Report 4: Lakes Shoreline Erosion Hazard

Gippsland Lakes/90 Mile Beach Local Coastal Hazard Assessment Project

April 2014

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Cover Photo: Lake Wellington, western shoreline north of the Latrobe silt jetties (December 2011)

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GLOSSARY

Aeolian	The erosion, transport and deposition of material by wind.
Alluvium	Alluvium is loose soil or sediments, which has been eroded, reshaped by water in some form, and redeposited in a non-marine setting.
Arcuate	Having the form of a bow; curved.
Australian Height Datum(AHD)	A common national plane of level corresponding approximately to mean sea level
Astronomical tide	Water level variations due to the combined effects of the Earth's rotation, the Moon's orbit around the Earth and the Earth's orbit around the Sun
Backshore	The area of shore lying between the average high-tide mark and the vegetation, affected by waves only during severe storms
Calibration	The process by which the results of a computer model are brought to agreement with observed data
Coastal Hazard	A term to collectively describe physical changes and impacts to the natural environment which are significantly driven by coastal or oceanographic processes.
Delta	A complex association of geomorphic settings, sediment types and ecological habitats, at a point where a freshwater sources enters an estuarine water body.
Ebb Tide	The outgoing tidal movement of water resulting in a low tide.
Embayment	A coastal indentation which has been submerged by rising sea-level and has not been significantly infilled by sediment.
EVC	Ecological Vegetation Class. These are the basis mapping units used for biodiversity planning and conservation in Victoria. Each EVC represents one or more plant communities that occur in similar types of environments.
Estuaries	The seaward limit of a drowned valley which receives sediment from both river and marine sources and contains geomorphic and sedimentary conditions influenced by tide, wave and river processes.
Flood Tide	The incoming tidal movement of water resulting in a high tide
Fluvial	Refers to the processes associated with rivers and streams and the deposits and landforms created by them.
Foreshore	The area of shore between low and high tide marks and land adjacent thereto
Geomorphology	The study of the origin, characteristics and development of land forms
GIS	Geographical Information System
Hydrodynamic Model	A numerical model that simulates the movement of water within a defined model area
Interglacial	An interglacial period is a geological interval of warmer global average temperature lasting thousands of years that separates consecutive glacial periods within an ice age.
Intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, eg. intertidal habitat
Lacustrine Deposits	Formed at the bottom or along the shores of lakes
Levee	Raised embankment along the edge of a coastal or riverine environment
LiDAR	**Li**ght **D**etection **a**nd **R**anging – also known as airborne laser scanning, is a remote

	sensing tool that is used to generate highly accurate 3D maps of the Earth's surface
Marine Transgression	A marine transgression is a geologic event during which sea level rises relative to the land and the shoreline moves towards higher ground, resulting in flooding.
Meta-sedimentary	Sediment or sedimentary rock that appears to have been altered by metamorphism (Metamorphism is the change of minerals or geologic texture in pre-existing rocks without melting into liquid magma. The change occurs primarily due to heat, pressure, and the introduction of chemically active fluids).
MSL	Mean Sea Level
Neap Tides	Neap tides occur when the sun and moon lie at right angles relative to the earth (the gravitational effects of the moon and sun act in opposition on the ocean).
Nearshore	The region of land extending from the backshore to the beginning of the offshore zone.
Paleochannel	A remanent of an inactive river or stream channel that has been either filled or buried by younger sediment.
Paleo-river	Another term for paleochannel.
Palaeozoic	The geological area covering the period from about 541 to 252 million years ago. Incorporates the Devonian, Silurian, Ordovician, and Cambrian geological periods
Paludal	Sediments that have accumulated in a marshy or swampy environment.
Pleistocene	The period from 2.5M to 12,000 years before present that spans the earth's recent period of repeated glaciations and large fluctuations in global sea levels
Pliocene	The period in the geologic timescale that extends from approximately 5.3 million to 2.5 million years before present.
Quaternary	The Quaternary Period is the most recent of the three periods of the Cenozoic Era in the geologic time scale. It spans from approximately 2.5 million years ago to the present.
Shoal	A shallow area within a water body; a sandbank or sandbar.
Sea Level Rise (SLR)	A permanent increase in the mean sea level.
Spring Tides	Tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean)
Storm Surge	The increase in coastal water levels caused by the barometric and wind set-up effects of storms. Barometric set-up refers to the increase in coastal water levels associated with the lower atmospheric pressures characteristic of storms. Wind set-up refers to the increase in coastal water levels caused by an onshore wind driving water shorewards and piling it up against the coast
Storm tide	Coastal water level produced by the combination of astronomical and meteorological (storm surge) ocean water level forcing
Susceptibility	The sensitivity of coastal landforms to the impacts of coastal hazards such as sea-level rise and storm waves. This may include physical instability and/or inundation.
Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides
Tides	The regular rise and fall in sea level in response to the gravitational attraction of the Sun, Moon and Earth

Vulnerability	Vulnerability is a function of exposure to climatic factors, sensitivity to change and the capacity to adapt to that change. In this report is means the degree to which a natural system is or is not capable of adapting or responding to the impacts of coastal hazards to which they are physically susceptible and exposed.[1]

[1] Definition taken from the Smartline glossary http://www.ozcoasts.gov.au/coastal/smartline_terms.jsp

1. INTRODUCTION

1.1 Overview

The Department of Sustainability and Environment commissioned Water Technology to undertake the Gippsland Lakes Coastal Hazard Assessment Project. The assessment has broadly identified key coastal processes and hazards within the study area through the application of various tools including detailed hydrodynamic modelling. The potential physical impact of these hazards has been further investigated in detail at a number of representative locations for a range of future sea level scenarios.

This report describes the assessment of shoreline erosion hazards undertaken for this study, and incorporates the following components:

- Identification of the physical, environmental and biological characteristics of the Gippsland Lakes shoreline which contribute to or impact upon shoreline erosion hazard,
- Development of a spatial assessment methodology and GIS tools for assessment of shoreline erosion hazards;
- Definition and refinement of the shoreline hazard throughout the system with specific focus on representative locations and potential future conditions.

1.2 Terminology

1.2.1 Overview

The term coastal hazard is generally used to collectively describe physical changes/impacts to the natural environment which are significantly driven or influenced by coastal or oceanographic processes. Coastal hazards can include a range of processes that result in physical impacts to the natural environment such as:

- **Coastal erosion and accretion** - the retreat or advancement of the coastal shore
- **Inundation** – flooding of areas due to river inflows or sea storms
- **Aeolian (wind) transport of sediments** – the formation or erosion of sand dunes

The scope of this study is limited to the potential magnitude and extent of coastal hazard impacts associated with sea level rise/climate change in the study area. The assessment does not consider, nor make judgements, as to the relative consequence of these potential hazard impacts on assets or social and environmental values. The study does therefore not constitute a full risk assessment where both consequence and likelihood area addressed.

Due to the dominant influence of catchment generated flows on flooding within the Gippsland Lakes, this study differentiates inundation hazards from erosion hazards.

Within erosion hazards we have further differentiated between erosion hazards associated with the coastal outer barrier and those associated with the lakes shoreline. These areas have been assessed separately due to the different processes taking place in these two very different systems. The erosion hazards on the outer barrier are discussed in detail in Report 3: Outer Barrier Coastal Erosion Hazards, while this report details the lake shoreline erosion hazard.

