird 1993). The distribution of seagrass within the Gippsland Lakes has varied significantly throughout this century. Natural events have caused either an increase or decrease in the abundance and distribution of the species of seagrass meadows (Roob and Ball 1997). Seagrass is an ecologically significant marine habitat, which serves as a nursery area for juvenile marine fauna as well as providing food and shelter. Seagrass meadows provide important habitat for fish and some juvenile species such as mullet, tailor, bream and flathead. The most recent survey of seagrass in the Gippsland Lakes by Roob & Ball (1997) found that 8.5% of the total area of the Lakes was vegetated with seagrass. Most of the seagrass occurs east of Sperm Whale Head, with the majority occurring along the nearshore areas of Lake King. The most abundant form of seagrass is *Zostera* spp. accounting for 66% of total cover while *Ruppia spiralis* accounted for less than one percent. A further 31% consisted of a combination of mixed species. Twenty eight percent of the seagrass was also covered by epiphytic filamentous algae. Some species of epiphytic algae grow in direct response to elevated nutrients in the water column.

Previous studies of the benthic communities in the Gippsland Lakes (Poore 1982) confirmed the presence of an extremely diverse and abundant infauna that was dominated by polychaetes, molluscs and crustaceans. These infaunal species are particularly important as dietary items for many of the fish species in the Gippsland Lakes including black bream (Longmore et al 2001).

At least 29 species of estuarine resident fish use the Gippsland Lakes as spawning and nursery grounds, including five species of economic significance; these include black bream, yellow-eye mullet, dusky flathead, southern sea garfish and luderick. Two marine resident species of commercial significance; sandy sprat and southern anchovy, also use the estuary as a nursery ground (Strong & Malcolm, 1996 in Roob & Ball 1997).

Black bream is an important species that forms the basis of a substantial commercial and recreational fishery. A recent review of literature and research into black bream (Norriss et al 2002) has identified that separate stocks reside within each estuarine system and there is considerable variation in feeding and growth of fish. For estuaries and rivers that are seasonally flushed in winter, downstream movement with the flush is followed by the annual upstream spawning run located near the encroaching salt wedge in spring or early summer. Spawning in the Gippsland Lakes is generally in late October and November but can be extended as late as March. The cues for successful spawning remain poorly described however research from other estuaries indicates that spawning is restricted by the seasonal fluctuation in the fresh water flow rate of rivers.
3.3 Socio-Economic

The Gippsland Lakes provides significant recreation and amenity values to residents and a large number of holiday-makers. Other values of the Lakes include commercial values associated with fishing, and aesthetic values to neighbouring property.

Provided below is a brief discussion on the socio-economic values of the Gippsland Lakes, with particular attention to:

- Recreation and tourism values
- Aesthetic and amenity values
- Commercial fishing values.

3.3.1 Recreation and tourism

It is estimated that the total number of visitor nights in selected towns around the Gippsland Lakes is approximately 3.4 million per annum (URS, 2004), comprising visitors staying in:

- Hotels and commercial camping sites
- Non-commercial camping sites
- Holiday houses
- Yachts and cruisers, and
- Visitors staying with friends.

In addition to overnight visitors, a survey by the Bureau of Tourism Research (2001 in URS, 2004) indicates that there were 494,000 domestic day trip visitors to the Lakes and Wilderness Region in 2001, of which 22% originated from Melbourne and 71% from regional Victoria.

A range of visitor activities takes place in and around the lakes, including:

- Camping
- Picnicking
- Fishing
- Swimming
- Boating and water-skiing
- Sailing
- Horse riding
- Walking
- Hunting (Wild Duck, Stubble Quail and Hog Deer may be hunted in season)
- Bird watching
Whilst picnicking is available throughout the Coastal Park and surrounds, camping is available at a number of commercial and non-commercial camping sites, and sites accessible by boat at Bunga Arm.

Swimming occurs along the sheltered lake shores as well as Ninety-mile beach, whilst water-skiing is popular in designated areas. Fishing occurs throughout the lakes from boats, banks or jetties, with the main fish caught being bream, flathead, Skip Jack, Luderick and Mullet (Parks Victoria, 2005). Boat ramps providing access to the Lakes and jetties providing access to the Coastal Park are available at a number of locations. Paynesville is a very popular location for boating and water skiing, and hosts the Australian Powerboat Racing Championships each Easter.

In July 2004, URS produced an assessment of the economic impact of the Central Gippsland Water Quality Management Plan for the West Gippsland Catchment Management Authority. It was found that the impact of algal blooms on recreation and tourism values is not clear-cut, with the following information noted:

- Regional data (that includes areas outside of the Gippsland Lakes) does not show a discernible difference in tourist numbers in bloom and non-bloom years. This indicates that other factors (e.g. weather) may have a greater influence on tourist numbers. Alternatively, it may also suggest that visitors have adjusted to recent algal bloom events and have a general expectation that an algal bloom event may/will occur.
- Some tourism operators note an immediate change in bookings following the warning of algal blooms, others no change.
- Nearby substitute sites are available at areas not affected by algal blooms, such as Lake Tyers Beach and Ninety-Mile Beach.

3.3.2 Aesthetic values
The Gippsland Lakes provides picturesque views for local residents and visitors. The waters adjacent to Paynesville, in particular, provides significant aesthetic values, given the site provides shelter for the mooring of hundreds of boats, and has a canal system for expensive waterfront homes and other accommodation (URS, 2004).

A study of the economic impacts of a change in water quality of the Gippsland Lakes (URS, 2004) estimated that:

- Lake King North (including Eagle Bay, Jones Bay, Swan Reach Bay, Tambo Bay, Paynesville, and waters off Raymond Island to the north and west) has approximately 200 landholders whose amenity may be affected by a change in water quality, based on aerial photos.
- Lake King South (including Metung, Reeve Channel to Lakes Entrance, Bunga Arm, Wollaston Bay, and waters south of Raymond Island including Newlands Arm) has
approximately 200 landholders whose amenity may be affected by a change in water quality, based on aerial photos.

- Lake Victoria (Loch Sport) has approximately 70 landholders whose amenity may be affected by a change in water quality, based on aerial photos.
- Lake Wellington has approximately 10 foreshore residences whose amenity may be affected by a change in water quality, based on CFA maps.

Freehold land is also situated near the site of the second entrance, at Ocean Grange, Steamer Landing, and on the peninsula opposite the second entrance channel to Sperm Whale Head (pers. comm., Rodger Grayson, 30/3/2005).

3.3.3 Commercial
Apart from revenue to tourist operators, the Gippsland Lakes also provides significant revenue to the local commercial fishing industry. A variety of species are caught in the Lakes, with the main commercial returns provided by catch of Black Bream, European Carp, Tailor, Yellow-eye Mullet and other species, providing a total catch value in the order of $2 million in recent years (Fisheries Victoria, 2003).

The total catch value of the Gippsland Lakes and Lake Tyers, and the proportion of the most valuable species, Black Bream and European Carp, is shown in Figure 3-2. As demonstrated by the chart, Black Bream has provided the majority of commercial returns up until the most recent year shown (2002-03).

In 2002-03 and 2003-04, the catch of Black Bream in the lakes system declined substantially, leading to interim increased size limits to protect remaining adult stocks (Fisheries Victoria, 2005). Other protection measures include reduced bag limits for recreational fishers, and commercial operators setting their nets further away from the mouths of rivers and creeks during the remainder of the 2003/04 bream spawning season (Fisheries Victoria, 2004). Whilst the reasons for the decline are not clear, they are suggested to include changes to the environment of the Lakes system leading to either declined spawning success or survival.
3.3.4 Other values

Other values of the Gippsland Lakes, as ascribed by in the Strategic Management Plan for the Gippsland Lakes Ramsar Site (DSE, 2003), include:

- Cultural heritage, and
- Education and interpretation

Cultural heritage sites, in the form of numerous aboriginal midden sites containing shellfish remains, charcoal and burnt pebbles (Parks Victoria, 2005), also form part of the socio-economic values present within the Coastal Park. Whilst some information is available, the cultural heritage values within the study area are yet to be fully assessed (*pers. comm.*, M. Phelan, Aboriginal Affairs Victoria, 3/6/2005).

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**Figure 3-2** Catch value ($ 000) for Gippsland Lakes and Lake Tyers. Source: Fisheries Victoria, *Commercial Fish Production Information Bulletin 2003*
4. **Existing Hydrodynamic and Water Quality Conditions**

4.1 **Introduction**
This section provides an overview of existing hydrodynamic and water quality conditions in the Gippsland Lakes.

It includes a description of numerical hydrodynamic modelling of the existing conditions within the Gippsland Lakes, further details of which are provided in Appendix C. It provides details of the hydraulic model parameters and a description of typical tidal conditions throughout the system.

It also includes discussion of catchment inputs to the Lakes, and the causes and current incidence of algal blooms in the Lakes.

4.2 **General Considerations**
The Gippsland Lakes are a series of large, shallow, coastal lagoons approximately 70 km in length and 10 km wide. They are connected to the ocean (Bass Strait) by a narrow, maintained man-made channel at Lakes Entrance. The surface area of the lakes is approximately 364 km² and the three main water bodies are Lakes Wellington, Victoria, and King. Lake Reeve, adjacent to the coastal dune of Ninety Mile Beach, has an area of approximately 50 km², but it is not tidal and usually dry except following periods of high rainfall and/or flooding in the lakes.

Mean water level in Lake King and Lake Victoria correlates with the mean water level in Bass Strait on moderate time scales (1 week or more). These variations are in response to the effect of longer period changes in atmospheric pressure on water level and storm event set up (or set down) of the water level. The resulting longer term variation in water levels dominates the observed pattern of water level variation throughout the lakes and can result in mean water level variations within the lakes of up to 1m over a period of 1-2 weeks. The tidal range in the lakes is small (order of 15 cm) and is superimposed on this longer period water level variation.

4.3 **Hydraulic Parameters**

4.3.1 **Bathymetry**
The bathymetry for the model has been derived from a comprehensive digital elevation model developed by Centre for Environmental Applied Hydrology at the University of Melbourne (Wealands et al., 2002), bringing together a number of survey data sets for the lakes system. The bathymetry for the model is shown below in Figure 4-1 Existing Conditions – Bathymetry, with further detail shown in Figure 4-2 Existing Conditions – Bathymetry Detail at Lakes Entrance and Figure 4-3 Existing Conditions – Bathymetry Detail at Ocean Grange.
Figure 4-1 Existing Conditions – Bathymetry

Figure 4-2 Existing Conditions – Bathymetry Detail at Lakes Entrance
4.3.2 Tidal Levels

Typical tidal variations at key locations throughout the Gippsland Lakes system are shown in Figure 4-4 (source: Centre for Applied Environmental Hydrology, University of Melbourne). This variation is typical, and occurs superimposed on longer term variations in mean water level.

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**Figure 4-3 Existing Conditions – Bathymetry Detail at Ocean Grange**

**Figure 4-4 Existing Conditions – Tidal Variation**
Figure 4-5 below shows maximum and minimum water levels throughout the lakes associated with mean spring tidal conditions. Again, it should be noted that these levels are typically superimposed on longer term water level variations.

**Figure 4-5 Existing Conditions – Mean Spring Tide Maxima and Minima**

### 4.3.3 Tidal Range

The mean spring tidal range for existing conditions is illustrated in Figure 4-6.
Note that at Lakes Entrance, in Cunninghame and North Arm, the tidal range is about 0.8-1.0 m, and this quickly reduces to less than 0.20 m at Metung. The entrance channel, Reeve and Hopetoun channels are reasonably shallow and constricted and result in significant attenuation of the tidal signature. Moreover, the area of the lakes is such that the volume of water that can pass through these entrance channels once distributed results in a small change in water level.

**4.3.4 Tidal Velocity**

Figure 4-7 shows peak tidal velocity for mean spring tidal conditions. Typical mean spring tidal peak velocities up to 1.5 m/s are observed in the entrance channel, with velocities up to 0.5 m/s observed in Reeve and Hopetoun Channels.
Other areas where the existing condition tidal velocity is elevated include around the end of the Mitchell River silt jetties (up to 0.15 m/s) and throughout McLennan Strait (up to 0.25 m/s).

4.4 Water Quality

4.4.1 Catchment Inputs

The Gippsland Lakes and Catchment Task Force recently commissioned the State of the Gippsland Lakes report which provides an update of the condition of the Gippsland Lakes since the CSIRO Gippsland Lakes Environmental Audit was released in 1999 (CSIRO, 1999). The State of the Gippsland Lakes report (SKM, 2004), contains information on catchment inputs and the influence these have on the health of the Lakes and the condition of the fringing wetlands. Some of this information has been used as the basis for the review presented below.

Since European settlement impacts from the upstream catchments have had an effect on inputs to the lakes through changing land use. Historical clearing of native vegetation, farming and past goldmining in the upper catchments of the main rivers influence water quality in the Gippsland Lakes. These land use changes, diversions of surface water and construction of dams have resulted in changes to the natural hydrology of waterways and the flooding regime of the wetlands and led to increases in saline water, nutrients and sediment to the lakes. Around the lakes, human activities such as urban development have increased shoreline erosion and reduced fringing vegetation.

Fresh water enters the lakes from six major river catchments: the Tambo, Mitchell, Avon, Latrobe, Thomson and Nicholson, which drain a catchment area of 20,600 km² (CSIRO 2001). These rivers are the main source of nutrients and sediments into the Lakes and are key determinants of the hydro-dynamics of the system. Freshwater from rivers flushes the lakes but salinity stratification can occur within the deeper basins. This stratification has implications for anoxia in sediments and sediment nutrient release. Water quality concerns such as high sediment and nutrient loads to the lakes from run-off events in the catchment, recurring blue-green algal blooms and long periods of bottom water hypoxia combine to make the lakes susceptibility to eutrophication (CSIRO, 2001).

The major rivers flowing into the Gippsland Lakes (Latrobe, Avon, Mitchell, Nicholson and Tambo) provide about 10 per cent of Victoria’s annual stream flow (Gippsland Coastal Board 1999). However, there is increasing evidence that the diversion and extraction of water from the rivers, especially the Thomson/Latrobe system, has had an impact on the ecology of the Gippsland Lakes in general, and Lake Wellington in particular (Gippsland Coastal Board 1999).

Lake Wellington is the shallowest lake with depths of 2-4 m. It is the freshest of the three lakes as it is fed by several rivers, the Latrobe, Thomson and Avon Rivers. Through bank erosion and erosion in its lower tributaries, the Latrobe River contributes several thousand tonnes of sediment into Lake Wellington each year. Many of these tributaries are heavily polluted as judged by national standards (DSE 2003). Consequently Lake Wellington receives large inputs of nutrients and is considered eutrophic by international (OECD) standards.
Compared to Lake Wellington, Lake Victoria and Lake King are more saline with depths of about 6-8 m, despite freshwater inflows into Lake King from the Mitchell, Tambo and Nicholson Rivers. However, due to their location and more marine nature, these lakes are not as severely affected by such large riverine nutrient inputs as Lake Wellington. EPA water quality records from the mid 1980’s show no marked decline in water quality in both these lakes (DSE 2003). Both lakes, however, are prone to stratification.

Nutrient and sediment loads calculated during 1995 –1999 from the western catchment flowing into Lake Wellington were greater than those from the eastern catchments which flow into Lake King. Lake Victoria and Lake King are not as severely affected as Lake Wellington due to their location and more marine nature.

Although river discharges into the Lakes show a seasonal pattern of low flows during summer and autumn and higher flows in winter and spring, a large proportion of the total flow is delivered in ‘events’ of relatively short duration. In most years, the western rivers (Latrobe, Thomson, and Avon rivers flowing into Lake Wellington) have a higher annual discharge than the eastern rivers (Mitchell, Nicholson and Tambo rivers flowing into Lake King). Fluctuations in nutrient and sediment loads tend to exhibit similar temporal behaviour to the river hydrographs (CSIRO 2001, and Grayson et al 2001).

The Thomson Macalister Environmental Flows Task Force was formed as a result of on-going concerns for the health of these rivers at the end of the original Bulk Entitlement process (Thomson Macalister Environmental Flows Task Force 2004). The Task Force has endorsed environmental flows studies conducted in 2002 and recommended an optimum flow regime for these rivers as the long-term target.

Conclusions and recommendations from the Thomson Macalister Environmental Flows Task Force (Thomson Macalister Environmental Flows Task Force 2004), suggest that the potential impacts of environmental flow options (compared to the current Bulk Entitlement flows) on current salinity levels is unlikely to result in any change in environmental condition in Lake Wellington or Dowd's Morass. Although there may be some positive benefits for migrating fish it is unlikely to be of any benefit to Black Bream populations in Lake Wellington and additional flows may allow for marginal increases in carp (Thomson Macalister Environmental Flows Task Force 2004). However, any of the flow scenarios presented apart from Bulk Entitlement flows may provide a significant opportunity for improvements in the management of Dowd's Morass and other wetlands in the lower Latrobe system and assist in halting the existing decline in wetland health.

4.4.2 Algal Blooms
The Gippsland Lakes are eutrophic by Organisation for Economic Co-operation and Development (OECD) standards and the frequency of algal blooms has increased since the 1970s as the nutrient load from the rivers has increased (Harris et al. 1998).
Algal bloom dynamics in the Gippsland Lakes are complex. Nutrient loads from the catchment are high enough to stimulate the growth of blooms but there is also a significant internal source of nutrients in the form of phosphorus and ammonia present in the sediments. Large blooms can be associated with major climatic patterns such as the southern oscillation index (ENSO) event (Harris et al. 1998). Smaller and more frequent algal blooms result from individual storms, river runoff and nutrient inputs into local bays and estuarine areas. The precise cause of each bloom is complex.

It is evident that nutrients in the surface waters of Lake Victoria and Lake King become depleted as a result of decaying algal growth, and that nutrients build up in bottom waters during stratified periods. Vertical mixing from wind and tidal mixing make these nutrients available for subsequent algal growth, which may stimulate the formation of a bloom.

Flood waters entering Lake King and Lake Victoria containing elevated nutrients, which then result in large transient blooms. Stratification and the lack of vertical mixing in the lakes create a positive feedback loop in which organic matter settling into bottom waters drives oxygen consumption and bottom water hypoxia. This leads to a shut down of the denitrification process and to a release of ammonia and phosphate into the water column which sustains further phytoplankton growth (Webster et al. 2001).

Longmore et al. (2001) also noted a probable link between an increase in algal biomass in the water column and nutrient release from the sediments; however, it was unclear which part of the process was the driving factor. Grazing by zooplankton was also an important control of chlorophyll biomass. The study by Longmore et al. (2001) attempted to develop the capacity for predicting blooms of blue-green algae (BGA) in the Gippsland Lakes by assessing links between external nutrient inputs, benthic nutrient fluxes and algal growth.

The floods in June 1998 and the subsequent sequence of events are shown on the flowchart in Figure 4-8. To summarise, the floods introduced high concentrations of oxidised nitrogen in the form of nitrate (but not ammonium or reactive phosphate) to surface waters. This stimulated algal growth, leading to large increases in biomass within 4–6 weeks. Over the next 6 weeks, algal cells settled from the water column and were recycled, resulting in anoxic conditions leading to large increases in ammonium and phosphate concentrations (Longmore et al. 2001).

The 1999 Nodularia Bloom
The 1999 bloom was first observed by Longmore et al. (2001) in southern Lake King and Reeve Channel on 5th February 1999, and spread westward over the next 2 weeks to Waddy Point. The bloom persisted until the 12th March when it began to die off which also coincided with a drop in temperature and increase in bottom water salinity. The waters of the Lakes were clear by April.
Prolonged Drought - Lakes Saline & Well Mixed

Major Rain Event - June 1998

Pulse of N (Nitrate) & Other Growth Promoters Enter Lakes

Major Dinoflagellate/Diatom Bloom - July/August 1998

Depletion of Nitrogen in Surface Waters/Depletion of Bloom

Smaller Rain Event - September 1998

Salinity Stratification, Increased Organic Load on Sediments from Senescing Bloom causing Anoxia

Anoxia in Bottom Waters, Release of Phosphorus from Sediments and Senescing Bloom

Strong Winds in December 1998, mixing of Nutrient Rich Bottom Waters with Warmer Surface Waters in Euphotic Zone

Low N + High P + Warm Water + Low Salinity

*Nodularia* Bloom January-March 1999

- Figure 4-8 Events Leading to a BGA Bloom in the Gippsland Lakes (EPA, 2004)
The 1999 *Nodularia* bloom most likely germinated in shallow areas of Lake King (e.g. Jones Bay), where pore water ammonium concentrations and bottom water salinity were low during February, when water temperature was above 20°C. Ammonium concentrations in sediments elsewhere in Lakes King and Victoria were probably so high that they inhibited germination (Longmore *et al.* 2001).

Conditions believed to promote prolific growth of *Nodularia* akinetes (resting cells) include:

- salinity <20 PSU;
- temperature >16°C;
- phosphate concentration >0.3 µM;
- ammonium concentration >40µM; and
- incident light >0.4µEi m²/s (PAR).

These findings were based on research undertaken in the Peel Harvey estuary in Western Australia.

It is also worth noting that the initial algal bloom that occurred in July 1998 was a dinoflagellate bloom (not a BGA bloom) that affected much of Lake Victoria and Lake King. The bloom did not cause any surface scums but did result in discolouration of the water (EPA 2004).

Longmore *et al.* (2001) noted that Jones Bay, and shallow parts of northern Lake King, were the areas where both salinity and ammonium concentrations were suitable for promoting germination. Even when suitable conditions present themselves, there is no guarantee that a bloom will occur.

More recent research on the conditions influencing the germination and growth of *Nodularia spumigenia* in the Gippsland Lakes has been undertaken by Holland & Beardall (2004) but the findings were not available for this draft report.

**Frequency of Blooms**

The EPA (2004) has documented all reports of algal blooms in the Gippsland Lakes between 1965 and 1997 and these have been summarised in Table 4-1 Algal Blooms Recorded in Gippsland Lakes 1965-1999. Large scale blooms of the toxic, blue-green alga *Nodularia spumigenia*, have occurred about every 10 years although other bloom species also occur frequently. The blue green algae *Mycrocystis* and *Anabaena* are potentially toxic and have also been recorded from the Gippsland Lakes.

It should be noted that the dates indicated in Table 4-1 Algal Blooms Recorded in Gippsland Lakes 1965-1999 represent the date the blooms were reported, not necessarily when they started. All of the blooms documented were usually preceded by periods of high rainfall and flooding, with a time...
lag of 6 months or more between the rain event and the resultant major bloom. The EPA (2004) postulated that major rainfall events drive the cycle of algal blooms in the Gippsland Lakes system. The URS (2003) report attempted to estimate the frequency of algal blooms per 10 year period but cautions that the forecasts should be viewed as indicative estimates of potential numbers. It is unclear how the forecasts were derived but it is assumed they are based on frequency of previous occurrences. According to their estimates, Lake King would expect 64 weeks, Lake Victoria would expect 48.5 weeks and Lake Wellington 8.6 weeks of algal blooms over the next 10 years. The study confirms that Lake King and to a lesser degree, Lake Victoria is most susceptible to blooms.