Inundation hazards primarily relate to the potential impact of sea level rise/climate change on extreme water level conditions driven by major catchment generated floods flows into the Gippsland Lakes. These hazards are described in detail in Report 2: Inundation Hazards. The effect of inundation on the lakes shoreline and implications for erosion hazard are discussed in this report.

1.2.2 Hazard Definition

The term "erosion susceptibility" is used to identify erosion hazards in this assessment as it represents the combination of individual erosion hazards or contributors to the hazard(s) and the relative impact of these different drivers or factors on the overall potential for shoreline erosion along any given section of the shoreline.

"Erosion hazard" is then defined as the potential zone of shoreline retreat associated with erosion susceptible shorelines based on available rates of erosion for the Gippsland Lakes over the time frames defined within the hazard scenarios (to year 2100).

The erosion hazard zone results presented in this report are concerned with lake-scale trends of shoreline change rather than small-scale changes, such as single property loss.

1.3 Reporting

This document is part 4 of a series of 5 reports produced as part of the Gippsland Lakes Coastal Assessment Project. It should be read in conjunction with the other reports. The complete set of reports is as follows:

- Report 1: Summary Report
- Report 2: Inundation Hazards
- Report 3: Outer Barrier Coastal Erosion Hazards
- **Report 4: Lakes Shoreline Erosion Hazard**
- Report 5: Coastal Monitoring

2. GIPPSLAND LAKES OVERVIEW

2.1 Geological Setting

2.1.1 The Gippsland Basin

The Gippsland Basin is one of the largest sedimentary basins of southern Australia. It comprises a series of sediment-filled tectonic depressions extending east and south of the South Gippsland Hills and for several hundred kilometres onto the Bass Strait continental shelf (Figure 2-1).

The basin overlies Palaeozoic meta-sedimentary rocks that form the elevated terrain of the Eastern Uplands defining the northern margin of the basin. The offshore part of the basin has been a major source of oil and gas since the 1960's. The Gippsland Basin is divided into tectonic units by east-west trending faults that define a stepped series of platforms and terraces with northern and southern components.

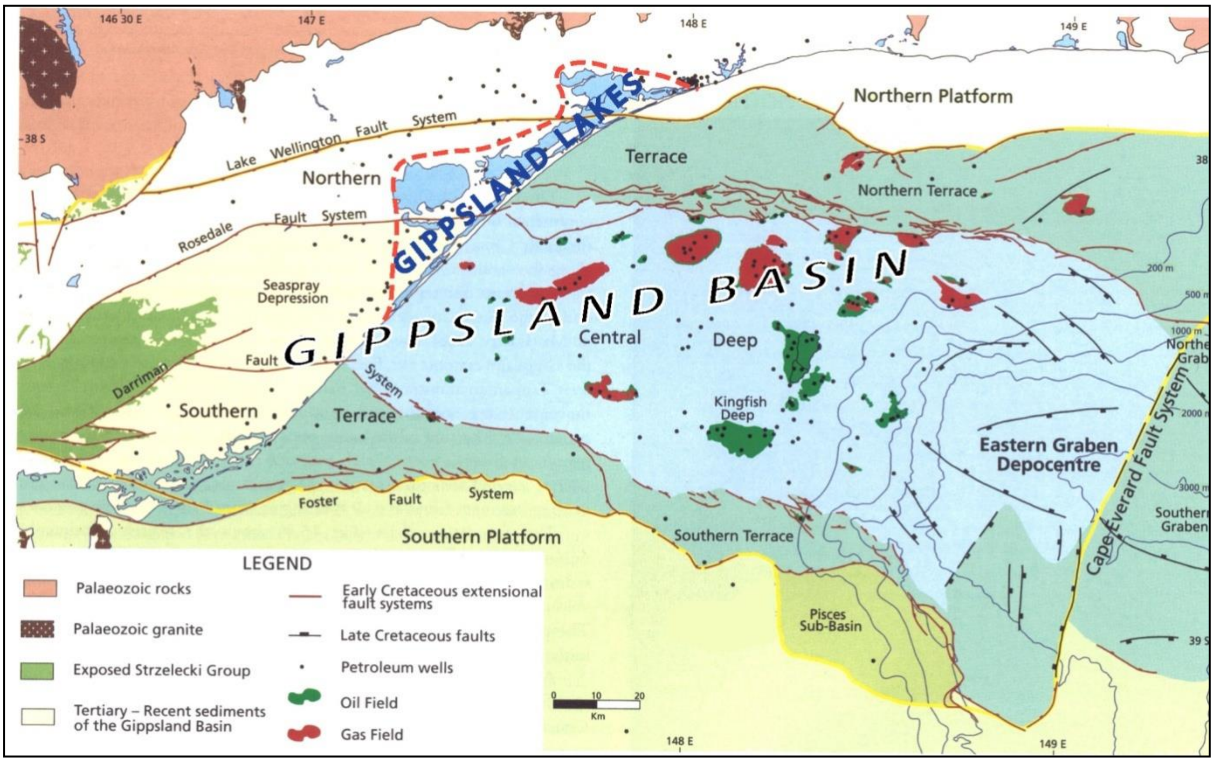

Figure 2-1 Gippsland Basin and Gippsland Lakes (after (Bernecker, 2003))

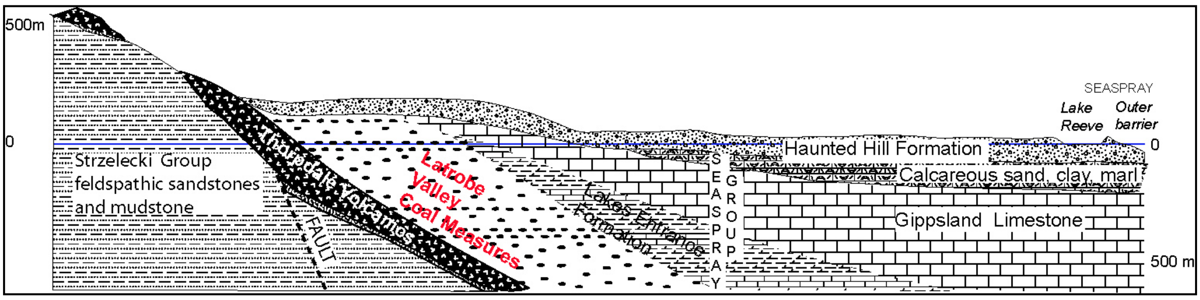

Figure 2-2 Geological cross section onshore Gippsland Basin (after (Holdgate, 2003))

2.1.2 The Gippsland Lakes

Origin

Cutting obliquely across the northern terrace and platform of the Gippsland Basin is a former marine embayment established during late Pliocene and Pleistocene higher sea levels, now enclosed and partly filled by a sequence of coastal sand barriers and lacustrine, paludal and fluvial deposits of Late Quaternary age. These deposits and associated landforms, developed during episodes of higher and lower sea level, comprise the largest coastal barrier and lagoon system on the Australian coast and are regionally referred to as the Gippsland Lakes, Figure 2-3.

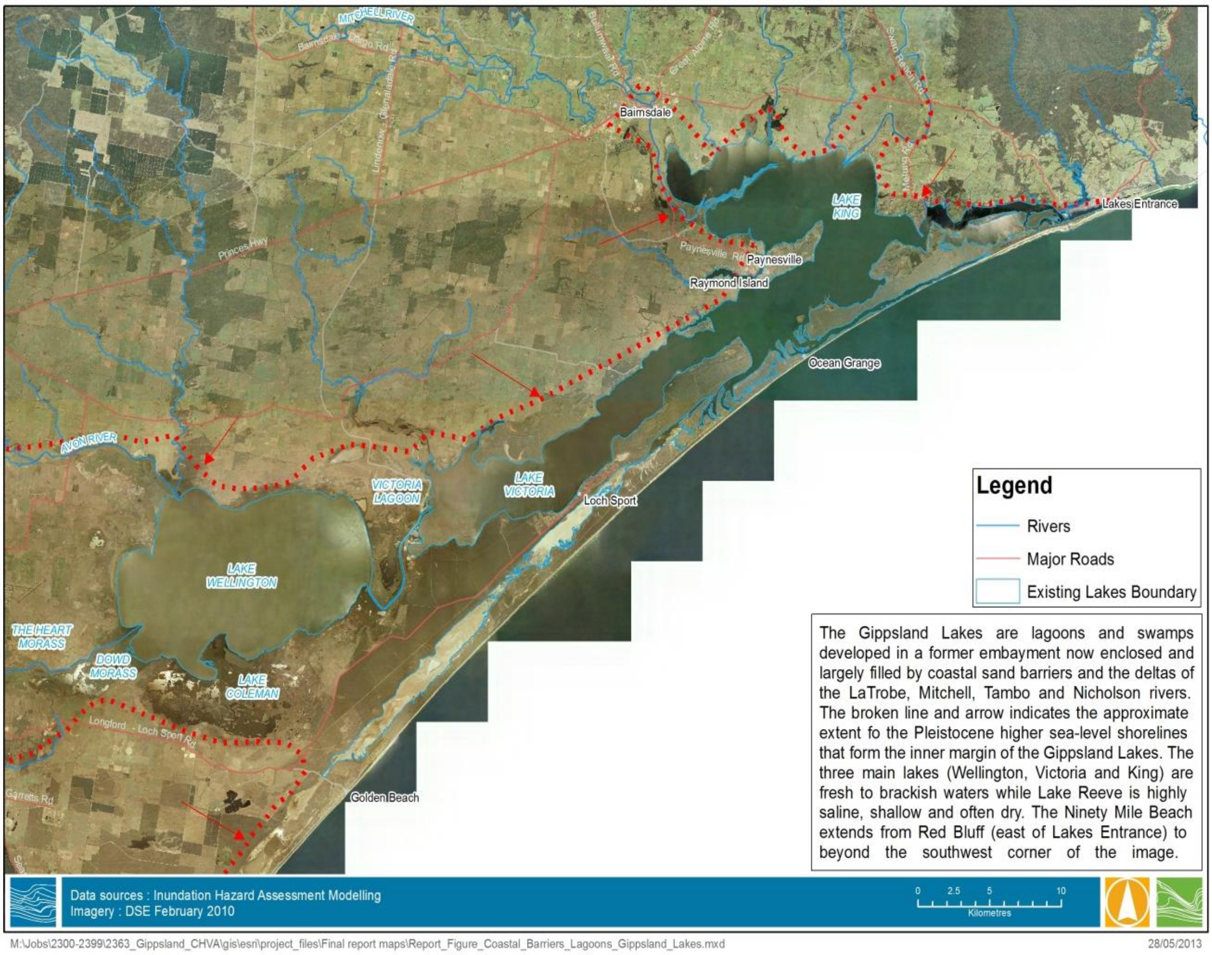

Figure 2-3 Coastal barrier and lagoons of the Gippsland Lakes

The former embayment that contains the Gippsland Lakes is cut into a level to gently sloping surface with a basement of Seaspray Group limestone covered by Haunted Hills Formation sand, clay and gravel.

During times of Pleistocene higher sea-levels, wave action during marine transgressions submerged and eroded the edge of this plain, forming an active cliffed coastline. The sea extended into the major river valleys forming estuaries. At lower sea levels, the marine cliff was abandoned and streams extended beyond the former shoreline cutting deeper valleys and partly backfilling these with alluvium. This sequence of submergence and emergence occurred on multiple occasions over the past 4 million years in response to global glacial and interglacial conditions.

Features formed at low sea-level were rapidly reshaped or submerged during the transgressions. Magnetic and seismic imagery of the lakes region reveals numerous traces of buried river channels and remnants of multiple barrier systems (Figure 2-4). The palaeo-river systems can be interpreted as low sea level extensions of the modern rivers; however the magnetic traces of the oldest coastal barriers have an orientation about 15^0 more northerly than the trend of the modern Ninety Mile Beach. There is no surface expression either onshore or offshore of these features.

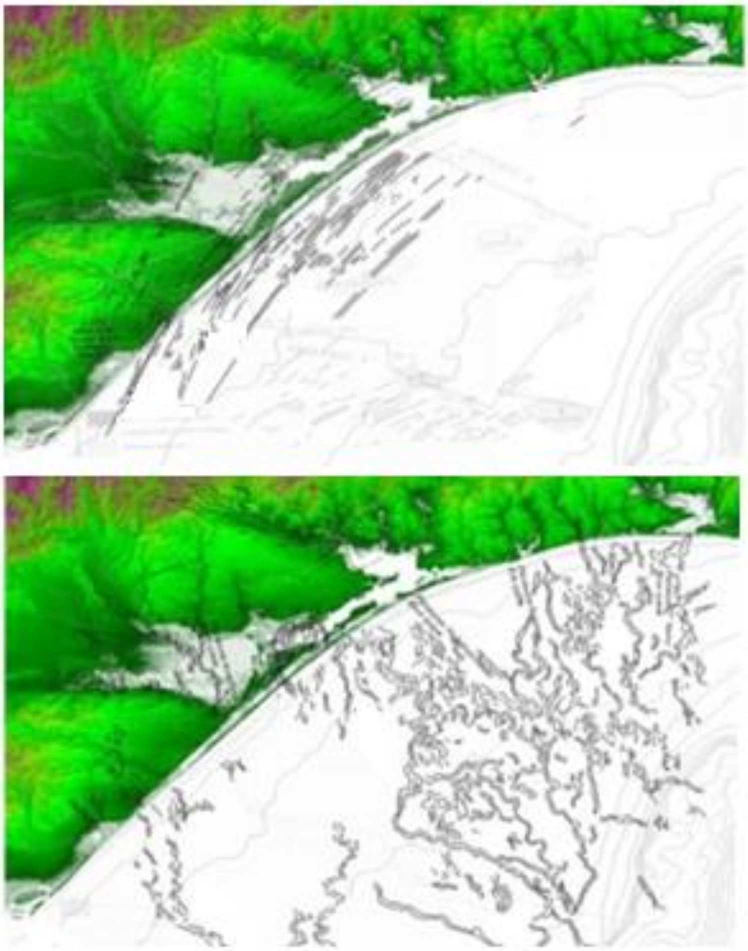

Figure 2-4 Palaeo Barrier and River Systems Onshore and Offshore – Gippsland Lakes. (Modified From Holdgate *et al.* 2003)