- **Table 4-1 Algal Blooms Recorded in Gippsland Lakes 1965-1999**

<table>
<thead>
<tr>
<th>Period</th>
<th>Bloom Type</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 1965</td>
<td>Nodularia</td>
<td>Lake Wellington</td>
</tr>
<tr>
<td>March 1971</td>
<td>Microcystis</td>
<td>Lake Wellington</td>
</tr>
<tr>
<td>May 1971</td>
<td>Dinoflagellate Bloom</td>
<td>Lake King</td>
</tr>
<tr>
<td></td>
<td>Diatom/Nodularia</td>
<td>Lake Victoria</td>
</tr>
<tr>
<td></td>
<td>Diatom/Nodularia</td>
<td>Lake Wellington</td>
</tr>
<tr>
<td>February 1974</td>
<td>Nodularia</td>
<td>Lake King</td>
</tr>
<tr>
<td>October 1984</td>
<td>Unspecified bloom</td>
<td>Lake Victoria</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lake Wellington</td>
</tr>
<tr>
<td>January 1986</td>
<td>Anabaena</td>
<td>Lake King</td>
</tr>
<tr>
<td>February 1987</td>
<td>Nodularia</td>
<td>Lake King</td>
</tr>
<tr>
<td>August 1987</td>
<td>Unspecified bloom</td>
<td>Lake Victoria</td>
</tr>
<tr>
<td>December 1987</td>
<td>Nodularia</td>
<td>Lake Victoria</td>
</tr>
<tr>
<td>December 1988</td>
<td>Dinoflagellate Bloom</td>
<td>Lake Victoria</td>
</tr>
<tr>
<td>July 1989</td>
<td>Nodularia</td>
<td>Gippsland Lakes</td>
</tr>
<tr>
<td>December 1989</td>
<td>Nodularia</td>
<td>East L Victoria</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South L King</td>
</tr>
<tr>
<td>July 1990</td>
<td>Unspecified bloom</td>
<td>North L King</td>
</tr>
<tr>
<td>September 1990</td>
<td>Unspecified bloom</td>
<td>South Lake King &amp; Lake Victoria</td>
</tr>
<tr>
<td>January 1993</td>
<td>Microcystis</td>
<td>Jones Bay/Lake King</td>
</tr>
<tr>
<td>January 1996</td>
<td>Unspecified bloom</td>
<td>Lake Victoria</td>
</tr>
<tr>
<td>May 1996</td>
<td>Nodularia</td>
<td>Lake King</td>
</tr>
<tr>
<td>February 1997</td>
<td>Nodularia</td>
<td>Lake King</td>
</tr>
<tr>
<td>January 1999</td>
<td>Nodularia</td>
<td>Lake King (South)</td>
</tr>
</tbody>
</table>

More recently, the frequency and occurrence of algal blooms within the Gippsland Lakes has been summarised in SKM (2004) for the Gippsland Lakes Catchment Taskforce. Between 2000 and 2003, there were localised occurrences of blue green algae in arms and backwaters of the Lakes and high alert levels of *N. spumigenia* and *Pseudonitzchia pseudodelicatissima* in Lake King.

Significant blooms occurred in Lake King during 2001 and in Lake King and Lake Victoria during 2002. In February 2002, there was a ban on prawn and mussel harvesting in the Lakes due to the occurrence of *P. pseudodelicatissima* which can cause amnesic shellfish poisoning (ASP).

The most recent outbreak of *N. spumigenia* was recorded from Eagle Bay in May 2002 (SKM 2004).

**Areas Affected By Blooms**

Table 1 shows that between 1965 and 1999, there were 11 algal blooms recorded from Lake King, nine algal blooms were recorded from Lake Victoria, while only 4 blooms were recorded from Lake Wellington.

The data also indicate where the blooms were recorded but not necessarily their point of origin eg, the likely origin of the 1999 bloom was Jones Bay in the northern section of Lake King, even though the areas most affected were Metung and the southern section of Lake King.

**Conclusions**

- The Gippsland Lakes are susceptible to eutrophication because of a number of factors including poor flushing, high nutrient loads per unit volume of receiving water and vertical salinity stratification.
- Algal blooms have the potential to occur all year round, but tend to occur in autumn/late summer when long, dry periods with low river flows during winter are followed by calm conditions conducive to stratification. Blooms sometimes also follow major rain events and floods in spring which are accompanied by high nutrient loads from the catchments.
- Large scale blooms of the toxic, blue-green alga *Nodularia spumigenia*, have occurred about every 10 years, although blooms of unspecified algal species including dinoflagellates and diatoms occur more often.
- Most *Nodularia* blooms have been recorded from Lake King.
- High concentrations of nutrients in the water and sediments of the Lakes together with elevated temperature and low salinity, provide the conditions conducive to the formation of algal blooms.
4.4.3 Water Quality Modelling
Existing water quality characteristics in the Gippsland Lakes system have been quantified by modelling in terms of hydraulic flushing and saline recovery.

Hydraulics flushing provides an assessment of the predicted residence time for the lakes and relates to the rate at which water within the lakes system is replaced with river or ocean water. Saline recovery provides an assessment of the rate at which the system returns to typical saline conditions following a moderate rainfall/runoff event where the salinity of the lakes has been significantly reduced from typical levels. Both assessments provide valuable insight to the hydraulic exchange mechanisms operating in the lakes.

Hydraulic Flushing
To conduct this assessment, the initial concentration of a conservative water quality constituent is set to 1,000 mg/L, with boundary condition concentrations set to 0 mg/L for all river inflows and ocean water. The simulation proceeds for a period of 60 days with results extracted at key locations throughout the system.

Boundary conditions for the simulation are representative of environmental conditions during the period 01/04/2000-31/05/2005. This is a typical dry period with low river inflows to the lakes. The model includes variable winds for this period based on data from Sale airport.

Figure 4-9 presents curves representing the reduction in the introduced water quality constituent resulting from hydraulic flushing.

These model results indicate very long hydraulic residence times throughout the lakes. In Lake Wellington concentrations reduce to around 85% in 60 days, due primarily to dilution from inflows from the Latrobe and Avon Rivers. In 60 days the concentration in Lake Victoria have not changed from the original concentration as high concentration water from Lake Wellington flows into Lake Victoria and there is no discernible ocean exchange. Similarly there is no significant reduction in concentrations in the Bunga Arm. In Lake King concentrations reduce to around 85% in 60 days, due primarily to dilution from inflows from the Mitchell and Tambo Rivers as well as some limited ocean exchange. At Metung, the effect of ocean exchange is more apparent with variations in concentration of up to 20% of original concentration over a tidal cycle. Flushing at Lakes Entrance is reasonably rapid due to its proximity to the ocean, with concentrations quickly reducing to low levels. Higher concentrations are noted on the ebbing tide as water of high concentration is transported towards the entrance.
The Gippsland Lakes Environmental Study undertook similar assessments of flushing due to combined tidal exchange and catchment runoff. Rather than median flows (adopted during this study), the GLES model determined flushing time using actual flows, beginning July 1997. Using constant median flows was adopted as a conservative approach to determining flushing times, independent of moderate flood events.

The river inflow boundary conditions used in the GLES model flushing simulations (July and August 1997) are presented in Figure 4-10 below. Note that the flow conditions at the start of the simulation period coincide with relatively high flows in the Latrobe, Avon and Mitchell Rivers.

Use of these relatively high flow conditions at the start of the simulation resulted in the reduction in pollutant concentrations in Lake King to around 50-60% of the original concentration in 60 days. These GLES simulations resulted in flushing rates about twice those determined in this study using median flows.

During the middle part of the GLES simulation, river inflows returned to approximately median flow rates (Tambo 2.40m³/s, Nicholson 0.21m³/s, Mitchell 9.29m³/s, Avon 0.78m³/s, Latrobe 17.46m³/s) and the flushing dropped to rates consistent with the present study. As such, although slightly different methodologies were adopted, flushing rates determined during this study are considered consistent with those modelled by CSIRO during the Gippsland Lakes Environmental Study.
Figure 4-10  Gippsland Lakes Rivers – Flow Conditions July-August 1997
Extrapolating the 60 day modelling indicates that Lake King has residence time in the order of 6 months for dry periods. Residence times in Lake Wellington are of the order 12 months. The results highlight the lengthy residence times that exist in the lakes system and the corresponding limited capacity of the system to flush pollutants derived from the catchments.

Saline Recovery
For this assessment, a low initial concentration of salinity of 10 g/L was specified throughout the lakes representative of conditions following a moderate flood event.

Boundary conditions for the simulation are representative of median stream flows for the rivers and a mean spring tide for the ocean boundary. A constant wind of 5 m/s from the WSW is applied and there is no rainfall throughout the simulation period. These characteristics are representative of typical dry weather conditions and have been applied to illustrate an “average” saline recovery capacity.

Figure 4-11 shows the extent of saline recovery throughout the lakes at high water on day 60 of the simulation.
External exchange of lake water with the ocean is limited primarily to those areas within the region of tidal excursion, from Lakes Entrance to around Bell Point. Beyond this, internal circulation processes (wind driven or related to the jetting of river inflows) and diffusion dominate the saline recovery processes. Other mixing processes such as wind-wave induced and density related mixing will further enhance saline recovery; however, these processes are not represented in the model. Nevertheless, the model results provide a useful tool for the analysis of the existing ocean exchange mechanisms suitable for subsequent impact analysis.

Discussion
Hydrodynamic processes in Gippsland Lakes are highly dependent on forcing characteristics of ocean water levels, river inflows, local rainfall and wind. During dry periods, the mean water level in the lakes follows mean water level in the ocean, which can be as much as 1.0 m change in mean water level over periods of a week or more. On timescales of a tidal cycle (approx 24 hours) water levels in the lakes are reasonably constant and vary locally due to wind stresses over a range greater than the observed tidal range.

The system exhibits poor hydraulic flushing with lengthy residence times. This results in a limited capacity to flush pollutants derived from the catchments out of the system.
5. Potential Second Entrance Configurations

The second entrance option investigated in Stage 1 of the project was based on the option considered by CSIRO in its 2001 study. This comprised an entrance with similar dimensions to the existing channel at Lakes Entrance, sited at Ocean Grange (refer Figure 5-1). Detailed hydrodynamic modelling of this option was undertaken, and this is described in Chapter 6. The likely impacts of this configuration on the frequency and severity of algal blooms is also documented in Chapter 6. In summary, it was concluded that whilst this configuration would be likely to improve water circulation and tidal flushing in the central section of the Lakes, the areas most susceptible to algal blooms such as Jones Bay and the shallow parts of northern Lake King, were likely to be largely unaffected.

![Figure 5-1 Potential Second Entrance Sites](base map from Gippsland Lakes Boating Guide, Gippsland Ports Committee of Management Inc.)

These findings were used as a basis for selecting other second entrance options that could potentially have a more significant impact on the frequency and severity of algal blooms in the key areas of Jones Bay, and northern Lake King.

The Ocean Grange site investigated in the 2001 CSIRO study, and again in Stage 1 of the current project, was selected because:

- This location provides the minimum distance between Bass Strait and the key algal bloom areas of Jones Bay and Lake King. A second entrance at this location would thus be likely have the maximum impact on algal blooms in the Lakes; and
- There is only a relatively narrow strip of land separating the Lakes from Bass Strait at this location. This would potentially minimise the length of channel, and thus construction costs of a second entrance.
No other sites beyond the general vicinity of Ocean Grange offer (1) the same proximity to Jones Bay and northern Lake King, and (2) the relatively short length of channel required to connect the Lakes to Bass Strait. Other sites beyond this general vicinity are thus unlikely to be significantly more cost effective in reducing algal blooms.

Other options beyond the general vicinity of Ocean Grange that were considered in the current study included:

(a) Enlarging the existing channel at Lakes Entrance. This was investigated in the 2001 CSIRO study. It was concluded that even an augmentation that would result in a 50% increase in tidal range would only induce a small change in salinity and flushing, and would thus be unlikely to have any significant impact on frequency and severity of algal blooms in Lakes King or Victoria. These findings are consistent with those of the current study (refer Chapter 6) that impacts of a second entrance are likely to be generally localised, and thus unlikely to impact on the Lakes as a whole.

(b) A channel connecting Bass Strait to western Lake Victoria, near Loch Sport. This would be significantly more costly, due to the length of channel required. Any impact on algal blooms would be localised to western Lake Victoria, and thus remote from the key locations of Jones Bay and northern Lake King.

It was thus concluded that the only other second entrance site options with the potential to provide a more cost effective outcome than the Ocean Grange site were likely to be local variants of this option. On this basis, sites near Rotamah Island, and near the eastern end of Lake Reeve, were selected (refer Figure 5-1) for further consideration. At both these locations, as with Ocean Grange, only a relatively short channel would be required to connect the Lakes to Bass Strait.
6. Impacts of Second Entrance on Hydrodynamic and Water Quality Conditions

6.1 Introduction
This section describes investigation of hydrodynamic and water quality conditions that would be expected following construction of a second entrance to the Lakes. Hydrodynamic modelling has been undertaken for a second entrance at Ocean Grange. The results of this modelling have then been used to infer the likely impacts of similar second entrances at both the Rotamah Island and Lake Reeve sites (refer Figure 5-1).

6.2 General Considerations
The modified conditions for use in the hydrodynamic model have been developed based on the second entrance option considered by CSIRO in its 2001 study, at Ocean Grange. This option comprises an entrance channel similar in dimension to the existing entrance channel at Lakes Entrance, and the “dredging” of the Bunga Arm Channel to a depth of approximately -4.0 mAHD.

6.3 Hydraulic Parameters
6.3.1 Bathymetry
Changes to the model bathymetry for the development of the second entrance option include modifications to the computational mesh to represent an entrance channel similar in dimension to that at Lakes Entrance and dredging within the Bunga Arm Channel to a depth of approximately -4.0 mAHD. The bathymetry of the remainder of the model is identical to existing conditions presented in Chapter 4. Figure 6-1 shows bathymetric detail around Ocean Grange at the site of the proposed second entrance.
6.3.2 Tidal Levels
Typical tidal variation at key locations throughout the Gippsland Lakes system under the modified second entrance conditions are shown in Figure 6-2. This variation is typical, and occurs superimposed on longer term variations in mean water level.
Figure 6-2 Modified Conditions – Tidal Variation

Figure 6-3 shows maximum and minimum water levels throughout the lakes associated with mean spring tidal conditions for the second entrance option. Again, it should be noted that these levels are typically superimposed on longer term water level variations.
Figure 6-3 Modified Conditions – Mean Spring Tide Maxima and Minima
6.3.3 Tidal Range
The mean spring tidal range for second entrance conditions is illustrated in Figure 6-4.

- **Figure 6-4 Modified Conditions – Mean Spring Tidal Range**
  Note that at Lakes Entrance, in Cunningham and North Arm, the typical spring tidal range is about 0.60 m, and this quickly reduces to less than 0.20 m at Metung, consistent with existing conditions. However, in the Bunga Arm at Ocean Grange for the second entrance conditions, tidal range is around 0.60 m and this range reduces to less than 0.20 m at the Lake Victoria side of the Bunga Arm Channel.

6.3.4 Tidal Velocity
Figure 6-5 shows peak tidal velocity for mean spring tidal conditions for the second entrance option. Tidal velocities up to 1.5 m/s are observed in the entrance channel at Lakes Entrance, with velocities up to 0.5 m/s observed in Reeve and Hopetoun Channels, consistent with the existing conditions. In the Bunga Arm, Bunga Arm Channel and Grange Channel tidal velocities up to 1.0 m/s are observed.
Other areas where the existing condition tidal velocity is elevated (around the end of the Mitchell River silt jetties and throughout McLennan Strait) continue to exhibit higher tidal velocity characteristics.

6.4 Water Quality
Water quality characteristics in the Gippsland Lakes system for the second entrance option have been quantified in terms of hydraulic flushing and saline recovery similar to that presented for the existing conditions.

6.4.1 Hydraulic Flushing
As with the existing conditions simulations, in the second entrance option the initial concentration of a conservative water quality constituent is set to 1000 mg/L, with boundary condition concentrations set to 0 mg/L for all river inflows and ocean water. The simulation proceeds for a period of 60 days with results extracted at key locations throughout the system.

Boundary conditions for the simulation are again representative of environmental conditions during the period 01/04/2000-31/05/2005.

Figure 6-6 presents curves representing the reduction in the introduced water quality constituent resulting from hydraulic flushing with the second entrance in place.
- Figure 6-6 Modified Conditions – Hydraulic Flushing

- Figure 6-7 Comparison between Modified and Existing Conditions – Hydraulic Flushing
Figure 6-7 shows the difference in flushing characteristics at each location between existing conditions and conditions with the second entrance in place.

These model results indicate significantly altered hydraulic residence times throughout the central part of the lakes. In Lake Wellington, concentrations reduce to around 85% in 60 days, consistent with existing conditions. In 60 days the concentration in Lake Victoria has also reduced to around 85% of original concentration due to ocean exchange at Ocean Grange. Concentrations in the Bunga Arm reduce to about 38% of original concentration in 60 days. In Lake King concentrations reduce to around 67% in 60 days, due to combined dilution from inflows from the Mitchell and Tambo Rivers as well as ocean exchange via Ocean Grange. At Metung and Lakes Entrance flushing characteristics are similar to existing conditions. The results demonstrate the localised effect of the second entrance on flushing in the Bunga Arm and the central parts of Lakes Victoria and King.

6.4.2 Saline Recovery

For this assessment, a low initial concentration of salinity is specified throughout the lakes representative of conditions following a moderate flood event. Initial concentrations and boundary conditions for the second entrance option are identical to those for existing conditions. As well, boundary conditions for the simulation are equivalent to those of the existing conditions.

Figure 6-8 shows the extent of saline recovery throughout the lakes at high water on day 60 of the second entrance option simulation.

As well as exchange of lake water with the ocean through the entrance at Lakes Entrance, saline recovery is promoted in Lake Victoria from ocean exchange via the Ocean Grange entrance. For
both the entrances, the majority of the tidal exchange is limited to those areas within the region of tidal excursion, from Lakes Entrance to around Bell Point and from Ocean Grange to Aurora Channel.

6.5 Impact of Second Entrance
This section presents a comparison of the numerical modelling results for the existing and second entrance conditions. The impact of the second entrance on hydrodynamic and water quality processes is discussed.

6.5.1 Overview
This section presents the impacts or changes to existing conditions presented in Section 4.1 resulting from the introduction of a second entrance at Ocean Grange. The information is presented as difference plots, where an increase in a parameter is shown as a positive impact and a decrease in a parameter is shown as a negative impact.

6.5.2 Hydraulic Parameters
Bathymetry
Changes to the model bathymetry directly resulting from the construction of a second entrance option is confined to the entrance itself and dredging of the Bunga Arm Channel. The bathymetry of the remainder of the model is identical to existing conditions. Figure 6-9 shows changes to the bathymetric detail around Ocean Grange at the site of the proposed second entrance.
Figure 6-9 Impacts – Bathymetry Detail at Ocean Grange

This illustrates dredging required to create a channel from the lakeside of the second entrance through to Lake Victoria and Aurora Channel to a depth of approximately -4.0 m AHD. An estimated 350,000-400,000 m$^3$ of material will need to be removed from within the Gippsland Lakes, and this material could be re-used to create or enhance areas of intertidal habitat.

Tidal Levels

The change in mean spring tidal variation at key locations throughout out the Gippsland Lakes system resulting form the introduction of a second entrance are shown in Figure 6-10.
Figure 6-10 Impacts – Tidal Variation

Significant changes to tidal variation are apparent in the Bunga Arm whereas throughout the remainder of the system, the second entrance results in impacts to tidal range by less than 0.05 m.

Figure 6-11 and Figure 6-12 show the change to tidal maximum and minimum water levels, respectively, throughout the lakes associated with mean spring tidal conditions for the second entrance option.

Figure 6-11 Impacts – Change in Mean Spring Tide Maxima
The change in mean spring tidal range for second entrance conditions is illustrated in Figure 6-13.

At Lakes Entrance, in Cunninghame and North Arm, and in Lake Wellington, the impact to tidal range is negligible. However, the second entrance results in an increase in tidal range in the Bunga Arm of up to 0.8 m. In Lake Victoria and Lake King the second entrance results in an increase in tidal range of less than 0.1 m.
Tidal Velocity
Figure 6-14 shows the change in peak tidal velocity for mean spring tidal conditions resulting from the second entrance option. Increases in tidal velocities greater than 1.0 m/s are observed in the Bunga Arm, Bunga Arm Channel and Grange Channel.

Other areas where the existing condition tidal velocity is reasonably high (around the end of the Mitchell River silt jetties and throughout McLennan Strait) continue to exhibit higher tidal velocity characteristics.

6.5.3 Water Quality
Impacts to water quality characteristics in the Gippsland Lakes system for the second entrance option have been quantified in terms of changes to hydraulic flushing and saline recovery.

Hydraulic Flushing
Figure 6-15 shows the impact of the second entrance on hydraulic flushing.
Comparison of modified and existing conditions for hydraulic flushing indicates a significant increase in flushing in the Bunga Arm (60% better turnover in 60 days) than for existing conditions. In Lake Wellington, as the primary driver to flushing is the inflow of new water from the Latrobe and Avon Rivers, flushing characteristics are unchanged. Lake King and Metung show enhanced flushing (20% more flushing in 60 days) and Lake Victoria exhibits slight increases in flushing.

**Saline Recovery**

Figure 6-16 shows the change in saline recovery throughout the lakes for the second entrance option.
Figure 6-16 Impacts – Change in Saline Recovery

The second entrance results in a significant change in saline recovery in the Bunga Arm and neighbouring channels. Lake Victoria in the vicinity of the Aurora Channel also exhibits significantly modified salinity characteristics.

6.5.4 Discussion

The second entrance enhances ocean exchange in central Lake Victoria and Lake King. However, the tidal range in these areas is not significantly altered. The dominant hydrodynamic process continues to be mean water level in the ocean, and the impact of the second entrance on hydrodynamics of the central lakes will be negligible. Further, the second entrance will not result in any significant change to the lakes response to long term variations in mean ocean water level (which occurs over periods of a week or more).

The flushing and saline recovery of the central part of the lakes is enhanced by the second entrance. This will slightly improve the existing poor hydraulic flushing and increase the capacity to flush pollutants derived from the catchments out of the system.

However, the second entrance results in high velocities in the Bunga Arm and Grange Channels and a comparatively large tidal range in the Bunga Arm. The hydraulic characteristics in the Bunga Arm and around Ocean Grange resulting from the second entrance are similar to those currently observed at Lakes Entrance and the Cunninghame Arm. Bed sediment characteristics in the Bunga Arm and Grange Channel are currently likely to consist mainly of silty sands, which would easily be mobilised under the modified current regime and replaced with coarser beach sands.

It is recognised that the Gippsland Lakes system is often strongly stratified, particularly in the deeper sections of Lake Victoria and Lake King. Strong tidal currents have the potential to break
up stratification, but the area of increased tidal velocity resulting from the second entrance is confined to the Bunga Arm, Grange and Aurora Channels, and will have negligible influence on stratification in the bulk of the lakes. Moreover, the second entrance could result in stronger stratification (particularly in Lake King) as the enhanced ocean exchange will allow more saline water to enter the system.

The second entrance is likely to improve water circulation and tidal flushing in the central section of the Gippsland Lakes, however, areas most susceptible to algal blooms such as Jones Bay and the shallow parts of northern Lake King are likely to be unaffected by the second entrance. The blooms of blue green algae are likely to continue to occur, however they are less likely to impact southern areas of the Lakes, where the increase in tidal exchange will result in an increase in the flushing of nutrient rich waters. This should result in a decrease in the persistence of algal blooms, particularly in the southern sections of the Gippsland Lakes. The increase in salinity, due to the influx of oceanic waters will also act to inhibit the bloom of *Nodularia* but will have no affect on more saline tolerant phytoplankton species that are equally likely to bloom under favourable conditions.

### 6.5.5 Comparison with CSIRO 2001 Model

Results from the CSIRO modelling completed as part of the Gippsland Lakes Environmental Study have been compared with results from the current study. Key areas of comparison are existing characteristics and the impacts of the second entrance on:

- Water levels and Tidal Range
- Hydraulic flushing

#### Water Levels and Tidal Range

The CSIRO model indicates that the second entrance results in an increase in tidal range in the lakes, almost doubling the existing tidal range. In absolute terms this is an increase of about 0.10m of tidal range, consistent with the results of this modelling assessment, reported in Section 5.2.3 of Appendix C as a predicted increase in range of about 0.10m. Within the context of broader water level variations within this impact is small.

The CSIRO report does not document modelled impacts to water level and tidal range in the Bunga Arm and direct comparison cannot be made.