Regional Geomorphology

Six fundamental groups of landforms comprise the key components of the Gippsland Lakes (Figure 2-5).

i. A marginal bluff (a former marine cliff) marking the limit of Pleistocene high sea level submergence of the Gippsland Basin. This submergence created the embayment that the lakes now occupy.
ii. The plains and low plateau bordering the marginal bluff. Surface features on these plains include palaeo-fluvial features (channels and levee banks) and broad, multiple terraces separated by low escarpments and with linear and arcuate sand ridges that appear to be traces of pre-Pleistocene marine transgressions.
iii. The lakes and lagoons and associated shorelines of the main lakes.
iv. Active and relict coastal barriers - elongate sand and gravel ridges initiated by ocean wave action and modified by wind action and vegetation growth. These have a complex topography of ridges and depressions, many with small lakes or wetlands.

v. The main river valleys and associated channels, floodplains and deltas that extend into the lakes.
vi. The Ninety Mile Beach and nearshore wave and current environment created by swell waves in Bass Strait.

Superimposed onto these fundamental landforms are secondary features and processes that have been directly attributed to European settlement of the region.

The most obvious of these include:

(i) The opening and maintenance of an artificial entrance at Lakes Entrance since 1889 has created a permanent tidal entrance allowing regular incursions of seawater into the lake system. This has altered the salinity regime of the lake systems from fresh or intermittently brackish to one of continuous higher salinity, with subsequent impacts on the ecology and geomorphology of many of the lake shorelines. It has also interrupted the longshore movement of sand on the Ninety Mile Beach and created ebb and flood tide deltas that require maintenance dredging. It has also triggered increased sedimentation and segmentation of the formerly open waterway of Cunninghame Arm.

(ii) Alterations to flow regime of rivers by dams, irrigation diversions, channel clearing and levee bank construction. This has reduced the mean fresh water inflow and changed the shape of the annual and flood hydrographs. There have been local increases in sediment load as a result of land clearing and river bank destabilisation.

(iii) An increase in physical pressures on the water and land surface by buildings, roads, harbour and marina construction, boat traffic and shoreline engineering works. These have altered the geometry of some landforms and changed the physical and ecological processes of the surface, lake and groundwater systems.

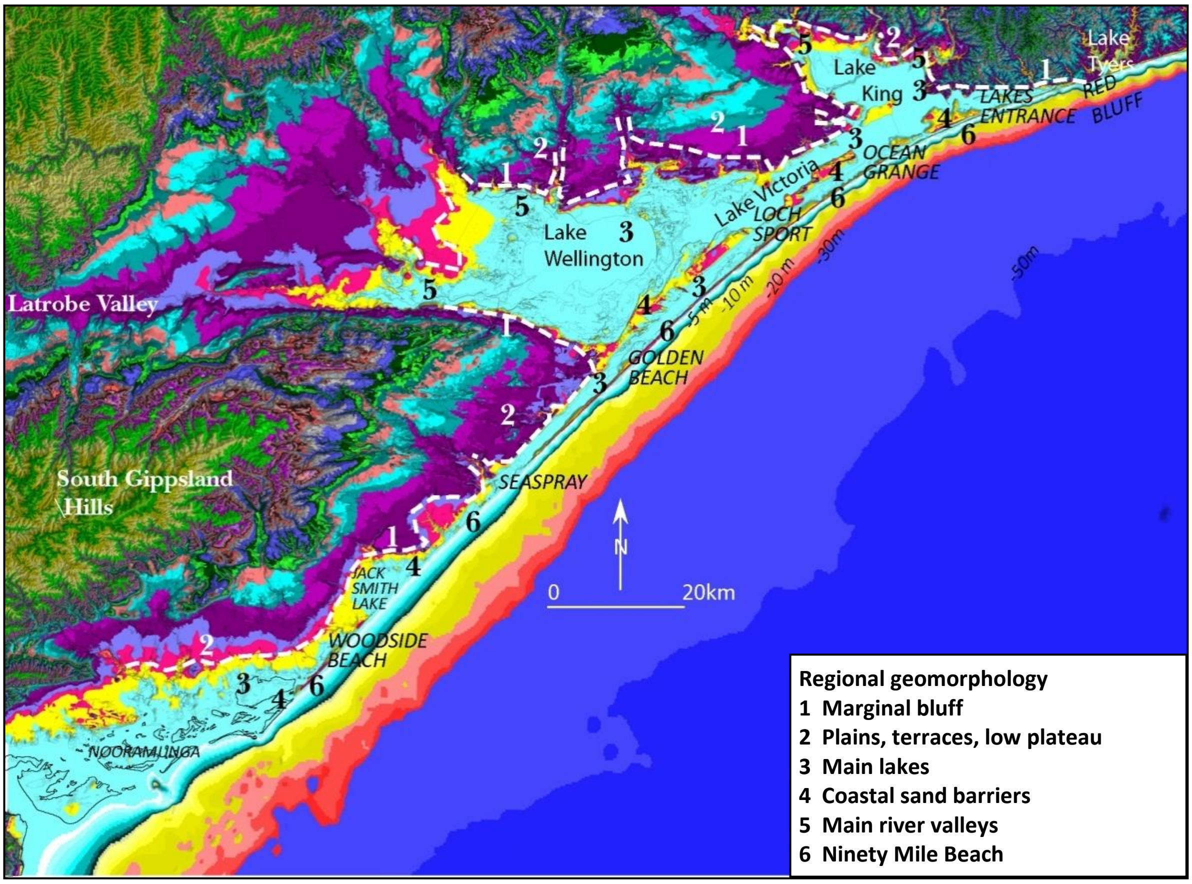

Figure 2-5 Regional geomorphology

2.2 Physical Setting

2.2.1 Overview

The Gippsland Lakes themselves are a system of coastal lagoons sheltered behind sandy barriers. They include Lake Wellington (area 138 km^2; shoreline length 60 km), Lake Victoria (area 110 km^2; shoreline length just over 100 km), Lake King (area 92 km^2; shoreline length 160 km), and various other smaller lagoons with extensive swamps across a broad, low-lying coastal plain (Bird, The Geomorphology of the Gippsland Lakes Region, 1978).

The system is linked to the sea by an artificial entrance near the eastern end (Lakes Entrance), opened in 1889. Before 1889 the entrance moved during floods or storms and became restricted during periods of low river flows (Ecos, unpublished).

The bathymetry of the Lakes themselves is highly varied and includes shallow mudflats and sand banks. Lake Wellington is quite shallow (2-3 m deep), as are other areas in the lakes (Jones Bay in Lake King, the western end of Lake Victoria, and between Barrier Landing and Kelly Head). The deepest areas, down to 10 – 12 m deep, occur in the central sections of Lake Victoria and Lake King (south of the Silt Jetties), and in Reeve Channel (BMT WBM, 2011).

Key geomorphic features associated with the Lakes shoreline are described in the following sub-section. Aspects related to the coastal barriers, particular the outer barrier are detailed in Report 3: Outer Barrier Coastal Hazards.

2.2.2 The Main Rivers

The Lakes are fed by several major rivers. The Latrobe and Avon rivers flow into the west end of Lake Wellington while the Mitchell, Tambo and Nicholson flow into the northern part of Lake King. Apart from the Nicholson, all have extensive cuspate deltas extending into the lakes. Cuspate refers to the shape of the delta, which takes on a tooth-like form. They are shaped by gentle, regular opposing marine processes and are often subject to long-shore currents which redistribute sediment.

The estuarine reaches of these rivers are characterised by a levee-backswamp morphology, where the river channel is situated between natural levees that are perched above “backswamps” – e.g. the fringing wetlands of Sale Common, Heart Morass and Dowd Morass adjacent to the Latrobe River estuary and Macleod Morass adjacent to the Mitchell River.

The primary source of sediment input into the lakes is from catchment sources. In the estuarine reaches of rivers/streams entering the Gippsland Lakes, some infilling may occur following flood events (Ecos, unpublished).

Delta and Silt Jetty Geomorphology

The most pronounced silt jetties in the Gippsland Lakes are those of the Mitchell River delta which extend almost 8 km into the lake as low, narrow tongues of sediment that were formerly bordered by a wide zone of reed swamp (DPI, n.d.). There has been debate about the origin of the Mitchell River silt jetties. Rosengren suggested that it was most likely that the silt jetties are a true deltaic form (DPI, n.d.), a view supported by Flack and Erskine (1996). Major factors in the growth of the Mitchell River silt jetties are thought to be the virtual absence of tidal currents in Lake King and the present of the shoreline reed swamp fringe, enabling trapping of riverine derived sediments and affording protection from wave attack.

The evolution of other silt jetties within the Gippsland Lakes, such as those on the Latrobe River in Lake Wellington, has not been specifically studied. They are likely to have been formed by progressive deposition and colonisation by reeds of sediment at the river mouth, as proposed for the Mitchell River silt jetties. An alternative hypothesis is that they are drowned remnants of natural levees that formed at a time of lower sea level.

Delta growth in the Gippsland Lakes has typically been curtailed or reversed over the last 100 years. The Mitchell River delta and Tambo River delta have been reduced substantially in area as a result of shoreline recession over the past 100 years, as described in Bird (1978). Both deltas now have extensive rock wall emplacements to manage the rate of shoreline recession. Until recently, only the Latrobe River silt jetties were considered to still be accreting.

However, a recent analysis of shoreline changes associated with the Latrobe silt jetties is provided in Water Technology (2013), which shows the same recession characteristics noted in the other systems. These silt jetties are bordered by a fringe of phragmites along the lake shoreline and submerged silt deposits extend further into the lake beyond the phragmites fringe, as shown in Figure 2-6. Comparisons of historical photographs indicate that the shoreline has receded and phragmites beds have narrowed since the 1950s, Figure 2-7. However, reed beds are still present along the lake-ward margin and appear to be more extensive to the south of the river mouth.

Figure 2-6 View of the Latrobe River silt jetties from Lake Wellington showing the retreat of shoreline vegetation and exposure of underlying sediments (taken in December 2011)

The most commonly postulated causes of the contraction of the Phragmites reedbeds and retreat of the various silt jetties on rivers entering the Gippsland Lakes include:

- A change in salinity regime since the opening of the permanent entrance in 1889, potentially exacerbated by reductions in river inflows associated with changes in water management;
- Erosion by wave action, with direct impact on Phragmites, as well as erosion of the lake shoreline (more extensive Phragmites beds remain on “sheltered” parts of the Lake Wellington shoreline); and
- Sea level rise, with water levels becoming too deep for Phragmites.

The effects of vegetation on shoreline erosion are discussed further in Section 4.3.

The Mitchell River Delta is a geological and geomorphological site of international significance, while the Latrobe and Tambo River Deltas are considered of state significance.

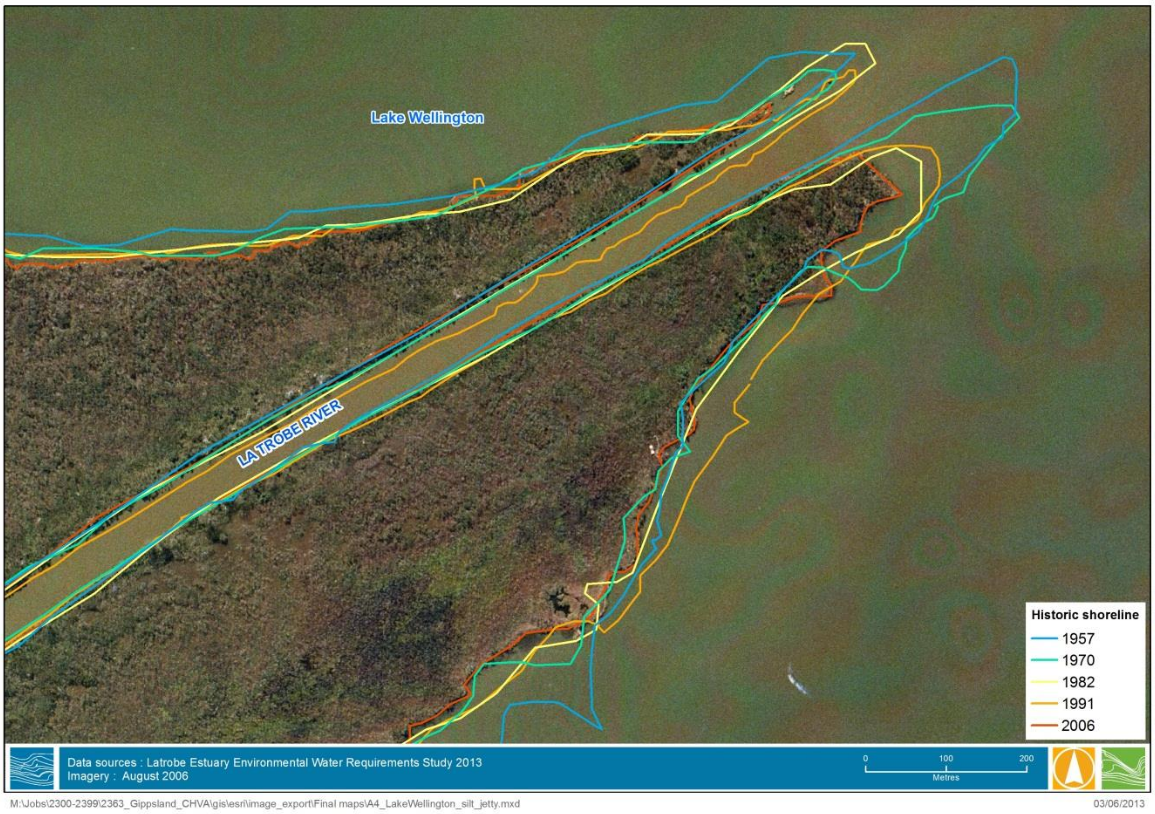

Figure 2-7 Comparisons of geo-rectified historical aerial photographs showing shoreline changes along the Latrobe River silt jetties since 1957 (Water Technology, 2013)

2.2.3 McLennans Isthmus and McLennans Strait

The following extract is taken from GL40 (8321) McLennans Isthmus and McLennans Strait (DPI, n.d.).