#### Hydraulic Flushing

Flushing of the lakes is enhanced by the introduction of a second entrance. In Lake King, CSIRO report approximate doubling in the flushing rate. The modelling undertaken for this study indicates slightly lower increases in flushing rate and is considered due to the more refined representation of the Bunga Arm and Grange Channels leading to the second entrance at Ocean Grange. In the
CSIRO model, these numerous channels are represented by a single 500m wide 4m deep channel, whereas in the RMA model, the dredged new channel exists only in the Bunga Arm Channel (refer to Figure 1-1 and Figure 5-1 in Appendix C for visual comparison). Accordingly, it is considered that the CSIRO model may somewhat overestimate the improved hydraulic performance of the lakes system resulting from the introduction of a second entrance.

Other characteristics modelled in detail in this study (eg velocity) cannot be directly compared with the CSIRO model due to significant differences in spatial resolution.

6.6 Other Considerations
Concurrent issues that would need to be addressed in detail should a second entrance option be considered include the following:

- The impact of the entrance on flooding in the Gippsland Lakes
- The design and impact of the second entrance and its impact on coastal processes along Ninety Mile Beach
- If the second entrance is to be a navigable channel, issues relating to navigation requirements (leads, lighting, tide and wave condition) and maintenance dredging would need to be addressed

6.6.1 Gippsland Lakes Flooding
Interpretation of modelling results suggests that, as a result of the second entrance, flood levels in Lake Victoria and Lake King would be slightly reduced, and that the period of inundation would also be reduced.

6.6.2 Coastal Processes
The second entrance as tested herein assumes a configuration similar in dimension and style to that at Lakes Entrance. The existing entrance suffers from extensive and almost continuous siltation from coastal sediments moving into the entrance channel and being deposited inside the entrance. A second entrance to the Gippsland Lakes on Ninety Mile beach, in the size and style of the existing entrance at Lakes Entrance would be expected to suffer from the same siltation problems resulting in significant maintenance requirements and/or the implementation of a sand bypassing system.

Numerous studies have investigated the sand transport regime along Ninety Mile Beach. However, the direction of net sand movement along the beach at Lakes Entrance is still not certain. A key similarity between the studies is that the gross transport was estimated at around 1 million m\(^3\)/year with the net transport typically less than 10% of this amount. The second entrance option
developed would need to incorporate a bi-directional sand-bypassing system to assist in preserving the longshore transport regime so as not to result in significant erosion of the adjacent beaches and minimise maintenance dredging requirements.

6.6.3 Navigation and Dredging

In order to be utilised for navigation, the second entrance would require maintenance dredging to preserve navigable depths. With appropriate design, the need for maintenance dredging of the second entrance could be significantly less than current requirements at Lakes Entrance. Nevertheless, from time to time maintenance dredging would be required to preserve navigability as well as to maintain a minimum cross sectional area to achieve desired flushing benefits.

At Lakes Entrance, the side-casting dredge *April Hamer* commenced operations in 1977. This sidecasting arrangement is still currently used to dredge the channel, predominantly across the bar, side-casting about 290,000 m³/year. Recent modifications to the dredging procedure have been introduced to better utilise the ebbing tide to move the sidecast sand. Nevertheless, the maintenance dredging cost is significant and is an ongoing burden for the Gippsland Port Authority.

To minimise the potential for dredging and siltation related issues at the second entrance, the actual configuration of the entrance may need to be quite different to that at Lakes Entrance. As well, a bi-directional sand-bypassing system would be required to assist in preserving the longshore transport regime so as not to result in significant erosion of the adjacent beaches.

An appropriately engineered entrance may result in reduced maintenance dredging requirements, but is likely to involved significant capital cost, of the order of $20 million. Due to reduced maintenance dredging requirements ongoing costs would be significantly less than those at Lakes Entrance (currently of the order of $2 million/year), perhaps of the order of $500,000/year.

6.7 Impacts of Second Entrance at Rotamah Island or Lake Reeve

The likely impacts of a second entrance at either of the other two sites considered, Rotamah Island and Lake Reeve (refer Figure 5-1), can be inferred from the hydrodynamic modelling results for the Ocean Grange site, and knowledge of the topography and bathymetry of the Lakes in the vicinity of the other two sites.

The hydrodynamic modelling shows that the impacts of a second entrance at Ocean Grange would generally be localised. Other than in Bunga Arm, and in Lakes Victoria and King within around 5 kilometres of the entrance itself, impacts on salinities, tidal velocities and water levels will generally be small. It can therefore be inferred that the impacts of a second entrance at either of the other two sites on salinities, tidal velocities and water levels, will also generally be localised, and any impacts on the wider lakes would generally be expected to be relatively small.
second entrance at either of these two sites on the frequency and duration of algal blooms in the wider lakes would be expected to be very similar to the impacts of an entrance at Ocean Grange (refer Section 6.5.4).

The Ocean Grange site is slightly to the east of the opening between Sperm Whale Head and Jubilee Head. The other two sites are generally to the west of this same opening, at the eastern end of Lake Reeve. The volume and surface area of Lake Reeve are generally greater than the volume and surface area of Bunga Arm. It would therefore be expected that the impacts of a second entrance at either of the other two sites, on tidal levels and salinities along the eastern end of Lake Reeve, would be similar to the impacts of a second entrance at Ocean Grange on Bunga Arm. Impacts on Lake Reeve would generally be expected to be slightly less than on Bunga Arm, due to the greater volume of Lake Reeve. Impacts on Lake Reeve would be expected to be greater for the Lake Reeve entrance site than for the Rotamah Island sites, due to its relative position along the Lake.

Whilst the Ocean Grange option was shown to have a relatively large impact on tidal velocities at the entrance to Bunga Arm, it would have relatively little impact on tidal velocities at the entrance to Lake Reeve. The converse would be expected for the Rotamah Island and Lake Reeve options, with the Rotamah Island option having the slightly greater impact on velocities.

Based on an examination of the bathymetry of Lake Reeve, it appears unlikely that a second entrance at either of the Lake Reeve or Rotamah Island sites would cause any permanent tidal inundation along Lake Reeve beyond (to the west of) Loch Sport.

6.8 Conclusions
Key conclusions of the investigation of hydrodynamic impacts of a second entrance are provided below:

- No significant change to water level variation would be expected in Lakes Wellington, Victoria or King, which would continue to respond to mean ocean water levels and river inflows.
- A significant increase in water level variation would be expected in the Bunga Arm (up to 0.8 m additional range) for the Ocean Grange site, and lesser localised increases in water level would be expected along the eastern end of Lake Reeve for the other two sites.
- Significant increase in tidal velocities would be expected in the Bunga Arm and Grange Channels (up to 1.0 m/s) for the Ocean Grange site. Similarly significant increases in tidal velocities between the entrance and Sperm Whale Head would be expected for entrances at either of the other two sites. This could result in significant scouring of the existing bed sediments and replacement with coarser beach sands.
Enhanced flushing and ocean exchange would be expected in Lake King and the eastern sections of Lake Victoria adjacent the proposed entrances.

No change or potentially a slight increase in stratification would be expected in Lake King/Victoria.

A significant change in salinity to near marine conditions would be expected in the Bunga Arm and neighbouring channels for the Ocean Grange site, and to a slightly lesser extent in Lake Reeve for either of the other two sites. Lake Victoria in the vicinity of the Aurora Channel would also be expected to exhibit significantly modified salinity characteristics under all options. Relatively little change would however be expected to salinity in the western section of Lake Victoria, and in Jones Bay.

*Nodularia* blooms could be expected to continue to occur in northern Lake King, Jones Bay and the western section of Lake Victoria, where only minor changes in salinity and tidal flushing are predicted.
7. Risks of a Second Entrance

An assessment of the potential risks associated with a second entrance is outlined in the following section.

7.1 Overview of Risk Assessment Framework

A risk assessment framework was developed to compare the risks associated with doing nothing, with the risks associated with the three second entrance options outlined in Chapter 6. The framework seeks to assess the risks against the values of the Lakes region (outlined in Chapter 3), which could potentially be impacted upon by a second entrance.

The framework seeks to provide a transparent means for assessing risk. For each of the identified values, one or more key indicators have been selected, and the impact of the second entrance on these indicators has been scored from –2 to +2, as follows:

- +2 - maximum positive impact
- 0 - no change from existing
- -2 - maximum negative impact.

The rules for determining the risk score for each value/indicator are detailed in the sections below. For example, for the value “Sites of State or National geomorphic/geological significance”, one of the selected indicators is the extent of the Mitchell River silt jetties. The rules used to assess the risk score for this value/indicator are as follows:

- +2 = >2 % increase in extent of silt jetties,
- 0 = no change in extent of silt jetties from existing
- -2 = >2% reduction in extent of silt jetties.

The rules are necessarily subjective. Wherever possible, the strength of the indicator, which then links back to the rule, has been assessed on the basis of a change in water quality or hydrodynamic characteristic that has been assessed as described in Chapter 6. For the silt jetties example, the change to their extent has been assessed on the basis of current velocities in their immediate vicinity.

A limited number of indicators have been used for each value to avoid over-complicating the risk assessment. In most cases, it is likely that the impact of the indicator(s) that have been selected for each value would be similar to the impact on other indicators that could have been selected for the same value.
The risk assessment for the Ocean Grange second entrance site is presented in Section 7.2. Assessments for the other two sites are presented in Sections 7.3 and 7.4. The risks associated with many of the values will be very similar for all three sites. In cases where this applies, Sections 7.3 and 7.4 only present the assessment for values where the risks would be expected to be different for the Rotamah Island or Lake Reeve sites.

7.2 Ocean Grange

7.2.1 Environmental

A number of key environmental values were assessed. The values were: areas of State and National geomorphic/geological significance, native fish species, seagrass, fringing wetlands and water birds. To assess these key values, indicators were chosen for each of the values based on discussions with Dick Brumley (DPI), Anthony Costigan (DSE), Belinda Hill (DSE) and Don Ripper (Central Gippsland Bird Studies).

**Value:** State and National geomorphic/geological significance such as coastal dune barriers and silt jetties

**Key Indicator:** Extent Mitchell River Silt Jetties

The Mitchell silt jetties are part of the Mitchell River Delta. The delta is a classic form of a digitate delta and is considered on of the finest examples of this type of landform in the world (DSE, 2003). The Mitchell River silt jetties are low, narrow tongues of sediment that extend almost 8 km into Lake King. The jetties were formerly bordered by a wide zone of Phragmites reeds, however this zone has retreated over the past decades (Sjerp et al 2002). The jetties have been armoured (rock beached) (Sjerp et al 2002) therefore limited impacts may occur from wave action. Increased water levels as a result of the second entrance may have small impact. Increased velocity around the ends of the jetties may also lead to erosion and loss of extent.

**Assessment:** Given the silt jetties extend up to 8 km into the Lakes a reduction of the jetties of 2% would equate to approximately 160 m loss in extent. The modelling results indicate a small increase in velocity may occur around the end of the silt jetties (refer Figure 6-14) however the maximum expected increase is only approximately 0.02 m/s which is unlikely to pose a great risk. There is no indication from the modelling that there will be any risk to the silt jetties from water level changes or tidal range. As the jetties have been armoured they are unlikely to be affected by velocity or erosion.

**Scoring:** Rule: -2 = >2% reduction in extent of silt jetties, 0= no change in extent of silt jetties, +2 = >2% increase in extent of silt jetties. Risk Score: 0

**Key Indicator:** Sperm Whale Head to Boole Poole Peninsula Coastline
The area of Sperm Whale Head to Boole Poole Peninsula are listed in the Gippsland Lakes Ramsar Management Plan as site of geomorphic significance. This section of the Gippsland Lakes includes the outer barrier and Ninety-Mile Beach. The barrier formations, dunes and dune lakes, relict entrance channels and tidal deltas are of major importance in illustrating the evolution of the barrier systems in the Gippsland Lakes (DSE, 2003). One of the critical factors in shoreline erosion appears to be die back of fringing reed beds as a result of salinity increase in the lakes since 1889. Other factors include trampling of banks by stock (Sjerp et al 2002).

The proposed second entrance at Ocean Grange is located near the features described above. Increased wave action, velocity, water levels and tidal range could potentially cause erosion such as scouring of the beaches and/or dunes and inundation and removal of the low lying sand islands near the mouth of Bunga Arm which contain tern colonies.

As the dunes, barrier formations associated with Sperm Whale Head and the Boole Poole Peninsula are a recognised component of the listed Ramsar site, any destruction or loss of the dunes or beaches in the area caused by building the entrance will trigger the EPBC Act (1999) and will need to be referred to the Commonwealth.

**Assessment:** Modelling indicates that Bunga Arm and areas in the immediate vicinity of the second entrance will be subjected to an increase in tidal range. This may be up to 0.98 m in areas of Bunga Arm and up to 0.20 m at the location of the entrance (refer Figure 7-1). This may lead to inundation of the beaches and possibly total loss of the low lying islands near Bunga Arm. Velocity and changes in water level (particularly at high tide) may also exacerbate this loss, as some locations may become susceptible to erosion and increased wave action (refer Figure 7-2).
Figure 7-1 Impact of Second Entrance on Tidal Range in Bunga Arm
Figure 7-2  Tidal Velocities in Vicinity of Second Entrance at Ocean Grange

Scoring: Rule: -2 = >2 % reduction in extent of beaches and/or dunes, 0 = no change in extent of beaches and dunes, + 2 = >2% increase in extent of beaches and/or dunes. Risk score: -2

Value: Native Estuarine Fish Species

Key Indicator: Abundance of Black Bream

Assessment: The second entrance is likely to result in an increase in the diversity and abundance of fish with marine affinities however the impact on bream is highly uncertain. The second entrance is likely to result in the spread of more oceanic water through eastern Lake King and Lake Victoria, however little change in the modelled salinity was noted for areas such as Jones Bay and the western section of Lake Victoria (refer Figure 6-16). The change in salinity may result in a redistribution of preferred bream habitat but it is unlikely to impact on the success of spawning which is reliant on a particular range of salinity and other water quality cues. The potential improvement in water quality and the increased distribution of seagrass will be offset by the potential impacts that may arise from the change in salinity. No consideration has been given to the impact of overfishing on this species in the score below.
Scoring:  *Rule*  -2 = decrease in annual commercial catch of black bream, 0 = no change in commercial catch, + 2 = increase in annual commercial catch of black bream.  *Risk Score* 0

**Key Indicator:**  *Abundance (and Distribution) of Dusky Flathead*

Dusky flathead is a sedentary bottom dwelling species that are found throughout the Gippsland Lakes including parts of Lake Wellington. The species occurs in association with mud, silt, sand and *Zostera* seagrass. The structure and composition of the Gippsland Lakes populations, and whether the adults enter the Lakes as juveniles or migrating adults, are not known. They spawn in response to increased day length and increasing water temperature, which usually occurs between January and March (in Victorian waters). The spawning ground for the Lakes populations is unknown but it is suspected that it does not occur within the Lakes. Key fishing localities are throughout Lake King and Lake Victoria. Locations around the Entrance are less important, indicating their preference for estuarine conditions over marine, oceanic conditions.

**Assessment:** The second entrance is likely to result in the spread of more oceanic water through eastern Lake King and Lake Victoria, resulting in an increase in salinity through the lower sections of Lake King and the eastern section of Lake Victoria (refer Figure 6-16). The increase in salinity may result in a loss of preferred flathead habitat but it is unlikely to impact on the success of spawning which is reliant on a change in water temperature and an increase in day length. The spatial distribution of this species has varied over the past 10 years, possibly in response to low dissolved oxygen in demersal waters (see Gunthorpe 1997). The potential improvement in water quality from a second entrance may offset the potential impacts that may arise from the change in salinity. No consideration has been given to the impact of overfishing on this species in the score below.

Scoring:  *Rule*  -2 = decrease in annual commercial catch of flathead, 0 = no change in commercial catch, + 2 = increase in annual commercial catch of flathead.  *Risk Score* -1

**Key Indicator:**  *Abundance (and Distribution) of Estuary Perch*

Estuary perch are commonly found in estuaries and the lower tidal reaches of rivers. Adults migrate into estuarine areas of high salinity in preparation for spawning which normally occurs in response to rising temperatures (usually November and December). Perch spawn over areas with aquatic vegetation and or submerged rocky reefs. Juvenile fish remain in areas of high salinity before returning upstream.

**Assessment:** As described in the previous section, the second entrance is likely to result in the spread of more oceanic water through eastern Lake King and Lake Victoria, however little change in the modelled salinity was noted for areas such as Jones Bay and the western section of Lake Victoria (refer Figure 6-16). Important fishing localities for estuary perch such as the Nicholson...
River estuary and McLennan Strait are therefore unlikely to be affected by changes in salinity that will occur from a second entrance option. The change in salinity may result in a redistribution of preferred perch habitat but it is unlikely to impact on the success of spawning which is reliant on a specific range of salinities and water temperature. No consideration has been given to the impact of overfishing on this species in the score below.

**Scoring:** Rule -2 = decrease in commercial catch of estuary perch, 0 = no change in catch, + 2 = increase in commercial catch of estuary perch.  
**Risk Score 0**

**Value:** Fringing Wetlands

**Key Indicator:** Abundance of Common Reed beds (*Phragmites australis*)

The abundance and distribution of *Phragmites australis* has reduced over the past 50 years mainly due to the increasing salinity caused by the opening of the entrance and more recently to the impact of carp. The distribution of this *Phragmites australis* habitat has not been mapped however remnant portions are known to exist in the lower reaches of the rivers entering the Lakes and in Lake Wellington, McLennan Strait and the western extremities of Lake Victoria (Sjerp, *et al.* 2002). Isolated stands are also reported in the North Arm.

*Phragmites australis* is a relatively salt tolerant species however maximum salinity tolerances vary from population to population with reported maximum range from 12 ppt (1.2%) in Britain, to 29 ppt in New York State, to 40 ppt on the Red Sea coast (Hocking *et al.* 1983). *Phragmites australis* in wetlands in Australia have been reported to have a salinity tolerance of up to 12 ppt (Centre for Stream Ecology 1989).

*Phragmites australis* does not require flooding to survive and can survive on groundwater alone however, its growth rates are highest when water levels are only a few centimetres deep but it can tolerate water depths >1.5 meters but not for an extended period of time (MDBC, 2003). Seedlings do not grow well under water. The estimated preferred rate of depth change for *P. australis* is 3 cm per day with a depth decrease of up to 5 cm per day (MDBC, 2003). Overseas studies on *P. australis* has shown that it has a low tolerance for wave and current action which can break its culms (vertical stems) and impede bud formation in the rhizomes (Marks *et al* 1993). It can survive, and in fact thrive, in stagnant waters where the sediments are poorly aerated (Marks *et al* 1993).

Migratory bird species require suitable habitat for breeding and refuge during migration. The fringing wetlands and associated reed beds (such as *Phragmites australis* and *Juncus sp.*) at the Gippsland Lakes provide this habitat. As the Lakes are listed as a RAMSAR sites and under treaty obligations for JAMBA/CAMBA these areas need to be kept in suitable condition to support migratory and native bird species.
Assessment: Modelling of salinity indicates the greatest changes will occur near the proposed second entrance and in Bunga Arm. In general however, salinity will increase throughout the lakes system with Lake Wellington and Jones Bay the least affected (refer Figure 6-16). Modelling outputs for water level, tidal range and velocity indicate there is unlikely to be an impact in Jones Bay, Lake Wellington and western Lake Victoria where most of the Phragmites australis is located (refer Figure 6-11, Figure 6-12, Figure 6-13 and Figure 6-14).

Scoring: Rule: -2 = 10% reduction from existing area of Phragmites australis, 0 = No change in existing area of Phragmites australis, + 2 = 10% increase from existing area of Phragmites australis. Risk score 0

Key Indicator: Abundance of Pale Rush (Juncus pallidus)

Pale Rush (Juncus pallidus) are usually located around the edges of Sea Rush (Juncus krausii) beds where freshwater runoff and springs are located (Belinda Hill, DSE, pers com). In the Gippsland Lakes, verified locations of Juncus pallidus include the western end of Lake Wellington, the western extremities of Lake Victoria (Jones Bay), in the vicinity of Wattle Point, in the estuary of the Nicholson River and in the southern parts of Tambo Bay in Lake King (Belinda Hill, DSE, pers com). There is also a stand located west of the existing entrance at Lakes Entrance. Juncus sp and sedges have specific hydrological requirements. The areas in which they will grow are determined largely by the minimum and maximum water levels. Very few of these plants are adapted to a static water level, as the wetlands, rivers and estuaries generally have large fluctuation in water level from winter to summer (Bell, 1999).

No information is available at this time on the salt sensitivity of Juncus pallidus, however, its scattered distribution around the outer edge of the Juncus krausii zones found in the Gippsland Lakes would imply its decline should water depths increase and higher salinities prevail (Belinda Hill, DSE pers com). Juncus krausii is found in very saline soils in all States mainly towards the coast. These rushes form extensive stands that are a significant habitat for birds (Romanowski, N, 1998). Juncus krausii and, in association, Juncus pallidus, will tolerate saline and semi saline environments (Belinda Hill, DSE, pers com).

Assessment: Modelling of salinity indicates the greatest changes will occur near the proposed second entrance and in Bunga Arm. In general however, salinity will increase throughout the lakes system with Lake Wellington and Jones Bay the least affected (refer Figure 6-16). Modelling outputs for water level, tidal range and velocity indicate there is unlikely to be an impact in Jones Bay, Lake Wellington and western Lake Victoria where most Juncus pallidus is located (refer Figure 6-11, Figure 6-12, Figure 6-13 and Figure 6-14). Beds near Wattle Point could potentially be affected (refer Figure 7-3).
**Figure 7-3  Typical Salinities in Vicinity of Second Entrance at Ocean Grange**

**Scoring:** *Rule: -2 = 10% reduction from existing area of Juncus pallidus, 0 = No change in existing area of Juncus pallidus, +2 = 10% increase from existing area of Juncus pallidus. Risk score: -1*

**Key Indicator:** *Abundance of Paperbark Swamps (Melaleuca ericofolia)*

Paperbark Swamps are usually found in areas of saline, poorly drained soil such as estuarine wetlands. Paperbark (*Melaleuca ericofolia*) is a native shrub which usually grows in association with reeds, rushes and sedges fringing wetland areas in the Gippsland Lakes. Significant stands of *M. ericofolia* are found in a number of locations around the Gippsland Lakes. These include western and southern parts of Lake Wellington, Dowds Morass, Rotamah Island and Sperm Whale Head (Don Ripper, Central Gippsland Bird Studies, pers com).

*Melaleuca ericofolia* seeds can germinate while submerged and therefore are metabolically adapted to anaerobic conditions (Bell, 1999). Germination is also influenced by the osmotic pressure of salt in the soil (Bell, 1999). This species grows at low elevations in moist often seasonally inundated sites such as swamps, riversides and lake margins, often in subsaline sites (Walsh and Entwisle, 1996). Long periods of inundation lead to waterlogging. It may not set seed or grow at certain water levels, although seeds will germinate while submerged. Germination is delayed by a...
submersion period of up to 3 weeks and seeds will not establish while still submerged (Ladiges et al., 1981; Bell, 1999).

*Melaleuca ericofolia* has an upper limit tolerance of 30,000 mg/l for salinity (Australian Biodiversity Salt Sensitivity Database). Growth starts to decline at 13,000 mg/l, and at 21,000 mg/l leaves brown and there is minimal growth (Australian Biodiversity Salt Sensitivity Database).

**Assessment:** Modelling of salinity indicates the greatest changes will occur near the proposed second entrance and in Bunga Arm. In general however, salinity will increase throughout the lakes system with Lake Wellington and Jones Bay the least affected (refer Figure 6-16). Modelling outputs for water level, tidal range and velocity indicate there is unlikely to be an impact in Jones Bay, Lake Wellington and western Lake Victoria (refer Figure 6-11, Figure 6-12, Figure 6-13 and Figure 6-14), therefore any stands of *Melaleuca* in those areas are unlikely to be affected.

**Scoring:** Rule: -2 =10% reduction from existing area of *Melaleuca ericofolia*, 0 = No change in existing area of *Melaleuca ericofolia*, + 2 = 10% increase from existing area of *Melaleuca ericofolia*. Risk score: 0

**Value:** Seagrass

**Key Indicator:** Distribution of *Zostera* spp.

Four species of seagrass have been recorded from the Gippsland Lakes, however the species *Zostera muellnerii* and *Zostera tasmanica* are the dominant forms. Seagrass beds are predominantly composed of *Zostera* spp., although *Ruppia* sp. has also been recorded from localities such as Lake Reeve, Bunga Arm and Lake Tyers. Seagrass has not been recorded from Lake Wellington. Species of Zostera occur in estuarine and marine localities where salinities are generally greater than 25 ppt. In the Gippsland Lakes, these species occur within the 0 to 2.5 metre depth range but were generally encountered in water less than 2 m deep (Roob & Ball 1997). Distribution is normally limited by light but can be affected by a suite of other environmental factors.

The distribution of epiphytic algae on seagrass, which can grow in response to increased nutrients in the water column, is also an important factor that can limit the distribution of seagrass. Epiphytic algae can smother seagrass by reducing light availability and causing die back. within the seagrass meadows are confined to areas with low energy and low tidal flow. High energy marine environments have a flushing effect on the seagrass keeping them clean and limiting the settlement of epiphytic algae (Roob & Ball 1997).

**Assessment:** The increase in salinity in the southern sections of the Gippsland Lakes (refer Figure 6-16) will lead to an increase in the distribution of seagrass between Sperm Whale Head and Loch Sport. Some potential habitat could be lost immediately around the second entrance although
Zostera spp. can occur in areas of high tidal exchange. The increase in tidal mixing and flushing could also improve water clarity in some sections of the Lakes, which could result in an increase in the existing depth distribution of Zostera spp.

**Scoring:** *Rule*: -2 =10% reduction from existing area of Zostera, 0 = No change in existing area of Zostera, + 2 = 10% increase from existing area of Zostera.  *Risk score*: +2

**Value:** Water bird diversity

**Key Indicator:** Abundance of Little Terns

Bunga Arm supports breeding populations of Little Tern, Fairy Tern, Hooded Plover and White Bellied Sea Eagle. Little Tern and Fairy Tern are FFG listed. The Little Tern and Fairy Tern populations use a number of islands within the Gippsland Lakes for breeding. There are known Little Tern breeding populations on a number of the low lying islands near the proposed location of the second entrance (Sjerp, *et al*, 2002). Both the Little Tern and Fairy Tern are ground nesting birds which make nests and lay eggs on beaches and on low lying islands associated with estuaries where the substrate is sandy and vegetation is usually low and sparse and nests can be flooded during high tide in stormy weather (DSE, undated). The potential for changes in water level, tidal range and velocity as a result of the second entrance may have a significant impact on these habitats (DSE, 2003). The most recent threat to Little Terns is competition for breeding space with Pelicans. Pelicans have increased in number in the Lakes in the last 5 years probably as a result of an impact to their habitat somewhere else and have stopped Little Terns breeding in one location in one year (Don Ripper, pers comm).

**Assessment:** Changes in water levels, velocity and tidal range will all have a negative impact on the habitat of Little Terns in the location of the second entrance. Increased wave action, scouring and inundation (refer Figure 7-1 and Figure 7-2) will probably lead to total loss of low lying habitat such as sand islands in the vicinity of the second entrance.

**Scoring:** *Rule*: - 2 = reduction of Little Tern habitat, 0 = no loss of Little Tern habitat; + 2 = increase in Little Tern habitat.  *Risk score*: -2

**Key Indicator:** Abundance of Striated Fieldwren (*Sericornis (Calamanthus) fuliginosus*)

The Striated Fieldwren inhabits areas of heath and moorland (Slater *et al* 2001). They build concealed domed grass nests under grass tussocks or shrubs and in stands of *Juncus krausii* (Slater *et al* 2001; Belinda Hill, DSE, pers com).

Populations of Striated Fieldwren are found throughout eastern Victoria and are ubiquitous to the Gippsland Lakes (Don Ripper, pers com). This species is insectivorous and feeds in areas with...
reeds and sedges (such as *Juncus krausii* beds) and grassy tussocks. Although sustained increases in water levels could result in retreat of their habitats, this species tends to be unconcerned with changes in salinity and is able to access both fresh and saline environments (Don Ripper, pers com). *Juncus krausii* is found throughout the Gippsland Lakes particularly in the western part of Lake Wellington and Lake Victoria, Lake Reeve, in the north eastern part of Sperm Whale Head and around Metung (Belinda Hill, DSE, pers com). Areas of salt marsh such as *Salicornia* are also important as the Striated Fieldwren use this plant as a food source (Belinda Hill, DSE, pers com).

**Assessment:** Changes in salinity, water levels, velocity and tidal range (refer Figure 7-1 and Figure 7-2) may have a negative impact on *Juncus sp* (the habitat of Striated Fieldwren) in the immediate vicinity of the second entrance and in Bunga Arm. However, this species is likely to be unaffected and would probably relocate to other sections of the Lakes that are less affected.

**Scoring:** *Rule:* - 2 = reduction of Striated Fieldwren habitat, 0 = no loss of Striated Fieldwren habitat; + 2 = increase in Striated Fieldwren habitat. *Risk score:* 0

**Key Indicator:** *Abundance of Blacked-winged Stilt (Himantopus himanoptus)*

Black-winged Stilt inhabit fresh and brackish swamps, shallow rivers or lake margins, saltmarsh and tidal estuaries and mud flats. They particularly frequent shallow, ephemeral inundated areas such as flooded paddocks (Don Ripper, pers com). Black-winged stilt build nests in the open in colonies on low hummocks in water, among dead bushes or in depression on ground. The nests consist of either a line scrape or of water plants and weeds that are often built up as water levels rise (Slater *et al* 2001). Although they tolerate fresh water they can still tolerate brackish conditions and have a salinity tolerance <10,000 mg/L (Australian Biodiversity Salt Sensitivity Database).

**Assessment:** Changes in water levels, velocity and tidal range will all have a negative impact on the habitat of Black-winged Stilt in the location of the second entrance and in Bunga Arm (refer Figure 7-1 and Figure 7-2). As these birds are waders, Black-winged Stilt will be unable to feed in deep water. Increased wave action, scouring and inundation will probably lead to total loss of low lying habitat such as sand islands and beaches in the vicinity of the second entrance and a reduction in the extent of fringing vegetation that may be used as habitat.

**Scoring:** *Rule:* - 2 = reduction of Blacked-winged Stilt habitat and feeding area, 0 = no loss of Black-winged Stilt habitat and feeding area; + 2 = increase in Black-winged Stilt habitat and feeding area. *Risk score:* -1
7.2.2 Socio-Economic

The selected key values and indicators for the socio-economic risk assessment are listed below in Table 7-1.

- **Table 7-1 Key values and indicators selected for socio-economic risk assessment framework**

<table>
<thead>
<tr>
<th>Value</th>
<th>Selected key indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultural</td>
<td>Preservation of aboriginal cultural heritage</td>
</tr>
<tr>
<td>Recreation</td>
<td>Public health of waterways</td>
</tr>
<tr>
<td></td>
<td>Availability of recreational fish species</td>
</tr>
<tr>
<td></td>
<td>Safe boating conditions and access to key areas</td>
</tr>
<tr>
<td>Amenity</td>
<td>Visual appearance of waterways</td>
</tr>
<tr>
<td></td>
<td>Odour of waterway areas</td>
</tr>
<tr>
<td>Commercial</td>
<td>Availability of commercial fish species</td>
</tr>
</tbody>
</table>

As mentioned in Section 3.3, tourism is considered a key economic value of the Gippsland Lakes region. However, this assessment assumes that tourism is dependent on the values listed in Table 7-1, and without the various recreation and amenity values there would be no significant tourism industry in the region (the *image* of tourism in the region is also assumed to be dependent on these values). As such tourism itself is not included in the framework, given this would effectively double count some values in the risk assessment.

The risk assessment focuses on the current values of the Gippsland Lakes. These key values and indicators do not directly reflect those values that may be included in other assessment methods such as a benefit-cost analysis. For example, the cost associated with dredging a second entrance is not covered in the risk assessment framework, given this is not considered a 'value' of the Gippsland Lakes, however such costs would be important to include in a separate economic benefit-cost analysis of a second entrance.

**Value: Cultural**

**Key indicator: Preservation of aboriginal cultural heritage**

**Assessment:** Aboriginal Affairs Victoria provided an indication of the potential impacts to aboriginal cultural heritage resulting from a second entrance, following consideration of a map of the general site locations as shown in Figure 5-1. It was advised that the general location of the second entrance option possesses numerous Aboriginal cultural heritage sites, and so is considered a highly sensitive zone (pers. comm., Garrick Hitchcock, AAV, 18/7/05). Aboriginal cultural sites, whether known or not, are protected by Victorian and Commonwealth legislation.
**Scoring:** *Rule:* -2 - significant potential for the development to result in a negative impact to cultural heritage sites, 0 - no change. *Risk Score = -2*

**Value:** Recreation

**Key indicator:** Public health of waterways

Given the lakes are used for purposes involving (or having the potential to involve) human contact with water, such as swimming, water-skiing, and boating activities, the ability to enjoy these recreational pursuits without the risk of adverse health impacts, due to poor quality water, is clearly important.

In July 2004, URS produced an assessment of the economic impact of the Central Gippsland Water Quality Management Plan for the West Gippsland Catchment Management Authority. The study commented that the impact of a bloom on visitor numbers is dependent on:

- The proportion of local versus visitors from outside the local region (this is considered the most important factor, given locals are less likely to plan their holidays well in advance, and are able to move sites on a daily basis to areas unaffected by algal blooms)
- The proportion of visitors who would otherwise enter or use the water
- The level of restrictions put in place by the managing authority
- The publicity of restrictions
- The availability of nearby substitute sites for water recreational activities
- The distance to large population centres.

Although the economic impact of toxic blue-green algal blooms, or potentially other water quality indicators such as e.coli, is not clear-cut, this is considered a very important component of the risk assessment from a socio-economic viewpoint.

**Assessment:** Several concurrent environmental conditions are required for the prolific germination of *Nodularia* akinetes. These relate to salinity, temperature, phosphate and ammonia concentrations and incident light. Jones Bay and the shallow parts of northern Lake King are two areas that have been previously identified as localities where ideal environmental conditions occur for certain times of the year that are suitable for the germination of *Nodularia* akinetes. Once the cysts germinate in these areas, the blooms have the potential to spread to other parts of the Lakes. The assessment of whether a change in the frequency of algal blooms is likely to occur is based on the modelled change in salinity only.
The second entrance is unlikely to have any marked impact on the existing salinity within northern Lake King and in particular Jones Bay, the areas most likely to be the source of algal blooms in the Gippsland Lakes. If salinity remains below 20,000 mg/l during critical periods of the year (which is still likely with a second entrance) and assuming there is no change to other important parameters measured above, the likelihood of blooms occurring will remain high.

Scoring: Rule: -2 - marked increase in algal bloom frequency in populated/frequently visited areas, 0 - no change in algal blooms in populated/frequently visited areas, +2 - marked decrease in algal bloom frequency in populated/frequently visited areas eg. double current frequency. Assuming that blue-green algal bloom and other public health outbreaks occur in only parts of the Gippsland Lakes at a time, such that there is some ability for recreational enthusiasts to switch locations, a maximum negative score of -2 would only be required in extreme cases. Risk Score = +0.5 (given locals may enjoy recreational values by opting to visit non-bloom locations)

Key indicator: Availability of recreational fish species

Recreational fishing is a popular activity for visitors throughout the Gippsland Lakes. The availability of key recreational fish species is highly important contribution to the overall recreational values of the area.

Black bream are apparently ‘the most sought after species by recreational anglers, as they’re excellent fighters and a superb table fish’ 1. Particular spots for catching bream include Hollands Landing, Paynesville and Lake King. Other species caught by recreational anglers include flathead, tailor, mullet, salmon, whiting and trevally. It is assumed that the presence of European Carp and other 'pest' species reduces the recreational values of the Gippsland Lakes for anglers, given such species are not traditional table fish.

Assessment: The second entrance is likely to result in an increase in the diversity and abundance of fish with marine affinities at the possible expense of purely estuarine species and species with freshwater affinities. The second entrance is likely to result in the spread of more oceanic water through eastern Lake King and Lake Victoria, however little change in the modelled salinity was noted for areas such as Jones Bay and the western section of Lake Victoria. This may result in a redistribution of where carp and bream are commonly caught but does not necessarily infer that a change in the proportion of these species caught will occur. The proportion of bream and carp caught is dependent on a suite of other known and uncertain factors that have not been modelled.

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1 http://www4.visitvictoria.com/displayObject.cfm/ObjectID.000EE124-B211-1A67-88CD80C476A90318/vvt.vhtml

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**Scoring:** The scoring method is based on the estimated ratio of catch of bream compared to carp.

*Rule:* 2 - marked reduction in proportion of bream caught compared to carp within the Gippsland Lakes, compared to average volume caught over the last 5-10 years, 0 - no change in species mix within the Gippsland Lakes, compared to average volume caught over the last 5-10 years, +2 - marked increase in proportion of bream caught compared to carp within the Gippsland Lakes, compared to average volume caught over the last 5-10 years. *Risk Score = 0*

**Key indicator:** *Safe boating conditions and access to key areas*

There are a number of popular locations in the Gippsland Lakes that are only publicly accessible by boat and/or foot, whose safe access is a key reason behind the popularity of the area. These locations include Bunga Arm, popular for camping and water sports, and Ocean Grange, an area with numerous private houses that are accessed using private jetties. From both of these locations, residents and visitors are able to walk along management tracks adjacent to Ninety Mile Beach and access the beach and Rotamah Island. Rotamah Island can also be accessed by boat, moored at a small, popular jetty (pers. comm., Fred Herbert, 27/7/2005).

The accessibility of popular locations by land is based on the relative positioning of the entrance to the campgrounds and residences.

The accessibility of camping and residential areas is based on safe boating conditions, indicated by the strength of the current (output by the model) and wave height. Wave height is not considered in the model, but is unlikely to be significantly affected by the second entrance. The second entrance will not affect wave conditions through the lakes, except highly localised effects near the lake side of the entrance. It is unlikely that waves will be a problem inside the second entrance due to significant attenuation along the entrance channel (which is relatively narrow). The ocean-influenced wave conditions inside the second entrance are expected to be no worse than the existing channel, which is not an issue. However, depending on the style and length of the second entrance channel, sand bypassing implementation, and the formation of an ocean bar, waves on the outer bar of the second entrance channel could be significant.

If this is to be a navigable channel, it is expected that the channel would be designed to provide a much safer entrance than that at Lakes Entrance, but like any ocean entrance it will still be dangerous at times.

**Assessment:** Without a bridge of some form, the second entrance is expected to dislocate popular camping grounds and residences from access by foot to parts of Ninety Mile Beach and management tracks to Rotamah Island. The second entrance is expected to increase current velocity by up to 2 m/s near Ocean Grange and the entrance to Bunga Arm (refer Figure 7-2), making conditions more dangerous for boating at this location. There is also expected to be a
marginal decrease in water level in Bunga Arm, that may slightly impact on activities at low tide (refer Figure 6-12). Charter boats are not allowed near the current entrance at Lakes Entrance for safety reasons - this philosophy may also apply to a second entrance, potentially restricting the access to Ocean Grange and Bunga Arm to non-charter craft only (pers. comm., Fred Herbert, 27/7/05).

**Scoring:** Safe boating conditions and access to key areas is expected to decrease with an increase in current strength and decrease in water depth (for boating), and the positioning of an entrance between popular locations accessed by land and/or boat. *Rule:* -2 - decrease in safe accessibility by boat and inaccessibility of tracks from campgrounds and residences, 0 - no change, +2 - increase in safe accessibility by boat and no impact on accessibility of tracks. *Risk Score = -2* for waters and land in and around Sperm Whale Head and Bunga Arm, *Risk Score = 0* for other areas.

**Value:** Amenity

**Key indicator:** Visual appearance of waterways

Blue-green algal blooms reduce visual amenity, creating a scum on the water surface and transforming clear waters to murky. Even once the toxicity of a bloom has subsided, the water may not be as inviting as before to swimmers and other water users.

As well as negatively affecting current residents and visitors, reductions in visual amenity have important economic ramifications. Empirical evidence sited by URS (2004) over the last 5 to 10 years indicates significant increases in land values, with significant development occurring. Discussion with real estate agents indicates that it is 'commonly thought that prices and turnover rates are affected by the presence of algal blooms in the Gippsland Lakes' (URS, 2004:A-14). One Bairnsdale agent estimated an impact of between 1 and 5% of housing prices during a bloom.

Apart from the presence of blue-green algal blooms, other water quality factors may also affect visual amenity. This includes suspended materials from inflows to the Gippsland Lakes, the current strength that may reduce the settlement of suspended solids, the presence of European Carp, and other environmental factors.

**Assessment:** Visual amenity should improve with a second entrance. While the frequency of algal blooms may not be reduced with the second entrance, when blooms do occur, they are unlikely to persist around the southern sections of the Gippsland Lakes, in the immediate vicinity of Ocean Grange because of the increase in tidal velocities and tidal flushing.

Areas in northern Lake King and Jones Bay are less likely to see improvements but as these areas are less frequently visited than other locations the score has been given less weight.
**Scoring:** Visual amenity is assumed to decrease linearly with increased duration of algal blooms.  
*Rule:* -2 - marked increase in algal bloom duration in populated/frequently visited areas, 0 - no change in algal blooms in populated/frequently visited areas, +2 - marked decrease in algal bloom duration in populated/frequently visited areas eg. double current frequency.  
*Risk Score = +1*

**Key indicator:** Odour of waterway areas

Rotting organic matter following blue-green algal blooms may create unpleasant smells for visitors and those residing near waterway areas, and amenity values are certainly negatively affected by such unpleasant odours. Rotting sea grass is a natural occurrence that is also a cause of unpleasant odours, particularly at the eastern end of the Lakes.

**Assessment:** Unpleasant odours arising from algal blooms should decrease with a second entrance. As discussed above, while the frequency of algal blooms may not be reduced with the second entrance, when blooms do occur, they are unlikely to persist around the southern sections of the Gippsland Lakes, in the immediate vicinity of Ocean Grange because of the increase in tidal velocities and tidal flushing.

Areas in northern Lake King and Jones Bay are less likely to see improvements but as these areas are less frequently visited than other locations the score has been given less weight.

Rotting sea grass occurs every year, and might be expected to be slightly exacerbated by the increased wave action associated with a second entrance.

**Scoring:** Unpleasant odours are assumed to increase with increased duration of algal blooms, and with increased wave action.  
*Rule:* -2 - marked increase in algal bloom duration and wave action in populated/frequently visited areas, 0 - no change in algal blooms or wave action in populated/frequently visited areas, +2 - marked decrease in algal bloom duration and wave action in populated/frequently visited areas.  
*Risk Score = 0*

**Value:** Commercial

**Key indicator:** Availability of commercial fish species

As discussed in Section 3.3.3, Black Bream is a very important commercial fish species in the Gippsland Lakes, whose numbers have decreased in recent years. Due to the important contribution of this species to the overall catch value, the abundance of Black Bream is considered a key indicator of commercial fishing values of the Gippsland Lakes.

**Assessment:** Fisheries data seem to indicate that the influence of habitat change and environmental factors on black bream is more severe than the influence of over-fishing (GCB, 1999b). Nevertheless, the factors which are important to the viability of a sustainable bream
fishery in the Gippsland Lakes remain poorly described. The second entrance is likely to result in improved water quality in Lake King as a result of improved flushing but only slight improvements to Lake Victoria. There is also likely to be an increase in the distribution of seagrass, which may be favourable to bream, but this may be offset by the increase in salinity, which will probably have a negative impact on the distribution of bream.

**Scoring:** An increase in the availability of Black Bream in the Gippsland Lakes will increase the commercial fishing values in the area. **Rule:** -2 - marked reduction in species availability within the Gippsland Lakes, compared to average volume caught over the last 5-10 years, 0 - no change in species availability within the Gippsland Lakes, compared to average volume caught over the last 5-10 years, +2 - marked increase in species availability within the Gippsland Lakes, compared to average volume caught over the last 5-10 years. **Risk Score:** 0 (on balance)

### 7.3 Rotamah Island

The information provided for the key values and indicators for the risk assessment for Rotamah Island is based on the information provided in the risk assessment for Ocean Grange unless otherwise stated. Specific information for Rotamah Island is given where available.

#### 7.3.1 Environmental Value

**State and National geomorphic/geological significance such as coastal dune barriers**

**Key Indicator:** Outer Barrier and associated dunes

This section of the Gippsland Lakes includes the outer barrier and Ninety-Mile Beach. The barrier formations, dunes and dune lakes, relict entrance channels and tidal deltas are of major importance in illustrating the evolution of the barrier systems in the Gippsland Lakes (DSE, 2003). Lake Reeve and the Outer Barrier to Paradise beach includes the widest section of the outer barrier of the Gippsland Lakes and the area with the greatest number of parallel dunes found along the entire length of Ninety-Mile Beach. One of the critical factors in shoreline erosion appears to be die back of fringing reed beds as a result of salinity increase in the lakes since 1889. Other factors include trampling of banks by stock (Sjerp *et al* 2002).

An entrance near Rotamah Island would be located near the features described above. Increased water action, velocity, water levels and tidal range could potentially cause erosion such as scouring of the islands beaches and/or dunes and inundation and removal of the low lying sections of Rotamah Island.
As Rotamah Island is a recognised component of the listed Ramsar site, any destruction of the dunes or beaches around the island caused by building the entrance will trigger the EPBC Act (1999) and will need to be referred to the Commonwealth.

**Assessment:** Based on the modelling carried out for the proposed Ocean Grange entrance we can extrapolate that any entrance built further east will have similar impacts such as increased tidal range, salinity and water levels. An entrance located in the immediate vicinity of Rotamah Island would result in an increase in tidal range. According to the modelling this may range anywhere from 0.20m to 0.98 m. Tidal ranges of this size may lead to inundation of the Islands beaches and possibly total loss of the low lying areas. Velocity and changes in water level (particularly at high tide) may also exacerbate this loss, as some locations may become susceptible to erosion and increased wave action.

**Scoring:** Rule: -2 = >2% reduction in extent of island beaches and/or dunes, 0 = no change in extent of island beaches and dunes, +2 = >2% increase in extent of island beaches and/or dunes. Risk score: -2

**Value** Fringing wetlands

Migratory bird species require suitable habitat for breeding and refuge during migration. The fringing wetlands and associated reed beds (such as *Phragmites australis* and *Juncus sp.*) at the Rotamah Island provide significant habitat. As the Gippsland Lakes are listed as a RAMSAR wetland and under treaty obligations for JAMBA/CAMBA these areas need to be kept in suitable condition to support migratory and native bird species.

The island supports Eucalypt and Banksia woodland and lower lying areas contain dense stands of saltmarsh and *Melaleuca* swamp. Rotamah Island is surrounded by *Juncus* sp marsh which is important habitat for birds. Rotamah Island is also part of the Gippsland Lakes National Park (Parks Victoria, Park Notes).

Reed and rush beds will potentially be inundated and scoured by increased velocities in the immediate vicinity of an entrance at Rotamah Island. Increases in salinity will also effect the growth of fringing vegetation leading to death if salinities reach greater than 12,000 mg/L for *Phragmites australis* and greater than 13,000 mg/L for *Melaleuca eriofolia*. Although no salinity tolerance information is known about *Juncus pallidus* and *J. krausii*, increases in water levels and salinity concentrations will probably lead to a decline in these species (Belinda Hill, DSE, pers com). *Melaleuca ericofolia* would also be affected by waterlogging if sustained water levels occur.