Lakes Victoria and Wellington are separated by a long broad tract of sandy and swampy terrain that represents an advanced stage of segmentation of a formerly larger lagoon. The lakes are now connected only by a narrow residual channel (McLennans Strait) and exhibit a marked contrast in hydrological and ecological conditions.

McLennans Isthmus is a long, sandy promontory that extends south-east from Roseneath Point as a narrow, gently curving beach, backed by low beach ridges crossed by numerous small blowouts and parabolic dunes. Erosion and retreat of this beach is evident along the northern sector where stumps of Melaleuca, banksias and eucalypts are stranded in Lake Wellington 40 to 50 metres from the shoreline. The spit has grown south-eastward from a remnant of the prior barrier that forms the low plain south-east of Meerlieu and has thus enclosed low lying areas with the resultant development of lakes and swamps. The marginal bluff lies well inland here, diverging adjacent to Toms Creek as valley side bluffs.

The southern section of McLennans Isthmus is a compound recurving spit with several parallel ridges that terminate in the swampland north of McLennans Strait. The spit has grown under the influence of waves generated by westerly winds which have moved sand across Lake Wellington from the mouths of the Latrobe and Avon rivers and from eroded shorelines on the north.

McLennans Strait is a deep narrow channel that connects Lakes Wellington and Victoria and maintains sufficient current flow to prevent the extension of the sandspit and incursion by reedswamp that would result in complete closure of Lake Wellington. The current pattern in the Strait is complex, and reflects tidal movement through Lake Victoria as well as wind generated currents in Lake Wellington. Outflow into Lake Victoria is indicated by the reed-fringed delta that forms Medusa Point and Griffin Point.

This low lying section of land and channel are highly vulnerable to changes in sea level, as demonstrated in Report 2: Inundation Hazards, and changes to the extent and formation of this area will significantly affect the shoreline responses in both Lake Wellington and Lake Victoria.

2.2.4 Other Sites of Geological and Geomorphological Significance

Additional sites of state geological and geomorphological significance around the shoreline of the Gippsland Lakes are summarised below. Further details are provided on Victoria Resources Online (***http://vro.dpi.vic.gov.au/dpi/vro/egregn.nsf/pages/eg_lf_sites_significance***).

The sites summarised in this section relate to the lakes shoreline only. Those sites associated with the barrier dunes and coast are not detailed herein.

GL20 (8422) McLeod Morass

McLeod Morass is a freshwater swamp, now partly drained and confined as a back swamp of the Mitchell River between the sloping levee banks and the base of the marginal bluff. At the foot of the bluff and extending north from Skene Creek is a distinctive low ridge consisting of sand and pebbles. These were derived from erosion of the gravels of the former cliff (marginal bluff) and reworked to form a beach and barrier system that blocked the valley of Hollis Creek and extended, with a slight recurve, as a spit into the former embayment at the mouth of McLeod Creek.

GL23 (8422) Point Turner – Banksia Peninsula

The cliffed shoreline near Point Turner is the best example of the composition and form of the prior barrier exposed in the Gippsland Lakes.

2.2.5 Sediment Sources

River Sourced Sediment

River sourced sediment is typically fine grained and is transported in suspension from the rivers into the Lakes, where the reduction in velocity, combined with higher salinity, results in settlement of the material out of the water column. Particle size analysis of sediment in the Gippsland Lakes has shown that ~90% by weight is less than ~10 µm (CSIRO, 2007).

The mean annual suspended sediment load from the rivers flowing into the Gippsland Lakes is estimated to be between 198 to 250 kt/year. This equates to a uniform sedimentation rate of around 2.3 mm/year for Lake Wellington and 1.3 mm/year for the entire Gippsland Lakes (Ecos, unpublished). These sedimentation rates are considered at the upper end of the likely range as large flood events can flush sediment from the Lakes, and deposition is not uniform across the system with a higher percentage of the inflowing sediment load depositing on river deltas and floodplains.

Coarser sediment such as sand is typically transported as bed-load in rivers and generally only transported in suspension during large flood events. However, mobilisation of sandy material in the river systems provides a sediment source into the Gippsland Lakes, with resultant sedimentation particularly along the shoreline. The Avon River is an example of this occurrence. Bird (1978) describes how historical changes in land-use practice have resulted in changes to the river channel, with shoals of sand and gravel exposed, resulting in sediment infilling in the lower reaches of the river. Some sand is also being transported into Lake Wellington, resulting in widening of beaches at Marely and Strathfieldsaye. Bird (1978) also notes that similarly, sand carried by Mitchell River floodwaters into Jones Bay, is subsequently delivered to the shore near Port Lardener, and sand discharged by Tambo floodwaters builds up beaches on adjacent parts of the shoreline of Lake King.

Both the fine and coarser grained sediments entering the lakes via the various inflowing rivers can then be re-entrained and deposited around the system depending on wind, wave and current action.

Marine Sourced Sediment

The permanent entrance linking the Gippsland Lakes to Bass Strait provides a conduit for sediment (predominantly sand) to enter the lakes system. Large volumes of sand have since accumulated within the entrance (between Bullock and Rigby Islands; as well as Cunninghame Arm) and offshore of the entrance (Ecos, unpublished). These areas have been dredged at various intervals since the entrance was opened. Sand moves between the offshore bar and internal channels on a daily basis with the tidal currents.

However, the ability of the inflowing ocean water to penetrate into the lakes system is affected by the capacity of Reeve Channel inside the entrance. Reeve Channel, being generally shallower than the entrance channel, acts as a further hydraulic control. The volume of Reeve Channel is greater than the volume of ocean water that flows in through the entrance over a tidal cycle and so provides a limit for the penetration of this saline water and any sandy sediment that it carries into the Lakes. The contribution of marine sands to deposition within the lakes is therefore limited to those areas close to the entrance.

Scouring of the entrance channel, whereby deposited sediment is mobilised and transported out of the channel onto the offshore bar or beyond, can occur when there are significant flood waters entering the lakes from one or more of the inflowing rivers.

3. HAZARD ASSESSMENT METHODOLOGY

The following section outlines the framework developed for assessing shoreline erosion hazard of the Gippsland Lakes system. The framework involved the development of a spatial data model which combined both quantitative and qualitative descriptors of the key physical, environmental and biological characteristics of the Gippsland Lakes to provide an assessment of the susceptibility of the lakes shoreline to erosion and from this, an indicative erosion hazard zone was developed.

The term "erosion susceptibility" is used to identify erosion hazards in this assessment as it represents the combination of individual erosion hazards or contributors to the hazard(s) and the relative impact of these different drivers or factors on the overall potential for shoreline erosion along any given section of the shoreline.

Erosion hazard is defined as the potential zone of shoreline retreat associated with erosion susceptible shorelines based on available rates of erosion for the Gippsland Lakes.