**Key Indicator:** Distribution of Common Reed (*Phragmites australis*)
Scoring: Rule: -2 = 10% reduction from existing area of *Phragmites australis* in the vicinity of Rotamah Island 0 = No change in existing area of *Phragmites australis* in the vicinity of Rotamah Island + 2 = 10% increase from existing area of *Phragmites australis* in the vicinity of Rotamah Island. Risk score: -2

**Key Indicator:** Distribution of Pale Rush *Juncus pallidus*

Scoring: Rule: -2 = 10% reduction from existing area of *Juncus pallidus* (and *J. krausii*) fringing Rotamah Island; 0 = No change in existing area of *Juncus pallidus* (and *J. krausii*) fringing Rotamah Island, + 2 = 10% increase from existing area of *Juncus pallidus* (and *J. krausii*) fringing Rotamah Island. Risk score: -2.

**Key Indicator:** Distribution of Paperbark Swamp *Melaleuca ericofolia*

Scoring: Rule: -2 = 10% reduction from existing area of *Melaleuca ericofolia*, 0 = No change in existing area of *Melaleuca ericofolia*, + 2 = 10% increase from existing area of *Melaleuca ericofolia*. Risk score: -1

Value: Waterbird diversity

Rotamah Island is a noted bird observatory. The bird observatory on Rotamah Island is involved in various research projects and attracts significant numbers of visitors to the island each year (Parks Victoria, Park Notes). Bird breeding and nesting sites would be lost if water levels and tidal ranges increase and scouring occurs.

The Black-winged Stilt wades in shallow lake and wetland edges such as Rotamah Island and the coastal areas. These birds will move away from areas of deep water. They prefer fresh water to marine and are know to the western section of Rotamah Island that is more often fresh (Don Ripper, pers com).

Both the Striated Fieldwren and the Black-winged Stilt would move to other suitable habitat available around the Gippsland Lakes if habitat is lost from Rotamah Island or salinity increases beyond tolerance limits for the Black-winged Stilt. Striated Fieldwren are unlikely to be affected by changes in salinity but may be affected by loss of habitat. The most impact is likely to be for Little Terns.

**Key Indicator:** Abundance of Little Tern

Scoring: Rule: -2 = reduction of Little Tern habitat, 0 = no loss of Little Tern habitat; + 2 = increase in Little Tern habitat. Risk score: -2

**Key Indicator:** Abundance of Striated Fieldwren

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I:\WCMS\Projects\WC0308S\ Deliverables\R02_dbs_Draft Final Report.doc PAGE 71
Scoring: Rule: -2 = reduction of Striated Fieldwren habitat, 0 = no loss of Striated Fieldwren habitat; +2 = increase in Striated Fieldwren habitat.  \textit{Risk score: 0}

\textbf{Key Indicator:} Abundance of Black-winged Stilt

Scoring: Rule: -2 = reduction of Blacked-winged Stilt habitat and feeding area, 0 = no loss of Black-winged Stilt habitat and feeding area; +2 = increase in Black-winged Stilt habitat and feeding area.  \textit{Risk score: -1}

7.3.2 Socio-Economic

\textbf{Key Indicator:} Safe boating conditions and access to key areas

See Section 7.2.2 for a description of this indicator.

\textbf{Assessment:} Rotamah Island is in the vicinity of the lakes area that is regularly visited by boating enthusiasts. The Island is also able to be visited by walkers via management tracks from Ocean Grange. The island is not as popular as Bunga Arm, given its small jetty and its location further away from Ninety Mile Beach (\textit{pers. comm.}, Fred Herbert, 27/07/05). Given the proximity of Rotamah Island to Bunga Arm, it is likely that there would be some effect on safe boating conditions in/around Bunga Arm as a result of an entrance at Lake Reeve, which would be less than if the entrance were located at Ocean Grange. There may also be a minor decrease in water level in Bunga Arm, that may slightly impact on activities at low tide (this will be less than that shown in Figure 6-12). Some management tracks may no longer be accessible by foot from Ocean Grange.

\textbf{Scoring:} Safe boating conditions and access to key areas is expected to decrease with an increase in current strength and decrease in water depth (for boating), and the positioning of an entrance between popular locations accessed by land and/or boat. \textit{Rule:} -2 - decrease in safe accessibility by boat and inaccessibility of tracks from campgrounds and residences, 0 - no change, +2 - increase in safe accessibility by boat and no impact on accessibility of tracks.  \textit{Risk Score} = -1 for waters and land in and around Sperm Whale Head and Bunga Arm, 0 for other areas.

7.4 Lake Reeve

The information provided for the key values and indicators for the risk assessment for Lake Reeve is based on the information provided in the risk assessment for Ocean Grange unless otherwise stated. Specific information for Lake Reeve is given where available.

7.4.1 Environmental

\textbf{Value:} Sites of State and National Geomorphic \textit{Significance such as coastal dunes and barriers.}

\textbf{Key Indicator:} Lake Reeve and Outer Barrier

\textit{SKM KNIGHT MERZ}
This area of the Gippsland Lakes includes the widest section of the outer barrier of the Gippsland Lakes and the area with the greatest number of parallel dune ridges found along the entire length of the Ninety Mile Beach (DSE, 2003). This area includes the outer barrier and ninety mile beach. The barrier formations, dunes and dune lakes, relict entrance channels and tidal deltas are of major importance in illustrating the evolution of the barrier systems in the Gippsland Lakes. Lake Reeve differs from other lagoons in the Gippsland Lakes in its ecology as well as its geomorphology as large areas of the lagoon frequently dry up completely and extensive saltmarsh areas have developed.

As the dunes and barrier formations are recognised components of the listed Ramsar site, any destruction caused by building the entrance will trigger the EPBC Act (1999) and will need to be referred to the Commonwealth.

**Assessment:** Based on the modelling carried out for the proposed Ocean Grange entrance we can extrapolate that any entrance built further east will have similar impacts such as increased tidal range, salinity and water levels. Areas in the immediate vicinity of the entrance will be subjected to an increase in tidal range. According to the modelling this may range anywhere from 0.20m to 0.98 m. Tidal ranges of this size may lead to inundation of the beaches and possibly total loss of the low lying areas (such as swamps). Velocity and changes in water level (particularly at high tide) may also exacerbate this loss, as some locations may become susceptible to erosion and increased wave action.

**Scoring:**  
*Rule:* -2 = >2% reduction in extent of Lake Reeve, barriers, beaches and/or dunes, 0 = no change in extent of Lake Reeve, barriers, beaches and dunes, + 2 = >2% increase in extent of Lake Reeve, barriers, beaches and/or dunes.  
*Risk score:* -2

**Key value:** Fringing wetlands

Lake Reeves is a shallow, brackish lake with abundant fringing vegetation along the shoreline (eg. *Juncus krausii*) and extensive areas of salt marsh bordered by plants such as succulents (glassworts) (Parks Victoria). The Lake Reeve shore vegetation has adapted to regular flooding and saline conditions. More permanent changes in water levels and tidal variation are likely to occur if a second entrance is built in the vicinity of Lake Reeves and potentially the lake could be permanently inundated. Impacts may include a decline in the extent of *Juncus krausii* beds. Increases in salinity above the tolerance levels *Melaleuca ericofolia* and *Phragmites sp* if any are present in the lake and could result in reduced growth of these vegetation types. More permanent inundation for longer duration could lead to die back in *Melaleuca ericofolia* swamps.

**Key Indicator:** Distribution of Common Reed (Phragmites australis).
Scoring: **Rule**: -2 = 10% reduction from existing area of *Phragmites*, 0 = No change in existing area of *Phragmites*, + 2 = 10% increase from existing area of *Phragmites*. **Risk Score**: 0

**Key Indicator**: Distribution of Pale Rush (*Juncus pallidus*)

Scoring: **Rule**: -2 = 10% reduction from existing area of *Juncus pallidus* (and *J. krausii*), 0 = No change in existing area of *Juncus pallidus* (and *J. krausii*), + 2 = 10% increase from existing area of *Juncus pallidus* (and *J. krausii*). **Risk score**: -2

**Key Indicator**: Distribution of Paperbark Swamps (*Melaleuca ericofolia*)

Scoring: **Rule**: -2 = 10% reduction from existing area of *Melaleuca ericofolia*, 0 = No change in existing area of *Melaleuca ericofolia*, + 2 = 10% increase from existing area of *Melaleuca ericofolia*. **Risk score**: -1

**Value**: Waterbird diversity

Lake Reeve is a site of international zoological significance. It attracts up to 12,000 migratory waders, provides important feeding and roosting habitat for a number of waterfowl species and is one of the five most important areas for waders in Victoria (DSE, 2003). The total concentration of waders at the south-western end of Lake Reeve fluctuates in response to local conditions of salinity, water depth and probably human disturbance (DSE, 2003).

The lake has supported the largest concentration (5,000) of Red Knot (*Calidris canutus*) recorded in Victoria, as well as up to 3,000 Sharp-tailed Sandpiper (*Calidris acuminata*) and up to 1,800 Curlew Sandpiper (*Calidris ferruginea*) (DSE, 2003).

Lake Reeve is a shallow lake therefore any increase in depth will potentially result in the loss of low lying areas for breeding and feeding areas for waders. Impacts of velocity would be greatest in the immediate vicinity of the entrance and any breeding areas are likely to be lost. The impact may be reduced in the western arm of Lake Reeve.

Any Little Tern that may be breeding in the low lying areas of Lake Reeve such as beaches may have their nesting areas inundated. However, there is no indication that Little Tern are breeding in this area. The main impact on Striated Fieldwren would be loss of some of the reed and rush habitats however they are likely to find suitable habitat in other parts of the Lake. Black-winged Stilt would be affected by increases in salinity above their tolerance limit and loss of habitat such as increased deep water (>5 cm) (Don Ripper, pers com). However, this species is also able to relocate to more suitable habitat elsewhere and are a migratory species therefore do not always use the Lake.

**Key Indicator**: Abundance of Little Tern

SINCLAIR KNIGHT MERZ
Scoring: Rule: -2 = reduction of Little Tern habitat, 0 = no loss of Little Tern habitat; +2 = increase in Little Tern habitat. Risk score: -1

Key Indicator: Abundance of Striated Fieldwren

Scoring: Rule: -2 = reduction of Striated Fieldwren habitat, 0 = no loss of Striated Fieldwren habitat; +2 = increase in Striated Fieldwren habitat. Risk score: 0

Key Indicator: Abundance of Black-winged Stilt

Scoring: Rule: -2 = reduction of Black-winged Stilt habitat and feeding area, 0 = no loss of Black-winged Stilt habitat and feeding area; +2 = increase in Black-winged Stilt habitat and feeding area. Risk score: -1

7.4.2 Socio-Economic

Key indicator: Safe boating conditions and access to key areas

See Section 7.2.2 for a description of this indicator.

Assessment: Lake Reeve is too shallow for boating and so is virtually unused for recreation purposes, except for perhaps some canoeing (pers. comm., Fred Herbert, 27/07/05). The management tracks from Ocean Grange extend up to the point at which the second entrance may be located, and so the second entrance would only reduce access for walkers from Ocean Grange who wish to travel further west along Ninety Mile Beach.

Given the proximity of Lake Reeve to Ocean Grange, it is likely that there would be an insignificant effect on safe boating conditions in/around Bunga Arm as a result of an entrance at Lake Reeve.

Similar to the Ocean Grange option (refer Figure 6-12), there may be a marginal decrease in water level in Lake Reeve. However, given there is no boating in the vicinity of Lake Reeve there are no impacts expected to safe boating conditions.

Scoring: Safe boating conditions and access to key areas is expected to decrease with an increase in current strength and decrease in water depth (for boating), and the positioning of an entrance between popular locations accessed by land and/or boat. Rule: -2 - decrease in safe accessibility by boat and inaccessibility of tracks from campgrounds and residences, 0 - no change, +2 - increase in safe accessibility by boat and no impact on accessibility of tracks. Risk Score = -0.5 for waters and land in and around Sperm Whale Head and Bunga Arm, 0 for other areas.
7.5 Summary of Risk Assessment

The risk assessment is summarised in Table 7-3.

In this table, the total risk score for each of the three options was calculated simply by adding the scores for each of the indicators assessed. No weightings were placed on any of the scores. On this basis, all three assessments scored negatively for the effect a second entrance would have on the environment and social values described above, with a second entrance in the vicinity of Rotamah Island having the greatest negative effect.

A total of twenty indicators have been considered (assuming intactness of island, coastline, etc is considered as one indicator (it is presented as three indicators in the table, due to the different locations of islands depending on which second location is being considered)). Of these twenty, the second entrance was assessed as having a predominantly negative impact on nine of the indicators, a predominantly neutral impact on eight of the indicators, and a predominantly positive impact on only three of the indicators. These three were:

- Abundance of seagrass communities;
- Public health of waterways; and
- Visual appearance of waterways.

An assessment was undertaken to determine the relative weightings that would need to be applied to each of these three indicators in order for the total risk score for each option be zero. The results of this assessment are presented in Table 7-2. By way of example, the assessment shows that for the total risk score for the Ocean Grange option to be zero (viz neutral overall risk):

- the three indicators on which the second entrance was assessed as having a predominantly positive impact (viz abundance of seagrass communities, etc) would each need to be assigned a weighting or importance of 2.7, relative to;
- a weighting of 1, for the nine indicators on which the second entrance was assessed as having a predominantly negative impact (abundance of black bream, etc).

In other words, on average, the indicators on which the second entrance was assessed as having a positive impact would need to assigned an importance nearly three times greater than the indicators on which the second entrance was assessed as having a negative impact, for the overall risk score for this option to be neutral.

It is considered most unlikely that the general community would assign such extreme differences in importance between the two groups of indicators.
Second Entrance Option Indicators on which a Second Entrance was Assessed as Having a Predominantly Negative Impact
- Abundance of black bream
- Abundance of dusky flathead
- Abundance of Juncus Pallidus
- Abundance of Melaleuca Ericofolia
- Abundance of little terns
- Abundance of black winged stilt
- Intactness of islands and coastline
- Preservation of aboriginal cultural heritage
- Safe boating conditions and access to key locations – Sperm Whale Head to Bunga Arm

Indicators on which a Second Entrance was Assessed as Having Predominantly Positive Impact
- Abundance of seagrass communities
- Public health of waterways
- Visual appearance of waterways

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Ocean Grange</th>
<th>Rotamah Island</th>
<th>Lake Reeve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance of black bream</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Abundance of dusky flathead</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abundance of Juncus Pallidus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abundance of Melaleuca Ericofolia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abundance of little terns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abundance of black winged stilt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intactness of islands and coastline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preservation of aboriginal cultural heritage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safe boating conditions and access to key locations – Sperm Whale Head to Bunga Arm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abundance of seagrass communities</td>
<td>2.7</td>
<td>3.3</td>
<td>2.6</td>
</tr>
<tr>
<td>Public health of waterways</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual appearance of waterways</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It must also be recognised this assessment ignores the capital cost of constructing a second entrance, and the on-going dredging costs that would incurred in maintaining such an entrance. This was discussed previously in section 6.6.3, where it was noted that the capital cost was likely to be in the order of $20 million, and annual costs in the order of $500,000 per year.

In the basis of this assessment, the environmental and social risks, in particular, of a second entrance appear to significantly outweigh any positive water quality benefits that such an entrance might provide.
Table 7-3 Risk Assessment Summary (N/A= not assessed).

<table>
<thead>
<tr>
<th>Value</th>
<th>Key Indicator</th>
<th>Ocean Grange</th>
<th>Rotamah Island</th>
<th>Lake Reeve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Values</td>
<td></td>
<td>Summary of Impacts</td>
<td>Summary of Impacts</td>
<td>Summary of Impacts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Risk Score</td>
<td>Risk Score</td>
<td>Risk Score</td>
</tr>
<tr>
<td>Native estuarine species</td>
<td>Abundance (and distribution) of black bream</td>
<td>No change in salinity in northern and western section of Lakes in southern section of Lakes and eastern section of Lake Victoria to more oceanic conditions</td>
<td>Improved water quality from increased flushing and mixing in southern section</td>
<td>As for Ocean Grange</td>
</tr>
<tr>
<td></td>
<td>Abundance (and distribution) of Dusky Flathead</td>
<td>Increase in salinity in southern section of Lakes and eastern section of Lake Victoria to more oceanic conditions</td>
<td>Species less likely to be affected (compared to bream and flathead) by second entrance as key fishing locations will be least affected by changes in hydrodynamic conditions and salinity</td>
<td>As for Ocean Grange</td>
</tr>
<tr>
<td>Fringing wetlands</td>
<td>Abundance of Phragmites australis</td>
<td>Small change in salinity may have little or no impact on Phragmites distribution in the Lakes.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Abundance of Juncus pallidus</td>
<td>Water depth increases and salinity increases could lead to decline in extent of Juncus pallidus and J. krausi zones (Belinda Hill (DSE). No information available on salinity tolerances of J. pallidus.</td>
<td>Water depth increases and salinity increases could lead to decline in extent of Juncus pallidus and J. krausi zones (Belinda Hill (DSE). No information available on salinity tolerances of J. pallidus.</td>
<td>Water depth increases and salinity increases could lead to decline in extent of Juncus pallidus and J. krausi zones (Belinda Hill (DSE). No information available on salinity tolerances of J. pallidus.</td>
</tr>
<tr>
<td></td>
<td>Abundance of Melaleuca ericofolia</td>
<td>This species will be affected by increases in salinity and changes to water levels and tidal range, in particular duration of inundation. Melaleuca ericofolia has an upper limit salinity tolerance of 30,000 mg/L. At 13,000 mg/L start to get decline in growth, at 21,000 mg/L browning of the leaves occur (Australian Biodiversity Salt Sensitive Database). Long periods of inundation lead to waterlogging. May not set seed or grow at certain water levels (Bell, 1999).</td>
<td>This species will be affected by increases in salinity and changes to water levels and tidal range, in particular duration of inundation. Melaleuca ericofolia has an upper limit salinity tolerance of 30,000 mg/L. At 13,000 mg/L start to get decline in growth, at 21,000 mg/L browning of the leaves occur (Australian Biodiversity Salt Sensitive Database). Long periods of inundation lead to waterlogging. May not set seed or grow at certain water levels (Bell, 1999).</td>
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</tr>
<tr>
<td>Seagrass communities</td>
<td>Abundance of seagrass communities</td>
<td>Increase in salinity will favour the establishment of more Zostera, increase in tidal velocity and flushing will reduce accumulation of algal epiphytes on seagrass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water birds</td>
<td>Abundance of Little Tens</td>
<td>Habitat islands in the immediate vicinity of second entrance likely to be largely destroyed by currents</td>
<td>Low lying islands and beaches parts of Rotamah Island in the immediate vicinity of an entrance are likely to be largely destroyed by currents</td>
<td>Any breeding grounds in the immediate vicinity of the entrance would be destroyed but impacts would decrease further west into Lake Reeve.</td>
</tr>
<tr>
<td>Value</td>
<td>Key Indicator</td>
<td>Summary of Impacts</td>
<td>Risk Score</td>
<td>Summary of Impacts</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------</td>
<td>------------</td>
<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Abundance of Striated Fieldwren</td>
<td>Water level increase and increase in tidal range as a result of second entrance could potentially lead to decrease in extent of habitat (Juncus).</td>
<td>0</td>
<td>Water level increase and increase in tidal range as a result of second entrance could potentially lead to decrease in extent of habitat and feeding areas (Juncus sp and Salicornia sp).</td>
</tr>
<tr>
<td></td>
<td>Abundance of Black winged Stilt</td>
<td>Water level increases and increases in tidal range as result of second entrance could lead to loss of extent of habitat. Also fewer areas of shallow water would be available for these waders to feed. Increases in salinities to above 10,000 mg/L may result in loss of species from some sections of the Gippsland Lakes.</td>
<td>-1</td>
<td>As for Ocean Grange</td>
</tr>
<tr>
<td></td>
<td>Intactness of islands and coastline near proposed second entrance, including Sperm Whale Head, Bunga Arm</td>
<td>Habitat islands in the immediate vicinity of second entrance likely to be largely destroyed by currents</td>
<td>-2</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Intactness of Rotamah island and coastline near proposed entrance</td>
<td>N/A</td>
<td>N/A</td>
<td>Low lying islands and beaches in the immediate vicinity of an entrance near Rotamah Island are likely to be largely destroyed by currents</td>
</tr>
<tr>
<td></td>
<td>Intactness of islands, barrier dunes and coastline near proposed entrance</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Intactness of Mitchell River silt jetties</td>
<td>No or minor impact of velocity changes on silt jetties and no impact from water level or tidal range changes.</td>
<td>0</td>
<td>As for Ocean Grange</td>
</tr>
<tr>
<td>Socio-Economic Values</td>
<td>Cultural Preservation of aboriginal cultural heritage</td>
<td>Significant potential for the development to result in a negative impact to cultural heritage sites</td>
<td>-2</td>
<td>As for Ocean Grange</td>
</tr>
<tr>
<td></td>
<td>Recreational Public health of waterways</td>
<td>Reduced duration of algal blooms at frequently visited locations, increasing ability of local recreation enthusiasts to switch locations to non-bloom areas</td>
<td>+0.5</td>
<td>As for Ocean Grange</td>
</tr>
<tr>
<td></td>
<td>Availability of recreational fish species</td>
<td>Redistribution of bream and carp locations within Lakes. Proportional change unknown.</td>
<td>0</td>
<td>As for Ocean Grange</td>
</tr>
<tr>
<td></td>
<td>Safe boating conditions and access to key locations - Sperm Whale Head to Bunga Arm</td>
<td>Increased current velocity and slight decrease in water levels at Bunga Arm. Decreased accessibility to walking tracks.</td>
<td>-2</td>
<td>Similar effects to Ocean Grange, but lesser in magnitude owing to greater distance of entrance to Bunga Arm. Some decrease in accessibility to walking tracks.</td>
</tr>
<tr>
<td>Value</td>
<td>Key Indicator</td>
<td>Ocean Grange</td>
<td>Rotamah Island</td>
<td>Lake Reeve</td>
</tr>
<tr>
<td>----------------</td>
<td>---------------------------------------------</td>
<td>--------------</td>
<td>----------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Amenity</td>
<td>Access to key locations - Lakes generally</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduced duration of algal blooms at popular locations</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td></td>
<td>Odour of waterway areas</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Commercial</td>
<td>Visual appearance of waterways</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduced duration of algal blooms at popular locations</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Availability of commercial fish species</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Favourable changes: improved water quality in Lake King, increased distribution of seagrass, countered by increased salinity.</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Total score</td>
<td>-7.5</td>
<td>Total score</td>
<td>-10.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-7.0</td>
</tr>
</tbody>
</table>
8. Conclusion

The assessments of the potential risks associated with a second entrance at either Ocean Grange, the vicinity of Rotamah Island or near Lake Reeve have identified several environmental and social values that will be severely impacted by a second entrance option. These include:

- Severe erosion of geologically significant habitats between Sperm Whale Head and Boole Poole Peninsula including inundation of low lying dunes and sand islands near the entrance to Bunga Arm and Lake Reeve and loss of low lying islands and beaches in the immediate vicinity of an entrance;
- Loss of important habitat for several water bird species including the FFG listed, Little Tern and Fairy Tern (which also includes a loss in the areas inherent Ramsar values);
- Potential for loss of cultural heritage sites; and
- Restricted boat access to Bunga Arm and restricted access to walking tracks near the vicinity of a second entrance.

The impacts on other environmental values such as the bream fishery are less certain due to a combination of lack of scientific research on which to make credible judgements and the impacts of other factors unrelated to a second entrance. These could include the impacts of overfishing or the impacts of riverine water quality, both of which are important factors for the successful spawning and recruitment of bream.

A second entrance is likely to improve water quality in the southern sections of the Gippsland Lakes through increased tidal flushing and mixing but is unlikely to have any benefit on water quality through the northern and western sections of the Lakes. Stratification will continue to persist in the Gippsland Lakes and the modelling indicates the potential for an increase in the incidence of stratification in parts of Lake Victoria and Lake King.

The frequency of algal blooms is unlikely to change in the northern sections of Lake King and Jones Bay, where the second entrance is likely to have little impact on water quality. However, the effects of algal blooms are unlikely to persist in the southern sections of the lakes where an increase in tidal flushing is likely. The increased salinity in the southern sections of the lakes will also discourage the growth of *Nodularia* but will have no impact on the potential bloom of more saline tolerant phytoplankton species.

On this basis, there is likely to be an improvement in water quality in the southern sections of the Lakes with positive implications for the socio-economic values of these locations. One aspect of the socio-economic values that will be negatively impacted by the second entrance is the loss of safe boating conditions (and therefore access) around the entrance to Bunga Arm, a locality of important recreational value.
The original premise for a second entrance was that it would reduce the frequency and severity of algal blooms in the lakes. The study has shown that this would occur only in the southern sections of the lakes in the immediate vicinity of the entrance itself, and that the second entrance would not substantially improve water quality in the wider lakes system. Furthermore a second entrance at any of the three sites considered would have significant adverse impacts on many of the lakes’ social and environmental values. On balance therefore, it appears that any water quality benefits that a second entrance might provide would be far outweighed its adverse environmental and social impacts.
9. References


DSE (undated). Action Statement No. 51. Little Tern (Sterna albifrons sinensis). Department of Sustainability and Environment.


http://www.fishvictoria.com/pnews/fish_fax/fishfax139.php


Norris, J.V., Tregonning, J.E., Lenanton, R.C.J and Sarre, G.A. (2002). Biological synopsis of the black bream, Acanthopagrus butcherii (Munro) in Western Australia with reference to information from other southern states. Fisheries Research Report No. 93, Department of Fisheries, Western Australia, 48pp.


Appendix A  Project Brief

RT2: Changing Hydrodynamic Conditions (Impacts of second Entrance)

Background: The CSIRO study identifies that a second entrance appears to be superficially attractive in terms of water quality indicators in Lakes King and Victoria. The report identifies that, if a second entrance is to be seriously contemplated, due consideration would need to be applied to all the other major environmental consequences of such an action.

This area of research and investigation is required to develop tools and knowledge to help assist the prediction of ecological, social and economic impacts of changed hydrodynamic conditions in the Gippsland Lakes.

Key elements of this research theme might include:

- Verification of the projected physical and chemical changes caused by a second entrance;
- Assessment of impacts on ecology of the Lakes and fringing wetlands, possible terrestrial impacts and impacts on fish spawning and habitat;
- Assessment of social and economic impacts;
- A series of public workshops to explore pros and cons of second entrance; and,
- Risk assessment to change hydrodynamic conditions.

Challenges: This area of research seeks to gain a holistic understanding of the impacts of entrances and changed hydrodynamics in the Lakes. These changes arise from changing entrance conditions, river flows and geomorphological changes. Will resolving one problem cause other problems? How will the existing work (being conducted on the Lakes by all stakeholders) be integrated in these assessments? How do you define and identify “community of interests” and the social values of existing or changed hydrodynamic states?

Research

- Do we understand the ecological, social and economic impacts of hydrodynamic changes that have been implemented
Questions: elsewhere? Can these lessons be applied in the Gippsland lakes?

- Do we understand the range of views of proposed options?
- Is a second entrance sustainable?
- Are there alternative options to deal with water ingress/egress (other than a second Entrance)?)
- What environmental/economic/community services are dependent on the current case situation (do we understand the base case)?
- Do we understand the total costs/benefits of proposals?
- Will future climate change make proposed changes irrelevant (climate change implications)?
- Do we know what the key knowledge gaps are (e.g. fish species impact)?

Outcomes Sought: A review and assessment is required to bring together the biophysical, social and economic aspects of changed hydrodynamic conditions under existing and new scenarios. This is to be based upon the best possible science and should harness existing knowledge from other similar systems in Australia and overseas. The process must ensure the community has a high level of confidence in the decision making process and its underpinning knowledge.

Skills Required: Many skills will be required to undertake research in this area, including:

- Knowledge of ecological systems
- Hydrodynamic modeling
- Social analysis
- Community/user input
- Engineering expertise
- Public education/assessment of community responses
Appendix B  Steering Committee

The Project is being undertaken under the direction of a Steering Committee comprising membership as follows:

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duncan Malcolm (Chair)</td>
<td>Gippsland Coastal Board</td>
</tr>
<tr>
<td>Chris Barry</td>
<td>Gippsland Coastal Board</td>
</tr>
<tr>
<td>Dick Brumley</td>
<td>Department of Primary Industries</td>
</tr>
<tr>
<td>Anthony Costigan</td>
<td>Department of Sustainability and Environment</td>
</tr>
<tr>
<td>Fred Herbert</td>
<td>Gippsland Coastal Board</td>
</tr>
<tr>
<td>Peter Kambouris</td>
<td>Parks Victoria</td>
</tr>
<tr>
<td>Kate Nelson</td>
<td>East Gippsland Shire</td>
</tr>
<tr>
<td>Joy Sloan</td>
<td>Department of Primary Industries</td>
</tr>
<tr>
<td>Bertrand Smedts</td>
<td>Gippsland Ports</td>
</tr>
</tbody>
</table>
Appendix C  Hydrodynamic Modelling
Gippsland Lakes
Changing Hydrodynamic Conditions

Entrance to the Bunga Arm

Report No. J144/R01
FINAL
September 2005
Gippsland Lakes
Changing Hydrodynamic Conditions

Report No. J144/R01
September 2005

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Notting Hill VIC 3168

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ACN No. 093 377 283
ABN No. 60 093 377 283
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EXECUTIVE SUMMARY

In 1998 CSIRO prepared an Environmental Audit of the Gippsland Lakes. The study found that the lakes system was potentially on the edge of significant and possibly irreversible degradation. Two of the major problems noted were nutrient inputs and associated algal blooms.

Broad scale numerical modelling was undertaken as part of the CSIRO Gippsland Lakes Environmental Study (Webster et al 2001), to assist in identifying the potential opportunities to improve water quality and reduce the incidence of algal blooms. One identified option suggested the creation of a 2nd entrance to the Lakes to improve flushing and increase salinity beyond tolerance levels for target algal species. However, due to the broad nature of the modelling undertaken, the CSIRO study did not fully assess other impacts of a 2nd entrance and it was recognised that a range of detailed investigations were required to fully identify the potential impacts of a 2nd entrance.

This report investigates hydraulic, water quality and coastal processes associated with the proposed 2nd entrance to determine the magnitude and extent of potential impacts. It has been prepared as a stand alone appendix to broader investigations by SKM as part of the Gippsland Coastal Board project RT2 Changing Hydrodynamic Conditions For The Gippsland Lakes.

Methodology

The CSIRO model was developed on a 500m grid for reasons of computational efficiency. CSIRO recognize that a 500m grid limits the ability to adequately represent the bathymetric features of the lakes, and state that the “horizontal resolution of 500m is not adequate to represent the narrower channels in the system. Topographic and bathymetric features that exist at scales below 500m are not well represented in the CSIRO model.

A key aim of this investigation was to undertake detailed modelling to provide improved representation of the topographic and bathymetric features of the Lakes system, providing a more spatially accurate modelling platform. This improved spatial resolution will enable examination of issues relating to, for example, detailed hydraulics around the existing and proposed 2nd entrance, and the impact of jetting of flood flows from the rivers discharging into the lakes system.

An unstructured finite element model was prepared using the RMA suite of models to investigate the impacts of the proposed 2nd entrance. The RMA suite of finite element models utilise a state of the art approach to the simulation of hydraulic and water quality processes. RMA2 is a depth-averaged finite element model for sub-critical flow suitable for application in coastal and estuarine environments. The model prepared to represent the lakes comprises triangular and quadrilateral elements of sufficient varying resolution to adequately represent the above bathymetry, and provides computational stability in areas of high hydraulic or water quality gradients.

Tide, wind, river inflow, rainfall and bathymetric data were sourced from the University of Melbourne, along with available water level data used in model calibration.

Existing Conditions

Hydrodynamic processes in Gippsland Lakes are highly dependent on forcing characteristics of ocean water levels, river inflows, local rainfall and wind. During dry periods, the mean water level in the lakes follows the mean water level in the ocean, which has typical variation of ±0.2m about mean sea level. During large ocean surge events in Bass Strait the lakes respond with variations in mean water level of as much as 1.0m change. These variations in
mean sea level typically occur over periods of a week or more. On timescales of a tidal cycle (approx 12.5 hours) water levels in the lakes are reasonably constant with only a small tidal variation (typically ±0.1m), and due to wind stresses can vary locally over a range greater than the observed tidal range.

The system exhibits poor hydraulic flushing with lengthy residence times. This results in a limited capacity to flush pollutants out of the system.

**Impacts of 2nd Entrance**

The 2nd entrance enhances ocean exchange in central Lake Victoria and Lake King. However, the tidal range in these areas is not significantly altered. The dominant hydrodynamic process continues to be variations in mean water level in the ocean. The impact of the 2nd entrance on the hydrodynamics of the central lakes will be negligible. Further, the 2nd entrance will not result in any significant change to the lakes response to long term variations in mean ocean water level (which occurs over periods of a week or more).

The flushing and saline recovery of the central part of the lakes is enhanced by the 2nd entrance. This will improve the existing poor hydraulic flushing slightly and increase the capacity to flush pollutants out of the system.

The 2nd entrance results in high velocities in the Bunga Arm and Grange Channels and a comparatively large tidal range in the Bunga Arm. The hydraulic characteristics in the Bunga Arm and around Ocean Grange resulting from the 2nd entrance are similar to those currently observed at Lakes Entrance and the Cunninghame Arm. Bed sediment characteristics in the Bunga Arm and Grange Channel are currently likely to consist mainly of silty sands, which would easily be mobilised under the modified current regime and replaced with coarser sands.

**Other Considerations**

Concurrent issues that would need to be addressed in detail should a 2nd entrance option be considered include the following:

- The impact of the entrance on flooding in the Gippsland Lakes
- The design and impact of the 2nd entrance and its impact on coastal processes along Ninety Mile Beach
- If the 2nd entrance is to be a navigable channel, issues relating to navigation (leads, lighting, tide and wave condition) and maintenance dredging would need to be addressed, including the management and/or disposal of the dredge spoil

**Conclusion**

Key conclusions of the investigation of hydrodynamic impacts of a 2nd entrance are provided below:

- No significant change to water level variations in Lakes Wellington, Victoria or King, which will continue to respond to mean ocean water levels and river inflows.
- Significant increase in tidal range in the Bunga Arm (increased range of up to 0.8m).
- Significant increase in tidal velocities in the Bunga Arm and Grange Channels (up to 1.0m/s). This could result in significant scouring of the existing bed sediments replacing them with coarser beach sands.
- Enhanced flushing and ocean exchange in Lake King and the eastern sections of Lake Victoria adjacent the Ocean Grange entrance.
TABLE OF CONTENTS

Executive Summary ................................................................................................................. ii
Methodology .............................................................................................................................. ii
Existing Conditions ..................................................................................................................... ii
Impacts of 2nd Entrance ........................................................................................................... iii
Other Considerations ................................................................................................................ iii
Conclusion ................................................................................................................................. iii

1 Introduction .......................................................................................................................... 1
   1.1 Background ..................................................................................................................... 1
   1.2 Scope of Work .................................................................................................................. 2

2 Previous Investigations ........................................................................................................ 5
   2.1 CSIRO Lakes Environmental Audit ................................................................................ 5
   2.2 CSIRO Lakes Modelling ............................................................................................... 5
   2.3 Gippsland Ports Sand Management Study ................................................................... 6
   2.4 Gippsland Lakes Flood Level Modelling Project .......................................................... 7

3 Methodology ........................................................................................................................ 8
   3.1 Overview ......................................................................................................................... 8
   3.2 Numerical Modelling ..................................................................................................... 8
       3.2.1 Hydraulic Model Description .................................................................................. 8
       3.2.2 Model Setup and Boundary Conditions ................................................................. 9
       3.2.3 Hydraulic Calibration ............................................................................................. 13
       3.2.4 Water Quality Model Description ........................................................................ 13
       3.2.5 Modelled Parameters ............................................................................................ 13

4 Existing Conditions .............................................................................................................. 15
   4.1 General Considerations ................................................................................................. 15
   4.2 Hydraulic Parameters ................................................................................................. 15
       4.2.1 Bathymetry ............................................................................................................. 15
       4.2.2 Tidal Levels ............................................................................................................. 17
       4.2.3 Tidal Range ............................................................................................................. 18
       4.2.4 Tidal Velocity ......................................................................................................... 19
   4.3 Water Quality ................................................................................................................ 21
       4.3.1 Hydraulic Flushing ............................................................................................... 21
       4.3.2 Saline Recovery .................................................................................................... 30
   4.4 Discussion ....................................................................................................................... 23

5 Modified Conditions ......................................................................................................... 25
   5.1 General Considerations ................................................................................................. 25
   5.2 Hydraulic Parameters ................................................................................................. 25
       5.2.1 Bathymetry ............................................................................................................. 25
       5.2.2 Tidal Levels ............................................................................................................. 26
       5.2.3 Tidal Range ............................................................................................................. 27
       5.2.4 Tidal Velocity ......................................................................................................... 28
   5.3 Water Quality ................................................................................................................ 30
       5.3.1 Hydraulic Flushing ............................................................................................... 30
       5.3.2 Saline Recovery .................................................................................................... 30

6 Impact of 2nd Entrance ...................................................................................................... 32
LIST OF FIGURES

Figure 1-1  CSIRO Model of Gippsland Lakes Showing 2nd Entrance  (Source: Webster et al 2001, Gippsland Lakes Environmental Study)

Figure 3-1  Gippsland Lakes Bathymetry
Figure 3-2  Model Setup – Lakes Entrance
Figure 3-3  Model Setup – Bunga Arm
Figure 3-4  Ocean Tidal Variation – Lakes Entrance
Figure 3-5  Existing Conditions – Modelled and Observed Water Levels
Figure 4-1  Existing Conditions – Bathymetry
Figure 4-2  Existing Conditions – Bathymetry Detail at Lakes Entrance
Figure 4-3  Existing Conditions – Bathymetry Detail at Ocean Grange
Figure 4-4  Existing Conditions – Tidal Variation
Figure 4-5  Existing Conditions – Mean Spring Tide Maxima and Minima
Figure 4-6  Existing Conditions – Mean Spring Tidal Range
Figure 4-7  Existing Conditions – Mean Spring Tide Peak Tidal Velocity
Figure 4-8  Flood and Ebb Tide Conditions at Lakes Entrance
Figure 4-9  Existing Conditions – Hydraulic Flushing
Figure 4-10  Gippsland Lakes Rivers – Flow Conditions July-August 1997
Figure 4-11  Existing Conditions – Saline Recovery
Figure 5-1  Modified Conditions – Bathymetry Detail at Ocean Grange
Figure 5-2  Modified Conditions – Tidal Variation
Figure 5-3  Modified Conditions – Mean Spring Tide Maxima and Minima
Figure 5-4  Modified Conditions – Mean Spring Tidal Range
Figure 5-5  Modified Conditions – Mean Spring Tide Peak Tidal Velocity
Figure 5-6  Flood and Ebb Tide Conditions at the Proposed 2nd Entrance
Figure 5-7  Modified Conditions – Hydraulic Flushing
Figure 5-8  Modified Conditions – Saline Recovery
Figure 6-1  Impacts – Bathymetry Detail at Ocean Grange
Figure 6-2  Impacts – Tidal Variation
Figure 6-3  Impacts – Mean Spring Tide Maxima and Minima
Figure 6-4  Impacts – Mean Spring Tidal Range
Figure 6-5  Impacts – Mean Spring Tide Peak Tidal Velocity
Figure 6-6  Impacts – Mean Spring Tide Peak Tidal Velocity – 2nd Entrance
Figure 6-7  Impacts – Hydraulic Flushing
Figure 6-8  Impacts – Saline Recovery
LIST OF TABLES

Table 3-1  Gippsland Lakes Rivers – Flow Characteristics (1995-2001)
Table 4-1  Saline Recovery Initial Conditions
1 INTRODUCTION

1.1 Background

In 1998 CSIRO prepared an Environmental Audit of the Gippsland Lakes. The study found that the lakes system was potentially on the edge of significant and possibly irreversible degradation. Two of the major problems noted were nutrient inputs and associated algal blooms.

The recent State of the Gippsland Lakes assessment found a steady but slow improvement in some areas of water quality since 1999 (SKM, 2004). However, due to a lack of appropriate data trends in algal blooms, improvements in the health of Gippsland Lakes’ ecosystems could not be accurately quantified.

Broad scale numerical modelling was undertaken as part of the CSIRO Gippsland Lakes Environmental Study (Webster et al 2001), to assist in identifying the potential opportunities to improve water quality and reduce the incidence of algal blooms. One identified option suggested the creation of a 2nd entrance to the Lakes to improve flushing and increase salinity beyond tolerance levels for target algal species. However, due to the broad nature of the modelling undertaken, the CSIRO study did not fully assess other impacts of a 2nd entrance and recognised that a range of detailed investigations were required to fully identify the potential impacts of a 2nd entrance, including:

- Effects of an increased lake salinity on lake and wetland ecology;
- Erosion processes from increased wave action;
- Turbidity and suspension of sediments (releasing stored nutrients that given the right circumstances, can also trigger algal growth);
- Terrestrial and estuarine habitats and species in the Lakes;
- Adjacent marine communities and species;
- Impact on community values in particular recreational activities;
- Costs of constructing and maintaining a 2nd entrance; or
- Impact on the economy if ecological changes reduce the commercial/recreational fish catch.

The CSIRO model was developed on a 500m grid for reasons of computational efficiency. CSIRO recognise that a 500m grid limits the ability to adequately represent the bathymetric features of the lakes, and state that “the horizontal resolution of 500m is not adequate to represent the narrower channels in the system. In particular, the opening to Bass Strait at Lakes Entrance, and McLennan Strait are both substantially too wide in this model.” (Webster et al 2001).

While the CSIRO model is an adequate tool for broad assessment of impacts, limitations in the spatial resolution place restrictions on the applicability of the model for simulating the effects of a 2nd entrance.

Water Technology has been commissioned by SKM as part of a broader study to investigate the potential impacts of a 2nd entrance to Gippsland Lakes. Water Technology’s role is to provide specialist expertise in numerical modelling to assess detailed hydraulic and salinity impacts of the proposal. The key objectives of Water Technology’s commission are:
• To provide independent review of numerical modelling undertaken by CSIRO in order to verify the spatial and temporal extent of predicted impacts of a 2nd entrance.
• To identify and assess the feasibility of alternative strategies to improve circulation in the Gippsland Lakes system.
• To assess the significance of other factors (including longshore transport, dredging, climate change, sea level rise, etc) and their potential impact on proposed circulation enhancement strategies.

1.2 Scope of Work

The numerical modelling components of the RT2 project are to provide an independent review and verification of numerical modelling undertaken by CSIRO, and an assessment of alternative strategies to improve circulation in the Gippsland Lakes system. This assessment will include consideration of other factors (including longshore transport, dredging, climate change, sea level rise, etc) to assess the veracity of proposed circulation enhancement strategies.

Water Technology’s scope of work is summarised as follows:

Preliminary Tasks

Preliminary activities will assist in developing a comprehensive understanding of relevant study background in support of subsequent tasks. Preliminary Tasks include:

• Collation and review of data necessary for model preparation and calibration (survey, water levels, salinity data, river flows, rainfall data, etc)
• Review of CSIRO work
• Search for and review of other relevant studies (e.g., West Gippsland Water Quality Management Plan)

Model Verification

The CSIRO model was developed on a 500m grid for reasons of computational efficiency. CSIRO recognize that a 500m grid limits the ability to adequately represent the bathymetric features of the lakes, and state that the “horizontal resolution of 500m is not adequate to represent the narrower channels in the system. In particular, the opening to Bass Strait at Lakes Entrance, and McLennan Strait are both substantially too wide in this model.” Some adjustments are made to the model bathymetry as part of the calibration process such that the conveyance characteristics are preserved in the simplified discretisation. Topographic and bathymetric features that exist at scales below 500m are not well represented in the CSIRO model.

While the CSIRO model is an adequate tool for broad assessment of impacts, limitations in the spatial resolution place restrictions on the applicability of the model. Accordingly, we propose to prepare a numerical model at much finer resolution using a finite element or nested finite difference formulation. This will provide improved representation of the topographic and bathymetric features of the Lakes system, providing a more spatially accurate modelling platform. This improved spatial resolution will enable examination of issues relating to, for example, detailed hydraulics around the existing and/or 2nd entrance, and the impact of jetting of flood flows from the rivers discharging into the lakes system.

Furthermore, as the model will be prepared using a method and modelling platform separate from the CSIRO model, it will provide an independent means to verify the overall performance of the CSIRO model in assessing the impact of a 2nd ocean entrance.
Tasks required for the independent preparation and calibration of a fine resolution numerical model include:

- Independent development of a detailed numerical model to simulate hydraulic and saline intrusion processes throughout the Gippsland Lakes system
- Calibration of the model to hydraulic and salinity measurements at locations throughout the Lakes
- Assessment of selected model scenarios tested by CSIRO to verify the magnitude and extent of identified impacts. This would include simulation of a 2nd entrance at Ocean Grange.

**2nd Entrance Alternatives**

The 2nd entrance was represented in the CSIRO model by a 500m wide cell, with a given depth of 1.6m, similar to the representation for the existing opening at Lakes Entrance. A 4 metre deep channel was ‘dredged’ from the 2nd entrance cell, running north-west along the eastern side of Crescent Island, and past the northern ends of Barton and Rotten Islands, into the main body of the Lakes. Figure 1-1 below shows a section of the CSIRO model including the 2nd entrance.

![CSIRO Model of Gippsland Lakes Showing 2nd Entrance](image)

As discussed above, the spatial resolution of the CSIRO model is too coarse to accurately represent the bathymetric detail of the 2nd entrance and ‘dredged’ channel connecting it to Lake Victoria. Our approach, using a much finer model resolution will, address these issues and provide improved representation of the local impacts of the proposed circulation enhancement option.

Numerical modelling of a 2nd entrance configuration similar to that of the CSIRO modelling was prepared initially as part of Stage I of the project to provide a basis for assessment of the potential impacts of the proposal.

Stage II of the project (if initiated) could include the investigation of alternative entrance configurations and/or locations. These could be developed to address likely problems of the proposed entrance location at Ocean Grange such as siltation similar to that observed at the existing entrance. Such siltation issues could significantly limit the viability of a 2nd open ocean entrance. As part of Stage II investigations, we propose to consider alternative options that do not include an open ocean entrance. This could include, for example, an ocean intake.
structure, unidirectional culverts through the frontal dune and a short open channel at the Ocean Grange location. Such a system would act as a source of clean ocean water and initiate a net hydraulic transport in Lake Victoria toward the existing entrance as well as avoiding issues relating to maintaining an open ocean entrance channel in a highly dynamic coastal system.

**Coastal Processes and Other Factors**

There are a range of other factors that may limit the viability of proposed hydraulic enhancement alternatives. For example, the 2nd entrance is likely to suffer from similar siltation problems as those currently experienced in the existing entrance, unless significant training walls were constructed and sand bypassing employed. We would undertake an assessment of other factors and their potential impact on selected hydraulic enhancement alternatives, to determine the viability of the selected option with respect to:

- Coastal processes including longshore sediment transport, wave penetration, and sand bypassing requirements
- Configuration of the 2nd entrance and/or hydraulic exchange structure, and the likely maintenance requirements for the given design
2 PREVIOUS INVESTIGATIONS

There have been numerous previous studies and investigations on various aspects of the Gippsland Lakes describing the characteristics of the system. The following provides a broad overview of the findings of a selection of studies relevant to the assessment of tidal hydraulic and tidal flushing.