3.1 Previous Lagoon & Estuarine Erosion Hazard Assessment Methods

The following section provides a brief review of existing coastal shoreline mapping and vulnerability assessment methods. These methods have been developed and applied to typically open coastal systems rather than for estuarine lagoons and lake systems such as the Gippsland Lakes. Therefore, the hazard assessment method described for this study has been developed independently and specifically for the assessment of erosion hazards within the Gippsland Lakes. It does build upon these studies, however the framework developed reflects issues specific to the Gippsland Lakes and potentially other estuarine lagoon and lake systems.

3.1.1 Shoreline Mapping Approaches

Smartline (as detailed in Sharples et al. (2009)) is a GIS map format that has been used to create a detailed nationally-consistent coastal geomorphic map of Australia, for the purpose of assessing the vulnerability of the Australian coastline to sea level rise and climate change. The system provides a framework for describing the geomorphic and stability conditions of the coastline and many of the attributes have been adopted for this study as described in the following sections. The approach considers landform and does not include vegetation, tidal and current conditions, waves or other attributes. No detailed characterisation of shorelines along estuarine or lagoon systems is included.

Howes et al. (1999) outlines a system for mapping the physical and biological character of an estuary. It was designed for large-scale mapping of estuarine shorelines. The work includes consideration of physical processes such as wave exposure, but does not link the various factors together in terms of a risk or hazard categorisation for the shoreline.

Hennecke & Cowell, (2000) present a GIS rule-based assessment technique for quantifying sea level rise response of coastal inlets and bays. The approach presents three methods for defining potential erosion of such shorelines, however none of the GIS models are applicable in the Gippsland Lakes system due to the distinct physical, environmental and biological conditions of the lakes. Nevertheless, the approach does provide a GIS framework for assessing erosion hazards for different coastal and estuarine shoreline types similar in concept to that adopted for this study.

3.1.2 Coastal Vulnerability Index (CVI)

Abuodha and Woodroffe (2006) summarise various techniques available for assessing the vulnerability of coasts to climate change, and in particular how these could be applied to the Australian coastline. They describe an application of the coastal vulnerability index approach (such as Gornitz et al. (1994); Thieler & Hammar-Klose, (1999)) to a section of NSW coastline.

In general, the coastal vulnerability index approach provides a ranking system of coastal vulnerability based on a range of risk variable factors. For example:

$$CVI = \sqrt{\frac{(a*b*c*d*e*f*g)}{7}}$$

Where a = dune height, b = barrier type, c = beach type, d = relative sea-level rise rate, e = shoreline accretion/erosion rate, f = mean tidal range, and g = mean wave height. Each of the variables is classified on a scale of typically 1 to 5 (Abuodha & Woodroffe, 2006). The risk factors themselves can be determined through a shoreline mapping approach such as described previously.

In all cases reviewed for the study, the application of this technique to estuarine or lagoon shorelines was not discussed.

3.2 Spatial Data Model

The conceptual spatial data model provides the framework for the hazard assessment, and is presented in Figure 3-1. The analysis has been undertaken along the entire shoreline for the Gippsland Lakes study area at a 5 m grid resolution. The shore line was derived from the DSE Vicmap 1:25,000 coastline with some minor modifications to include silt jetties and other coastal details. A grid-based analysis was selected due to the large number of data inputs combining grid, linear, polygon and point features. A raster (grid cell) based analysis is an effective method to combine many sources of information as it reduces the numbers of small slivers and overshoots that are artefacts of input data that is not coincident or in perfect alignment.

The first step was to collate and assign a numeric score for each input factor based on susceptibility to erosion or impact on susceptibility to erosion. The source information for the input factors is listed in Table 3-1 below, with further descriptions and details of the input factors provided in Section 4.

Table 3-1 Summary of spatial data model inputs

Input factor	Data source
Fabric	Adapted from Smartline (Sharples, Mount, & Pederson, 2009); Geology (DPI, 2010)
Form	Coastal 1 m DEM (DSE, Future coasts)
Artificial shoreline structures	Coastal Asset Information (DSE Future Coasts) and Aerial photography interpretation (Water Technology)
Wave environment	Hydrodynamic models (Water Technology)
Currents	Hydrodynamic models (Water Technology)
Coastal vegetation	EVC (DSE) and Aerial photography interpretation (Water Technology)
Land use	PLM25 (DSE), Aerial photography interpretation (Water Technology)

The scores for each input factor have been combined into three components, defined as:

- The Physical component score combining the fabric, form, geology / geomorphology and artificial shore line data. This approach is based upon the Smart Line analysis methodology developed by Sharples et al. (2009).

- The Environmental component score combining the wave / wind and current data derived from hydrodynamic modelling.
- The Biological component score combining the EVC and land use data.

By producing the three component scores, the opportunity is provided to weight the inputs separately to produce the integrated shoreline erosion susceptibility mapping data layer. The analysis was designed to allow the weighting exercise to be undertaken iteratively to test the sensitivity of the analysis and to view the outputs from different weighting options.