2.1 CSIRO Lakes Environmental Audit

In 1998 CSIRO prepared an Environmental Audit of the Gippsland Lakes. The study found that the lakes system was potentially on the edge of significant and possibly irreversible degradation. Two of the major problems noted were nutrient inputs and associated algal blooms.

The recent State of the Gippsland Lakes assessment found a steady but slow improvement in some areas of water quality since 1999 (SKM, 2004). However, due to a lack of appropriate data trends in algal blooms, improvements in the health of Gippsland Lakes’ ecosystems could not be accurately quantified.

These studies initiated the call for further investigations to assess the health of the lakes and develop and test management strategies to protect the environmental values of the system.

2.2 CSIRO Lakes Modelling

Following the Environmental Audit, CSIRO undertook broad scale numerical modelling as part of the Gippsland Lakes Environmental Study (Webster et al 2001), to assist in identifying the potential opportunities to improve water quality and reduce the incidence of algal blooms. One option identified suggested the creation of a 2nd entrance to the Lakes to improve flushing and increase salinity beyond tolerance levels for target algal species. The study states:

The hydrodynamic model was used to investigate the impact of constructing a second entrance to the Lakes near Ocean Grange, similar in cross-section to the present Entrance. The second entrance approximately doubles the rate at which the main body of the Lakes exchanges with Bass Strait, but would have a smaller effect on Lake Wellington. The model simulations show the median and 95%ile phytoplankton concentrations to reduce by a factor of two in Lakes Victoria and King, although peak levels following flood events are not affected. The Nodularia blooms in the autumn are predicted to be virtually eliminated probably due to increased salinity. It should be noted that this prediction depends on an assumed salinity tolerance for Nodularia in the Gippsland Lakes, and is therefore uncertain and needs to be tested through process studies. The model suggests that episodes of stratification, hypoxia, and nutrient accumulation in bottom waters in L. Victoria and L. King would still occur, but for significantly shorter periods. These results are based on the model prediction that vertical mixing would increase with the construction of a second entrance. The second entrance is not predicted to have significant benefits for nutrient cycling or phytoplankton blooms in L. Wellington.

There were a range of uncertainties within the modelling approach that CSIRO recognised and indicated were sources of potential error requiring further investigation, including the following:
The hydrodynamic- and box-model representations of overall flushing rates are considered to be robustly calibrated against observed salinity. However, the model representation of vertical mixing is less certain, and this does affect predictions of bottom water hypoxia and consequently N and P cycling in L. Victoria and L. King.

Furthermore, due to the broad nature of the modelling undertaken, the CSIRO study did not fully assess other impacts of a 2nd entrance and recognised that a range of detailed investigations were required to fully identify the potential hydraulic impacts of a 2nd entrance, including:

- Localised changes in water level and tidal range;
- Localised and detailed impacts due to tidal currents;
- Potential impacts of these changes on sediments and sediment transport mechanisms within the lakes systems.

While the CSIRO model is an adequate tool for broad assessment of impacts, limitations in the spatial resolution place restrictions on the applicability of the model for simulating the effects of a 2nd entrance.

### 2.3 Gippsland Ports Sand Management Study

Gippsland Ports commissioned a feasibility study for the redevelopment of the Lakes Entrance port (CES 2003) to improve the ocean access to Lakes Entrance to accommodate larger recreational and commercial vessels. The aim of the study was to identify appropriate management actions to address ongoing sand management issues in the entrance and on the outer bar.

The study identified the following key findings:

- The net direction of sand movement is uncertain.
- The bar is growing in size.
- Removal of the bar is not financially feasible and even if it was removed, it is likely to re-establish.
- For the foreseeable future, ongoing dredging of a channel through the bar will be necessary to maintain vessel access from the ocean into Gippsland Lakes.
- Installation of by-pass pumps at the ocean ends of the existing training walls will reduce the amount of sand entering the channel and, over time, will reduce the size of the bar.
- There is a strong business case and significant community benefits to be gained by maintaining and improving the ocean access at Lakes Entrance.

Gippsland Ports has sought funding for the installation and operation of an appropriate sand by-pass system adjacent to the ocean ends of each of the training walls and connection of the pumps through the existing sand transfer station. The Authority is also exploring alternative dredge profiles and disposal strategies.

The study highlights the existing requirements to maintain the channel and the difficulties in doing so under current sand management strategies.
2.4 Gippsland Lakes Flood Level Modelling Project

The Gippsland Lakes Flood Modelling Project (GLFMP, Grayson et al 2004) was undertaken to review and revise 100 year design flood levels throughout the Gippsland Lakes. These levels take into consideration the various combined influences of ocean tide and storm surge, rainfall/runoff and joint probability considerations for the numerous catchments entering the lakes.

The project has drawn together an extensive range of background data that has been made available to this study, including:

- A digital elevation model drawing together available survey from a variety of sources
- Ocean tide levels derived from available predictions and measured data
- River flows into the lakes
- Distributed rainfall
- Wind data

The main outcome of the study is revised 100 year design flood levels throughout the Gippsland Lakes system.
3 METHODOLOGY

This section presents the methodology undertaken to investigate the effects of a 2\textsuperscript{nd} entrance to the Gippsland Lakes. It provides a broad introduction to the RMA models used, model setup and calibration, and a description of the parameters used to measure impacts.

3.1 Overview

The CSIRO model was developed on a 500m grid for reasons of computational efficiency. CSIRO recognize that a 500m grid limits the ability to adequately represent the bathymetric features of the lakes, and state that the “horizontal resolution of 500m is not adequate to represent the narrower channels in the system. In particular, the opening to Bass Strait at Lakes Entrance, and McLennan Strait are both substantially too wide in this model.” Some adjustments are made to the model bathymetry as part of the calibration process such that the conveyance characteristics are preserved in the simplified discretisation. Topographic and bathymetric features that exist at scales below 500m are not well represented in the CSIRO model.

A key aim of this investigation was to undertake detailed modelling to provide improved representation of the topographic and bathymetric features of the Lakes system, providing a more spatially accurate modelling platform. This improved spatial resolution will enable examination of issues relating to, for example, detailed hydraulics around the existing and proposed 2\textsuperscript{nd} entrance, and the impact of jetting of flood flows from the rivers discharging into the lakes system.

3.2 Numerical Modelling

The Gippsland Lakes is a large system of low lying coastal lagoons, approximately 70km long. The Lakes are connected to Bass Strait by a narrow maintained channel at Lakes Entrance, and receive inputs from 5 major river systems (Latrobe, Avon, Mitchell, Nicholson and Tambo). Lake Wellington is connected to Lake Victoria via a narrow relatively deep channel (McLennan Strait) and there are many other narrow and complex channels (e.g., the entrance to the Bunga Arm, McMillan Strait).

The size, complexity and variable resolution of lakes and channels in the system presents challenges for modelling. The spatial resolution of the model in some areas needs to be quite fine (e.g., to represent the entrance channels) but in other areas such fine resolution is not required (e.g., central areas of Lakes King and Victoria). Such difficulties are highlighted in the CSIRO modelling approach where important features that are finer than the model spatial resolution of 500m (e.g., McLennan Strait) had to be represented in “equivalent” terms.

A finite element model was selected for the hydrodynamic and water quality assessments of the 2\textsuperscript{nd} entrance. The finite element approach allows variable computational mesh size to be used allowing direct and accurate representation of hydraulic features without excessive computational overhead.

3.2.1 Hydraulic Model Description

The RMA suite of finite element models utilise a state of the art approach to the simulation of hydraulic and water quality processes. RMA2 (See Appendix A) is a depth-averaged finite element model for sub-critical flow suitable for application in coastal and estuarine environments. It includes capabilities for wetting and drying, and porous transport (marshing).
in intertidal wetlands. The model comprises triangular and quadrilateral elements with water levels and velocity represented at discrete corner and mid-side nodal locations.

The model supports a range of boundary conditions including spatially and temporally varying tide, river inflow, wind, rainfall and evaporation. The model allows use of a range of eddy viscosity formulations including the Smagorinsky closure methodology.

In the depth averaged model, the flow is simulated in 2 horizontal dimensions (x and y) with depth-averaged conditions representative of the vertical z dimension. As such, the model does not directly represent conditions in the third dimension and does not simulate the effects of stratification. Accordingly the issues raised in the CSIRO study relating to "bottom ventilation" are not directly addressed. However, by providing significantly enhanced spatial resolution in the x and y domain over the CSIRO model, a detailed assessment of hydraulic characteristics is provided from which a more thorough assessment of the hydraulic and flushing impacts of the 2nd entrance can be undertaken. Issues regarding bottom ventilation and stratification can be assessed by inference, comparing the 3D representation of the CSIRO model with the results from the 2D RMA model.

3.2.2 Model Setup and Boundary Conditions

The Gippsland Lakes model has been developed from available information sourced from the University of Melbourne (Centre for Environmental Applied Hydrology). These data have been drawn together in the preparation of the Gippsland Flood Modelling Project (Grayson et al 2004), which uses the WL Delft 1D model SOBEK. Considerable effort was placed in the preparation of an accurate digital elevation model for the Flood Modelling Project, which has been adopted for this study. The wet-dry boundary of the lakes has been adopted from the 0m AHD contour and the defined boundary of the lakes. Given the area of the lakes, small errors in the definition of the “edge” of the system will have negligible effect on hydraulics. Figure 3-1 below present the bathymetry adopted for the study.

The model prepared to represent the lakes comprises triangular and quadrilateral elements of sufficient varying resolution to adequately represent the above bathymetry, and provides computational stability in areas of high hydraulic or water quality gradients. Details of the mesh are shown below in Figure 3-2 (at Lakes Entrance) and Figure 3-3 (at the entrance to the Bunga Arm).

The model comprises 7514 element (3444 triangles and 4070 quadrilaterals) and 21272 computation nodes (at element corners and mid-sides). The distance between computation nodes varies as the element sizes vary from minimums of less than 25m in areas of high hydraulic or water quality gradients to over 1500m in areas of low hydraulic or water quality gradients.

Boundaries applied to the model include a temporally varying ocean boundary, inflows from the 5 major river systems, direct rainfall and wind. These data have also been sourced from the University of Melbourne (Centre for Environmental Applied Hydrology). These data are described below.
Figure 3-1  Gippsland Lakes Bathymetry

Figure 3-2  Model Setup – Lakes Entrance
The tidal ocean boundary has been derived from available data combined with tidal predictions. Extensive data analysis was undertaken to correlate tidal predictions, measurements and anomalies at Bullock Island (inside the entrance at lakes Entrance) with ocean water levels. The derived ocean water level data series was developed by the University of Melbourne (Tan and Grayson, 2002) as a combination of offshore tidal predictions and a correlated tidal anomaly at Bullock Island. Ocean levels have been derived for the period 1974-2001 inclusive.

These ocean levels have been adopted for use in this study. Typical ocean tidal variation is illustrated in Figure 3-4 below. The ocean conditions are a combination of diurnal (one tide per day) and semi-diurnal (two tides per day), with spring tidal range around ±0.7m. A variation in mean sea level of around ±0.1m is apparent in Figure 3-4, and mean sea level variations of ±1.0m can occur.

River Inflows

Inflows from the 5 major river systems are represented at characteristic locations just upstream of the confluence of the river with the lakes. Data representing the period 1/1/1974-31/12/2001 has been provided to the study (Tan and Grayson, 2002). Key characteristics of the river flow data is shown be low in Table 3-1.
Table 3-1  Gippsland Lakes Rivers – Flow Characteristics (1995-2001)

<table>
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</table>

Rainfall

Rainfall is applied to the model directly. The rainfall data has been derived from the Bureau of Meteorology’s SILO database, which provides spatially and temporally varying interpretation of rainfall characteristics. These data have been sourced from the University of Melbourne (Tan and Grayson, 2002). Lakes Entrance has a mean annual rainfall of 714mm varying between 490mm (10 percentile) and 900mm (90 percentile).

Wind

Wind driven circulation is very important in the Gippsland Lakes. Data from Sale Airport, just west of Lake Wellington has been used to define wind characteristics throughout the lakes system. It is recognised that wind conditions will vary throughout the lakes, particularly during light to moderate conditions. Also, sea breeze effects may not be well represented at Sale as it is approximately 20km from the coast. Such effects will not be well represented by applying the wind at Sale over the entire modelling domain and may result in some localised calibration inconsistencies. Nevertheless, during major wind events, the spatial variation of wind fields across the lakes will be limited, and it is during such events that the influence of wind on the lakes will be at its most apparent. Therefore, the wind data from Sale is considered adequate for modelling purposes.
3.2.3 Hydraulic Calibration
Modelled and observed tidal variation at various locations throughout the lakes is shown in Figure 3-5. The model shows adequate reproduction of observed water level variation and is considered appropriate for the assessment of characteristic hydrodynamic changes to the Gippsland Lakes associated with the introduction of a 2nd entrance. Some short term and transient inconsistencies were identified (e.g., Lake King approx 16/01/01), which are considered the result of localised set up or set down effects associated with spatially varying winds, not adequately represented in the Sale wind data.

As presented in Figure 3-5, typical tidal range at Lakes Entrance is around 0.3m which quickly reduces to a range of around 0.1m at Metung and throughout Lake Victoria and Lake King. In Lake Wellington, tidal influences are barely discernable, with greater influence from wind effects apparent (e.g., localised water level set up about 16/01/01).

3.2.4 Water Quality Model Description
RMA11 is a finite element model for the simulation of advection and dispersion processes for conservative or decaying water quality constituents. It is applied to one, two and three-dimensional RMA hydraulic models of estuaries, bays, lakes and rivers. Additional terms for each constituent represent source or sinks and growth or decay and provide mechanisms for interactions between constituents.

3.2.5 Modelled Parameters
RMA2 is used to simulate hydraulic characteristics in the Gippsland Lakes and provides information on water level, and current speed and direction. RMA11 is used to simulate water quality processes (advection and dispersion) resulting from the hydrodynamic conditions. Modelled constituents are salinity and an arbitrary conservative pollutant, used to assess hydraulic flushing.
Figure 3-5  Existing Conditions – Modelled and Observed Water Levels
4 EXISTING CONDITIONS

This section describes numerical modelling of the existing conditions within the Gippsland Lakes. It provides details of the hydraulic model parameter and a description of typical tidal conditions throughout the system.

4.1 General Considerations

The Gippsland Lakes are a series of large, shallow, coastal lagoons approximately 70km in length and 10 km wide. They are connected to the ocean (Bass Strait) by a narrow, maintained man-made channel at Lakes Entrance. The surface area of the lakes is approximately 364km² and the three main water bodies are Lakes Wellington, Victoria, and King. Lake Reeve, adjacent to the coastal dune of Ninety Mile Beach, has an area of approximately 50 km², but it is not tidal and usually dry except following periods of high rainfall and/or flooding in the lakes.

Mean water level in Lake King and Lake Victoria correlates with the mean water level in Bass Strait on moderate time scales (1 week or more). These variations are in response to the effect of longer period changes in atmospheric pressure on water level and storm event set up (or set down) of the water level. The resulting longer term variation in water levels dominates the observed pattern of water level variation throughout the lakes and can result in mean water level variations within the lakes of ±0.2m about mean sea level. During large ocean surge events in Bass Strait the lakes respond with variations in mean water level of as much as 1.0m change. These variations in mean sea level typically occur over periods of a week or more. On timescales of a tidal cycle (approx 12.5 hours) water levels in the lakes are reasonably constant with only a small tidal variation (typically ±0.1m), and due to wind stresses can vary locally over a range greater than the observed tidal range.

4.2 Hydraulic Parameters

4.2.1 Bathymetry

As discussed above in Section 3.2.2, the bathymetry for the model has been derived from a comprehensive digital elevation model developed by the Melbourne University, bringing together a number of survey data sets for the lakes system. The bathymetry for the model is shown below in Figure 4-1, with further detail shown in Figure 4-2 and Figure 4-3.
Figure 4-1  Existing Conditions – Bathymetry

Figure 4-2  Existing Conditions – Bathymetry Detail at Lakes Entrance
4.2.2 Tidal Levels
Typical tidal variation at key locations throughout the Gippsland Lakes system are shown in Figure 4-4. This variation is typical, and occurs superimposed on longer term variations in mean water level.
Figure 4-5 below shows maximum and minimum water levels throughout the lakes associated with mean spring tidal conditions. Again, it should be noted that these levels are typically superimposed on longer term water level variations.

4.2.3 Tidal Range

The mean spring tidal range for existing conditions is illustrated in Figure 4-6.
Note that at Lakes Entrance, in Cunninghame and North Arm, the tidal range is about 0.8-1.0m, and this quickly reduces to less than 0.20m at Metung. The entrance channel, Reeve and Hopetoun channels are reasonably shallow and constricted and result in significant attenuation of the tidal signature. Moreover, the volume of water that can pass through these entrance channels in a tidal rise is limited and once distributed over the area of the lakes results in a small change in water level.

4.2.4 Tidal Velocity

Figure 4-7 shows peak tidal velocity for mean spring tidal conditions. Typical mean spring tidal peak velocities up to 1.5m/s are observed in the entrance channel, with velocities up to 0.5m/s observed in Reeve and Hopetoun Channels. Detail around Lakes Entrance is shown in Figure 4-8.
Figure 4-8  Flood and Ebb Tide Conditions at Lakes Entrance

Other areas where the existing condition tidal velocity is elevated include around the end of the Mitchell River silt jetties (up to 0.15m/s) and throughout McLennan Strait (up to 0.25m/s).
4.3 Water Quality

Existing water quality characteristics in the Gippsland Lakes system have been quantified in terms of hydraulic flushing and saline recovery.

Hydraulic flushing provides an assessment of the predicted residence time for the lakes and relates to the rate at which water within the lakes system is replaced with river or ocean water. Saline recovery provides an assessment of the rate at which the system returns to typical saline conditions following a moderate rainfall/runoff event where the salinity of the lakes has been significantly reduced from typical levels. Both assessments provide valuable insight to the hydraulic exchange mechanisms operating in the lakes.

It is noted that the depth averaged modelling approach does not allow for the representation of stratification, which CSIRO consider to be important in triggering of algal blooms. This may be particularly applicable to deep areas within the lakes system (e.g., Lake Victoria) and to regions considered to be the primary area for bloom growth (e.g., Jones Bay). Nevertheless, in well mixed areas around the existing and proposed 2nd entrance, the depth averaged approach is adequate for defining hydraulic flushing characteristics.

4.3.1 Hydraulic Flushing

To conduct this assessment, the initial concentration of a conservative water quality constituent is set to 1000mg/L, with boundary condition concentrations set to 0mg/L for all river inflows and ocean water. The simulation proceeds for a period of 60 days with results extracted at key locations throughout the system.

Hydrodynamic boundary conditions for the simulation are representative of environmental conditions during the period 01/04/2000-31/05/2005. This is a typical dry period with low river inflows to the lakes. The model includes variable winds for this period based on data from Sale airport.

Figure 4-9 below presents curves representing the reduction in the introduced water quality constituent resulting from hydraulic flushing.

![Figure 4-9: Existing Conditions – Hydraulic Flushing](attachment:image)
These model results indicate very poor hydraulic flushing throughout the lakes. In Lake Wellington concentrations reduce to around 85% in 60 days, due primarily to dilution by inflows from the Latrobe and Avon Rivers. In 60 days the concentrations in Lake Victoria has not changed from the original concentrations as high concentration water from Lake Wellington flows into Lake Victoria and there is no discernable ocean exchange. Similarly there is no significant reduction in concentrations in the Bunga Arm. In Lake King concentrations reduce to around 85% in 60 days, due primarily to dilution from inflows from the Mitchell and Tambo Rivers as well as some limited ocean exchange. At Metung, the effect of ocean exchange is more apparent with variations in concentration of up to 20% of original concentration over a tidal cycle. Flushing at Lakes Entrance is reasonably rapid due to its proximity to the ocean, with concentrations quickly reducing to low levels. Higher concentrations are noted on the ebbing tide as water of high concentration is transported towards the entrance.

Extrapolating the 60 day modelling indicates that Lake King has flushing time in the order of 6 months for dry periods. Hydraulic flushing in Lake Wellington is of the order 12 months. The results highlight the poor hydraulic flushing that exists in the lakes system and the corresponding limited capacity of the system to flush pollutants derived from the catchments.

The Gippsland Lakes Environmental Study undertook similar assessments of hydraulic flushing due to combined tidal exchange and catchment runoff. Rather than median flows (adopted during this study), the GLES model determined flushing time using actual flows, beginning July 1997. Using constant median flows was adopted during this investigation as a conservative approach to determining flushing times, independent of moderate flood events.

The river inflow boundary conditions used in the GLES model flushing simulations (July and August 1997) are presented in Figure 4-10 below. Note that the flow conditions at the start of the simulation period coincide with relatively high flows in the Latrobe, Avon and Mitchell Rivers.

![Figure 4-10 Gippsland Lakes Rivers – Flow Conditions July-August 1997](image)

Use of these relatively high flow conditions at the start of the simulation resulted in the reduction in pollutant concentrations in Lake King to around 50-60% of the original concentration in 60 days. These GLES simulations resulted in flushing rates about twice those determined in this study using median flows.
During the middle part of the GLES simulation, river inflows returned to approximately median flow rates (Tambo 2.40m$^3$/s, Nicholson 0.21m$^3$/s, Mitchell 9.29m$^3$/s, Avon 0.78m$^3$/s, Latrobe 17.46m$^3$/s) and the flushing dropped to rates consistent with the present study. As such, although slightly different methodologies were adopted, flushing rates determined during this study are considered to be consistent with those modelled by CSIRO during the Gippsland Lakes Environmental Study.

### 4.3.2 Saline Recovery

For this assessment, a low initial concentration of salinity is specified throughout the lakes representative of conditions following a moderate flood event. Initial concentrations used in the simulations are shown below in Table 4-1.

<table>
<thead>
<tr>
<th>Location</th>
<th>Initial Salinity (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Wellington</td>
<td>10</td>
</tr>
<tr>
<td>McLennan Strait</td>
<td>10</td>
</tr>
<tr>
<td>Lake Victoria</td>
<td>10</td>
</tr>
<tr>
<td>Lake King</td>
<td>10</td>
</tr>
<tr>
<td>Jones Bay</td>
<td>10</td>
</tr>
<tr>
<td>Bunga Arm</td>
<td>10</td>
</tr>
<tr>
<td>Reeve Channel / Hopetoun Channel</td>
<td>10</td>
</tr>
<tr>
<td>North Arm / Cunninghame Arm</td>
<td>10</td>
</tr>
<tr>
<td>Lakes Entrance</td>
<td>10</td>
</tr>
</tbody>
</table>

Boundary conditions for the simulation are representative of median stream flows for the rivers and a mean spring tide for the ocean boundary. A constant wind of 5m/s from the WSW is applied and there is no rainfall throughout the simulation period. These characteristics are representative of typical dry weather conditions and have been applied to illustrate an “average” saline recovery capacity.

Figure 4-11 shows the extent of saline recovery throughout the lakes at high water on day 60 of the simulation.
External exchange of lake water with the ocean is limited primarily to those areas within the region of tidal excursion, from Lakes Entrance to around Bell Point/Mosquito Point (just east of Metung). Beyond this, internal circulation processes (wind driven or related to the jetting of river inflows) and diffusion dominate the saline recovery processes. Other mixing processes such as wind-wave induced and density related mixing will further enhance saline recovery; however, these processes are not represented in the model. Nevertheless, the model results provide a useful tool for the analysis of the existing ocean exchange mechanisms suitable for subsequent impact analysis.

4.4 Discussion

Hydrodynamic processes in Gippsland Lakes are highly dependent on forcing characteristics of ocean water levels, river inflows, local rainfall and wind. During dry periods, the mean water level in the lakes follows the mean water level in the ocean, which has typical variation of ±0.2m about mean sea level. During large ocean surge events in Bass Strait the lakes respond with variations in mean water level of as much as 1.0m change. These variations in mean sea level typically occur over periods of a week or more. On timescales of a tidal cycle (approx 12.5 hours) water levels in the lakes are reasonably constant with only a small tidal variation (typically ±0.1m), and due to wind stresses can vary locally over a range greater than the observed tidal range.

The system exhibits poor hydraulic flushing with lengthy residence times. This results in a limited capacity to flush pollutants out of the system.
5 MODIFIED CONDITIONS

This section describes numerical modelling of the modified conditions within the Gippsland Lakes. It presents outcomes of modelling undertaken to assess the resultant hydraulic and water quality characteristics of the Gippsland Lakes system with a 2nd entrance in place at Ocean Grange.

5.1 General Considerations

The modified conditions have been developed based on the 2nd entrance option considered by CSIRO in its 2001 study. This option comprises an entrance channel similar in dimension to the existing entrance channel at Lakes Entrance, and the “dredging” of the Bunga Arm Channel to a depth of approximately -4.0mAHD.

5.2 Hydraulic Parameters

5.2.1 Bathymetry

Changes to the model bathymetry for the development of the 2nd entrance option include modifications to the computational mesh to represent an entrance channel similar in dimension to that at Lakes Entrance and dredging within the Bunga Arm Channel to a depth of approximately -4.0mAHD. The bathymetry of the remainder of the model is identical to existing conditions presented in Section 4.2.1. Figure 5-1 shows bathymetric detail around Ocean Grange at the site of the proposed 2nd entrance.

![Modified Conditions – Bathymetry Detail at Ocean Grange](image)
5.2.2 Tidal Levels

Typical tidal variation at key locations throughout the Gippsland Lakes system under the modified 2nd entrance conditions are shown in Figure 5-2. This variation is typical, and occurs superimposed on longer term variations in mean water level.

![Modified Conditions – Tidal Variation](image)

**Figure 5-2**

Figure 5-3 below shows maximum and minimum water levels throughout the lakes associated with mean spring tidal conditions for the 2nd entrance option. Again, it should be noted that these levels are typically superimposed on longer term water level variations.
5.2.3 Tidal Range
The mean spring tidal range for 2nd entrance conditions is illustrated in Figure 5-4.

Figure 5-3  Modified Conditions – Mean Spring Tide Maxima and Minima

Figure 5-4  Modified Conditions – Mean Spring Tidal Range
Note that at Lakes Entrance, and in Cunninghame and North Arms, the typical spring tidal range is about 0.60m. This quickly reduces to less than 0.20m at Metung, consistent with existing conditions. However, in the Bunga Arm at Ocean Grange for the 2\textsuperscript{nd} entrance conditions, tidal range is around 0.60m and this range reduces to less than 0.20m at the Lake Victoria side of the Bunga Arm Channel.

### 5.2.4 Tidal Velocity

Figure 5-5 shows peak tidal velocity for mean spring tidal conditions for the 2\textsuperscript{nd} entrance option. Tidal velocities up to 1.5m/s are observed in the entrance channel at Lakes Entrance, with velocities up to 0.5m/s observed in Reeve and Hopetoun Channels, consistent with the existing conditions. In the Bunga Arm, Bunga Arm Channel and Grange Channel tidal velocities up to 1.0m/s are observed. Detail around the 2\textsuperscript{nd} entrance is shown in Figure 5-6.
Other areas where the existing condition tidal velocity is elevated (around the end of the Mitchell River silt jetties and throughout McLennan Strait) continue to exhibit higher tidal velocities characteristics as before.
5.3 Water Quality

Water quality characteristics in the Gippsland Lakes system for the 2\textsuperscript{nd} entrance option have been quantified in terms of hydraulic flushing and saline recovery similar to that presented for the existing conditions.

5.3.1 Hydraulic Flushing

As with the existing conditions simulations, in the 2\textsuperscript{nd} entrance option the initial concentration of a conservative water quality constituent is set to 1000mg/L, with boundary condition concentrations set to 0mg/L for all river inflows and ocean water. The simulation proceeds for a period of 60 days with results extracted at key locations throughout the system.

Boundary conditions for the simulation are again representative of environmental conditions during the period 01/04/2000-31/05/2005.

Figure 5-7 below presents curves representing the reduction in the introduced water quality constituent resulting from hydraulic flushing with the 2\textsuperscript{nd} entrance in place.

![Figure 5-7 Modified Conditions – Hydraulic Flushing](image)

These model results indicate significantly altered hydraulic flushing throughout the central part of the lakes. In Lake Wellington concentrations reduce to around 85% in 60 days, consistent with existing conditions. In 60 days the concentration in Lake Victoria has also reduced to around 85% of original concentration due to ocean exchange at Ocean Grange. Concentrations in the Bunga Arm reduce to about 38% of original concentration in 60 days. In Lake King concentrations reduce to around 67% in 60 days, due to combined dilution from inflows from the Mitchell and Tambo Rivers as well as ocean exchange via Ocean Grange. At Metung and Lakes Entrance flushing characteristics are similar to existing conditions. The results demonstrate the localised effect of the 2\textsuperscript{nd} entrance on flushing in the Bunga Arm and the central parts of Lakes Victoria and King.

5.3.2 Saline Recovery

For this assessment, a low initial concentration of salinity is specified throughout the lakes representative of conditions following a moderate flood event. Initial concentrations for the
2nd entrance option are identical to those of the existing conditions shown in Table 4-1. As well, boundary conditions for the simulation are equivalent to those of the existing conditions.

Figure 5-8 shows the extent of saline recovery throughout the lakes at high water on day 60 of the 2nd entrance option simulation.

As well as exchange of lake water with the ocean through the entrance at Lakes Entrance, saline recovery is promoted in Lake Victoria from ocean exchange via the Ocean Grange entrance. For both the entrances, the majority of the tidal exchange is limited to those areas within the region of tidal excursion, from Lakes Entrance to around Bell Point and from Ocean Grange to Aurora Channel.
6 IMPACT OF 2ND ENTRANCE

This section presents a comparison of the numerical modelling results for the existing and 2\textsuperscript{nd} entrance conditions. The impact of the 2\textsuperscript{nd} entrance on hydrodynamic and water quality processes is discussed.

6.1 Overview

This section presents the impacts or changes to existing conditions presented in Section 4 resulting from the introduction of a 2\textsuperscript{nd} entrance at Ocean Grange. The information is presented as difference plots, where an increase in a parameter is shown as a positive impact and a decrease in a parameter is shown as a negative impact.

6.2 Hydraulic Parameters

6.2.1 Bathymetry

Changes to the model bathymetry directly resulting from the construction of a 2\textsuperscript{nd} entrance option is confined to the entrance itself and dredging of the Bunga Arm Channel. The bathymetry of the remainder of the model is identical to existing conditions presented in Section 4.2.1. Figure 6-1 shows changes to the bathymetric detail around Ocean Grange at the site of the proposed 2\textsuperscript{nd} entrance.

![Impacts – Bathymetry Detail at Ocean Grange](image)

This illustrates dredging required to create a channel from the lakeside of the 2\textsuperscript{nd} entrance through to Lake Victoria and Aurora Channel to a depth of approximately -4.0mAHD. An
estimated 350,000-400,000m³ of material will need to be removed from within the Gippsland Lakes, and this material could be re-used to create or enhance areas of intertidal habitat.

6.2.2 Tidal Levels

The change in mean spring tidal variation at key locations throughout the Gippsland Lakes system resulting from the introduction of a 2nd entrance are shown in Figure 6-2.

![Image of tidal variation chart with key locations including Lake Wellington, Lake Victoria, Lake King, Bunga Arm, Metung, and Lakes Entrance. The chart shows the water level change over time (hours) with a range from -0.4 to 0.4 meters. Significant changes are apparent in the Bunga Arm whereas throughout the remainder of the system, the 2nd entrance results in impacts to tidal range by less than 0.05m.]

Figure 6-2 Impacts – Tidal Variation

Significant changes to tidal variation are apparent in the Bunga Arm whereas throughout the remainder of the system, the 2nd entrance results in impacts to tidal range by less than 0.05m.

Figure 6-3 below shows the change to tidal maximum and minimum water levels throughout the lakes associated with mean spring tidal conditions for the 2nd entrance option.
6.2.3 Tidal Range

The change in mean spring tidal range for 2nd entrance conditions is illustrated in Figure 6-4.
At Lakes Entrance, in Cunninghame and North Arm, and in Lake Wellington, the impact to tidal range is negligible. However, the 2\textsuperscript{nd} entrance results in an increase in tidal range in the Bunga Arm of up to 0.8m. In Lake Victoria and Lake King the 2\textsuperscript{nd} entrance results in an increase in tidal range of less than 0.1m.

6.2.4 Tidal Velocity

Figure 6-5 and Figure 6-6 shows the change in peak tidal velocity for mean spring tidal conditions resulting from the 2\textsuperscript{nd} entrance option. Increases in tidal velocities greater than 1.0m/s are observed in the Bunga Arm, Bunga Arm Channel and Grange Channel.
Other areas where the existing condition tidal velocity is reasonably high (around the end of the Mitchell River silt jetties and throughout McLennan Strait) continue to exhibit higher tidal velocities characteristics.

### 6.3 Water Quality

Impacts to water quality characteristics in the Gippsland Lakes system for the 2\textsuperscript{nd} entrance option have been quantified in terms of changes to hydraulic flushing and saline recovery.

#### 6.3.1 Hydraulic Flushing

Figure 6-7 below shows the impact of the 2\textsuperscript{nd} entrance on hydraulic flushing.

![Figure 6-7: Impacts – Hydraulic Flushing](image)

Comparison of modified and existing conditions for hydraulic flushing indicates a significant increase in flushing in the Bunga Arm (60% better turnover in 60 days) than for existing conditions. In Lake Wellington, as the primary driver to flushing is the inflow of new water from the Latrobe and Avon Rivers, flushing characteristics are unchanged. Lake King and Metung show enhanced flushing (20% more flushing in 60 days) and Lake Victoria exhibits slight increases in flushing.

#### 6.3.2 Saline Recovery

Figure 6-8 shows the change in saline recovery throughout the lakes for the 2\textsuperscript{nd} entrance option.
6.4 Discussion

The 2nd entrance enhances ocean exchange in central Lake Victoria and Lake King. However, the tidal range in these areas is not significantly altered. The dominant hydrodynamic process continues to be mean water level variations in the ocean, and the impact of the 2nd entrance on hydrodynamics of the central lakes will be negligible. Further, the 2nd entrance will not result in any significant change to the lakes response to long term variations in mean ocean water level (which occurs over periods of a week or more).

The flushing and saline recovery of the central part of the lakes is enhanced by the 2nd entrance. This will slightly improve the existing poor hydraulic flushing and increase the capacity to flush pollutants out of the system.

However, the 2nd entrance results in high velocities in the Bunga Arm and Grange Channels and a comparatively large tidal range in the Bunga Arm. The hydraulic characteristics in the Bunga Arm and around Ocean Grange resulting from the 2nd entrance are similar to those currently observed at Lakes Entrance and the Cunninghame Arm. Bed sediment characteristics in the Bunga Arm and Grange Channel are currently likely to consist mainly of silty sands, which would easily be mobilised under the modified current regime and replaced with coarser beach sands.

It is recognized that the Gippsland Lakes system is often strongly stratified, particularly in the deeper sections of Lake Victoria and Lake King. Strong tidal currents have the potential to break up stratification, but the area of increased tidal velocity resulting from the 2nd entrance is confined to the Bunga Arm, Grange and Aurora Channels, and will have negligible influence on stratification in the bulk of the lakes. Moreover, the 2nd entrance could result in stronger stratification (particularly in Lake King) as the enhanced ocean exchange will allow more saline water to enter the system.
6.5 Comparison with CSIRO 2001 Model

Results from the CSIRO modelling completed as part of the Gippsland Lakes Environmental Study have been compared with results from the current study. Key areas of comparison are existing characteristics and the impacts of the 2nd entrance on:

- Water Levels and Tidal Range
- Hydraulic Flushing

**Water Levels and Tidal Range**

The CSIRO model indicates that the 2nd entrance results in an increase in tidal range in the lakes, almost doubling the existing tidal range. In absolute terms this is an increase of about 0.10m of tidal range, consistent with the results of this modelling assessment, reported in Section 5.2.3 as a predicted increase in range of about 0.10m. Within the context of broader water level variations, this impact is small.

The CSIRO report does not document modelled impacts to water level and tidal range in the Bunga Arm and a direct comparison cannot be made.

**Hydraulic Flushing**

Flushing of the lakes is enhanced by the introduction of a 2nd entrance. In Lake King, CSIRO report approximate doubling in the flushing rate. The modelling undertaken for this study indicates slightly lower increases in flushing rate (relative to the CSIRO study) and is considered due to the more refined representation of the Bunga Arm and Grange Channels leading to the 2nd entrance at Ocean Grange. In the CSIRO model, these numerous channels are represented by a single 500m wide 4m deep channel, whereas in the RMA model, the dredged new channel exists only in the Bunga Arm Channel (refer Figure 1-1 and Figure 5-1 for visual comparison). Accordingly, it is considered that the CSIRO model may somewhat overestimate the improved hydraulic performance of the lakes system resulting from the introduction of a 2nd entrance.

Other characteristics modelled in detail in this study (e.g., velocity) cannot be directly compared with the CSIRO model due to significant differences in spatial resolution.

The significantly improved spatial resolution of the modelling used in this investigation is considered to provide a more realistic representation of hydrodynamic conditions in the lakes system compared to those presented in the CSIRO study. This is particularly the case in those areas where the effects of stratification are minimal.
7 OTHER CONSIDERATIONS

Concurrent issues that would need to be addressed in detail should a 2nd entrance option be considered include the following:

- The impact of the entrance on flooding in the Gippsland Lakes
- The design and impact of the 2nd entrance and its impact on coastal processes along Ninety Mile Beach
- If the 2nd entrance is to be a navigable channel, issues relating to navigation requirements (leads, lighting, tide and wave condition) and maintenance dredging would need to be addressed, including the management and/or disposal of the dredge spoil

7.1 Gippsland Lakes Flooding

Impact of the 2nd entrance on flooding is to be considered as part of Stage II. Interpretation of modelling results during Stage I suggests that, as a result of the 2nd entrance, flood levels in Lake Victoria and Lake King would be slightly reduced, and that the period of inundation would also be reduced.

7.2 Coastal Processes

The 2nd entrance as tested herein assumes a configuration similar in dimension and style to that at Lakes Entrance. The existing entrance suffers from extensive and almost continuous siltation from coastal sediments moving into the entrance channel and being deposited inside the entrance and on the offshore bar.

Numerous studies have investigated the sand transport regime along Ninety Mile Beach. However, the direction of net sand movement along the beach at Lakes Entrance is still not certain. A key similarity between the studies is that the gross transport was estimated at around 1 million m$^3$/year with the net transport typically less than 10% of this amount.

The option developed would need to incorporate considerable longer training walls than those at Lakes Entrance. As well, a bi-directional sand-bypassing system would be required to assist in preserving the longshore transport regime so as not to result in significant erosion of the adjacent beaches. Although only the net transport would need to be by-passed, it is likely that the direction of net transport would vary year to year corresponding to the observed wind/wave conditions.

7.3 Navigation and Dredging

In order to be utilised for navigation, the 2nd entrance would require maintenance dredging to preserve navigable depths. With appropriate design, the need for maintenance dredging of the 2nd entrance could be significantly less than current requirements at Lakes Entrance.

At Lakes Entrance, the side-casting dredge April Hamer commenced operations in 1977. This sidecasting arrangement is still currently used to dredge the channel, predominantly across the bar, side-casting about 290,000 m$^3$/year. Recent modifications to the dredging procedure have been introduced to better utilise the ebbing tide to move the sidecast sand.
Nevertheless, the maintenance dredging cost is significant and is an ongoing burden for the Gippsland Port Authority.

To minimise the potential for dredging and siltation related issues at the 2\textsuperscript{nd} entrance, the actual configuration of the entrance may need to be quite different to that at Lakes Entrance. As well, a bi-directional sand-bypassing system would be required to assist in preserving the longshore transport regime so as not to result in significant erosion of the adjacent beaches.

Material dredged from the channel as part of maintenance activities will need to be disposed of to an appropriate location. The material is likely to be clean sand suitable for disposal to Ninety Mile Beach, returning it to the littoral zone. It could also be used to create/restore habitat in and around the Bunga Arm.

An appropriately engineered entrance (i.e., with long training walls and a bypassing system) may result in reduced maintenance dredging requirements, but is likely to involve significant capital cost, of the order of $20 million. With appropriate design, the channel would require maintenance dredging requirements significantly less than those at Lakes Entrance (currently of the order of $2 million/year, pers comm. Gippsland Ports). It is difficult to determine the likely maintenance costs, as sediment transport investigations required to assess this are beyond the scope of the present study. While a full economic evaluation has not been undertaken, it is considered feasible that an appropriately designed channel with adequately bypassing could result in maintenance dredging requirements of the order of 25% of those currently incurred at Lakes Entrance.
8 STUDY CONCLUSIONS

Key conclusions of the investigation of hydrodynamic impacts of a 2\textsuperscript{nd} entrance are provided below:

- No significant change to water level variation in Lakes Wellington, Victoria or King, which will continue to respond to mean ocean water levels and river inflows.

- Significant increase in tidal water level variation in the Bunga Arm (up to 0.8m additional range).

- Significant increase in tidal velocities in the Bunga Arm and Grange Channels (up to 1.0m/s). This could result in significant scouring of the existing bed sediments replacing them with coarser beach sands.

- Enhanced flushing and ocean exchange in Lake King and the eastern sections of Lake Victoria adjacent the Ocean Grange entrance.

- Potentially slight increase in stratification in Lake King/Victoria due to increased availability of ocean waters.
9 REFERENCES


APPENDIX A

RMA MODEL DESCRIPTION
RMA2 is a depth averaged finite element model for the simulation of flow in coastal, estuarine and floodplain environments. The finite element method is applied to two dimensional depth averaged equations in the numerical assessment. The controlling differential equations are set out below.

**Momentum Equation X-Direction**

\[
\rho \left( \frac{\partial u}{\partial t} + hu \frac{\partial u}{\partial x} + hv \frac{\partial u}{\partial y} + gh \left( \frac{\partial a}{\partial x} + \frac{\partial h}{\partial x} \right) + g \frac{C^2}{2} \left| V \right| u + uq_s - \Omega vh \right) - h \frac{\partial}{\partial x} \left( \varepsilon_{xx} \frac{\partial u}{\partial x} \right) \\
- h \frac{\partial}{\partial y} \left( \varepsilon_{xy} \frac{\partial u}{\partial y} \right) - W_x = 0
\]

**Momentum Equation Y-Direction**

\[
\rho \left( \frac{\partial v}{\partial t} + hu \frac{\partial v}{\partial x} + hv \frac{\partial v}{\partial y} + gh \left( \frac{\partial a}{\partial y} + \frac{\partial h}{\partial y} \right) + g \frac{C^2}{2} \left| V \right| v + vq_s + \Omega uh \right) - h \frac{\partial}{\partial x} \left( \varepsilon_{yx} \frac{\partial v}{\partial x} \right) \\
- h \frac{\partial}{\partial y} \left( \varepsilon_{yy} \frac{\partial v}{\partial y} \right) - W_y = 0
\]

**Continuity Equation**

\[
(h \frac{\partial u}{\partial x} + u \frac{\partial h}{\partial x} + v \frac{\partial h}{\partial y} + \frac{\partial h}{\partial t}) = 0
\]

where

- \(x, y\) = horizontal cartesian coordinates
- \(t\) = time
- \(u, v\) = the horizontal velocity components in the \(x\) and \(y\) directions respectively
- \(h\) = depth
- \(a\) = bottom elevation
- \(\varepsilon_{xx}, \varepsilon_{xy}, \varepsilon_{yx}\) and \(\varepsilon_{yy}\) = the turbulent eddy coefficients.
- \(C\) = Chezy bottom friction coefficient
- \(V\) = Total water velocity
- \(q_s\) = Tributary flow into the system
- \(\Omega vh\) and \(\Omega uh\) = The coriolis forcing in the \(x\) and \(y\) directions respectively.
- \(W_x\) and \(W_y\) = forces due to wind stresses in the \(x\) and \(y\) directions respectively.
Partial integration is applied for the viscous and depth terms. Terms are integrated over the horizontal plan area and along the line boundaries of the elements.

The following element residual vectors result.

**Momentum Equation X-Direction**

\[
f_x = \int NT \left[ \rho \left( h \frac{\partial u}{\partial t} + hu \frac{\partial u}{\partial x} + hv \frac{\partial u}{\partial y} + \frac{g}{C^2} |V| + uq_s - \Omega vh - W_x \right) \right. \\
\left. + \varepsilon_{xx} \frac{\partial u}{\partial x} + \varepsilon_{xy} \frac{\partial u}{\partial y} \right] dA
\]

**Momentum Equation Y-Direction**

\[
f_y = \int NT \left[ \rho \left( h \frac{\partial v}{\partial t} + hu \frac{\partial v}{\partial x} + hv \frac{\partial v}{\partial y} + \frac{g}{C^2} |V| + vq_s + \Omega uh - W_y \right) \right. \\
\left. + \varepsilon_{yx} \frac{\partial v}{\partial x} + \varepsilon_{yy} \frac{\partial v}{\partial y} \right] dA
\]

**Continuity Equation**

\[
f_c = \int MT \left[ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial u}{\partial x} + \frac{\partial h}{\partial y} + \frac{\partial h}{\partial t} \right] dA
\]

where \( A_h \) represents integration over the horizontal plan area.

After differentiation the following integral derivatives form contributions to the finite element equations

**Momentum Equation X-Direction**

\[
\frac{\partial f_x}{\partial u} = \int NT \left[ \rho \left( \frac{\partial u}{\partial \Delta t} + \frac{\partial u}{\partial x} + q_s + \frac{g}{C^2 |V|} \left( 2u^2 + v^2 \right) \right) N_x \right. \\
\left. + \left( \rho hu + \varepsilon_{xx} \frac{\partial h}{\partial x} \right) N_x \right] dA
\]

\[
\frac{\partial f_x}{\partial \nu} = \int NT \left[ \rho \left( \frac{\partial u}{\partial \Delta t} + \frac{g}{C^2 |V|} \nu - \Omega h \right) N \right] dA
\]
\[
\frac{\partial f_x}{\partial h} = \int \mathbf{N}^T \left[ \rho \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} - \Omega v + g \frac{\partial a}{\partial x} \right) \mathbf{M} - \varepsilon_{xx} \frac{\partial u}{\partial x} \mathbf{M} + \varepsilon_{xy} \frac{\partial u}{\partial y} \mathbf{M} \right] dA_h \\
+ \mathbf{N}_x^T \left[ (\varepsilon_{xx} - \rho g) \mathbf{M} \right] + \mathbf{N}_y^T \varepsilon_{xy} \frac{\partial u}{\partial y} \mathbf{M} dA
\]

**Momentum Equation Y-Direction**

The terms for the derivatives of \( f_y \) are symmetrical with those of \( f_x \) and will not be presented.

**Continuity Equation**

\[
\frac{\partial f_c}{\partial u} = \int \mathbf{M}^T \frac{\partial h}{\partial x} \mathbf{N} + \mathbf{M}^T h \mathbf{N}_x dA \\
\frac{\partial f_c}{\partial v} = \int \mathbf{M}^T \frac{\partial h}{\partial y} \mathbf{N} + \mathbf{M}^T h \mathbf{N}_y dA \\
\frac{\partial f_c}{\partial h} = \int \mathbf{M}^T \left[ (\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\alpha}{\Delta t}) \mathbf{M} + u \mathbf{M}_x + v \mathbf{M}_y \right] dA
\]