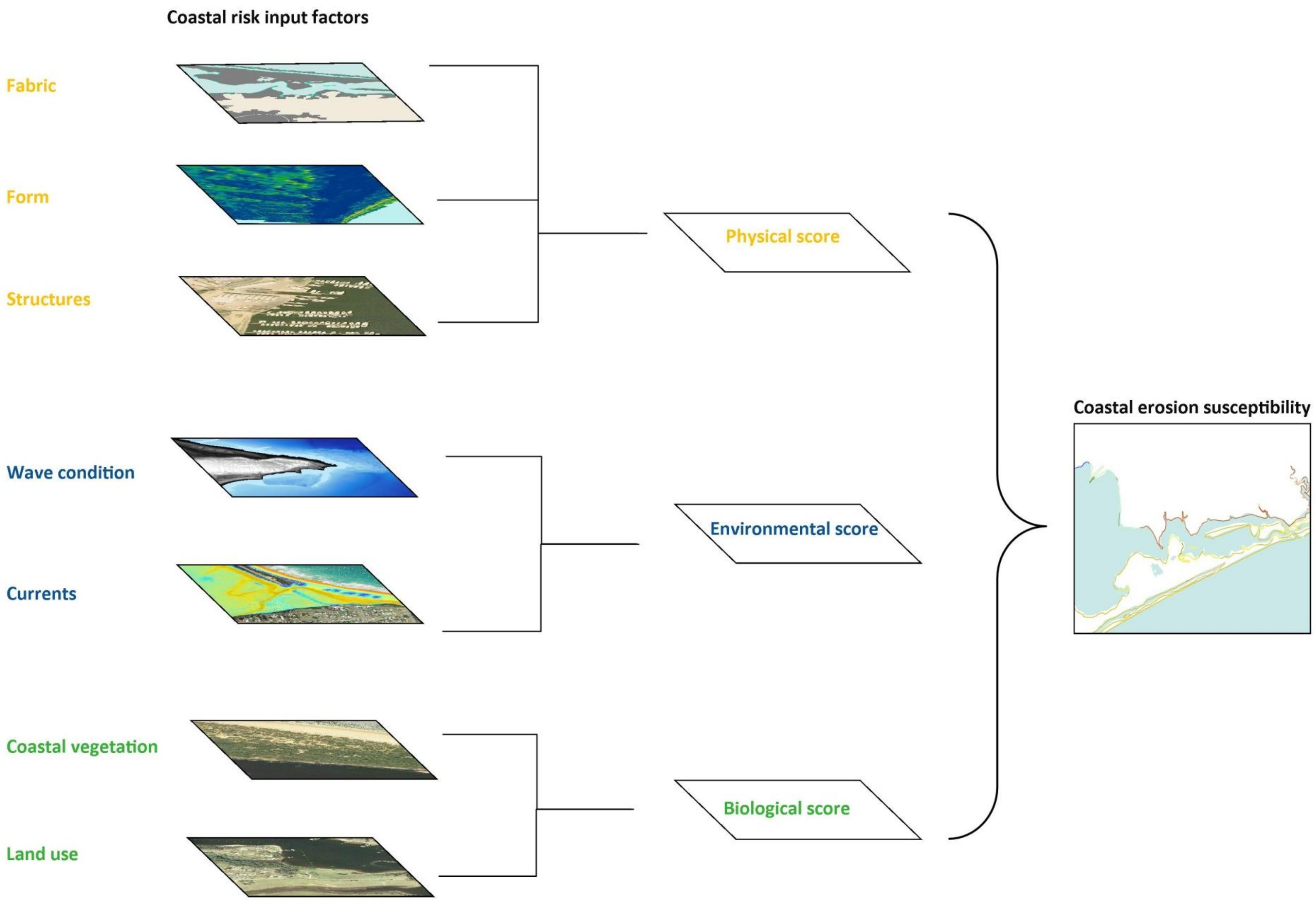

Figure 3-1 Overview of conceptual spatial data model

3.3 Erosion Susceptibility Components

As discussed, the focus of the shoreline erosion susceptibility assessment was based on the three key components:

- ***Physical***: based on the Smartline (Sharples, Mount, & Pederson, 2009) characterisation of fundamental factors such as fabric and form,
- ***Environmental***: wind, wave and current characterisation, and
- ***Biological***: vegetation and land use characterisation.

For each component, a susceptibility score has been assigned to sections of the Lakes shoreline. A weighting has then been applied to the three individual component scores and these values are then combined to form an overall shoreline erosion susceptibility rating. A summary of the approach is provided below in Table 3-2. The overall rating has been split into 2 categories (high and very high), to describe the potential erosion hazard.

Table 3-2 Summary of erosion susceptibility score approach

Component	Erosion Susceptibility Score (a)	Weighting (b)	Overall Shoreline Erosion Susceptibility Rating
Physical	1-5	1	$\sum(a \times b)$
Environmental	1-5	0.5	
Biological	1-5	0.25	

The scores and weightings for each component were developed through an iterative benchmarking process, described in more detailed in Section 5.2.

3.4 Overall Susceptibility Rating

The overall shoreline erosion susceptibility rating is therefore based on the resultant score for the three different contributing components. The resultant scores ranged from 2 to 8.75, and for this assessment scores above 5.5 (the 50th percentile) were identified as indicating potential susceptibility to erosion and these have been categorised as high and very high erosion susceptibility. This percentile value was adopted based on the method benchmarking results, described further in Section 5.2. They can be compared to the slowly eroding, eroding and mobile status types previously determined by Sjerp et al. (2002). Slowly eroding sections typically exhibited erosion rates in the range 0.1 m/year to 0.2 m/year, while eroding or mobile sections showed rates of > 0.2 m/year and up to 0.5 m/year (Sjerp, Martin, Riedel, & Bird, 2002). A summary of the likely erosion rates associated with the erosion susceptibility ratings detailed in this report is provided in Table 3-3. These are relatively low rates of erosion and reflect the typically low energy environment of the Gippsland Lakes system.

Table 3-3 Summary of Erosion Ratings and Likely Erosion Rates

Erosion Susceptibility Rating	Erosion Rates (based on Sjerp et al, 2002) (m/year)
High	0.1 – 0.2
Very High	0.2 – 0.5

3.5 Shoreline Hazard Zone

Based on the erosion susceptibility ratings and erosion rates shown in Table 3-3, and a representation of potential inundation extent, a zone of likely shoreline hazard for the Gippsland Lakes shoreline has been developed.

Where the shoreline has an erosion rating of high or very high the erosion rate range shown in the table has been used to estimate a shoreward extent of the potential erosion hazard over the time frame of this project (to 2100).

The results of the erosion hazard assessment were then overlain with an inundation hazard extent to ascertain whether the inundation hazard is more significant than the erosion hazard for a section of shoreline. The inundation hazard extent is represented by the 0.9 m AHD contour. The 0.9 m AHD contour was chosen to represent the “mean” shoreline within the Gippsland Lakes under Scenario 3 (+0.8 m SLR), refer to Report 1 for details. This level incorporates the +0.8 m of sea level rise plus an additional 0.1 m representing the typical mean water level setup within the lakes associated with a combination of tidal pumping, stream inflow and the difference between AHD and MSL in the Gippsland region.

The final shoreline hazard zone has then been created as the zone of maximum likely change either through erosion or inundation along the lakes shoreline.

The erosion component of the shoreline hazard zone represents the expected maximum extent of potential shoreline erosion to 2100, based on current erosion rates within the Gippsland Lakes. There will be significant local variability in erosion rates throughout the lakes, with different erosion rates for different sections of shoreline. Erosion of the shoreline is often episodic rather than a continuous process, with periods of enhanced shoreward migration interspersed with periods of minor or no change; however without detailed monitoring data it is presently not possible to refine the erosion hazard component further.

4. COMPONENT DESCRIPTIONS

4.1 Physical Characterisation

4.1.1 Introduction

The physical characteristics of a shoreline influence erosion susceptibility, as they directly relate to how easily the driving forces of erosion (waves, currents, winds etc.) are able to translate to actual erosion of the shoreline. For example, unconsolidated sand is much more easily eroded than hard rock. The presence and type of artificial engineering structures has also been incorporated into the physical characterisation component of this assessment due to the large number of artificial structures found around the Gippsland Lakes shoreline, and their ability to influence shoreline erosion susceptibility.

Figure 4-1 An example of a Sandy/Semi-consolidated Silt Shoreline (Left) and an Artificially Engineered Shoreline within the Gippsland Lakes

4.1.2 Assessment Description

The physical characterisation of the shoreline is based on that outlined by Sharples et al. (2009) for the Smartline project. The most critical physical characteristics in terms of erosion susceptibility are defined as the *Fabric* and *Form* components. The characterisation adopted for this study is provided in Table 4-1.

The physical score shown in Figure 3-1 for each of the different form and fabric combinations is the final value adopted after benchmarking of the results against previous Gippsland Lakes shoreline erosion studies (Sjerp, Martin, Riedel, & Bird, 2002). It was found that the overall assessment results were particularly sensitive to the score applied to 'dominantly sandy' shorelines and the score shown in the table was adopted based on the best fit of the current study results to previous erosion studies of the Gippsland Lakes shoreline.

While not incorporated into the Fabric and Form categories by Sharples et al. (2009), artificial shorelines have been defined as a category for this assessment. This is due to their significant ability to modify the potential erosion susceptibility along a coastal or estuary shoreline. Where an artificial shoreline is present this may override the Fabric and Form characterisation.

The final physical susceptibility score for a section of artificial shoreline depends on the original shoreline fabric and form, as well as the type and condition of the artificial structure (if present). Both have been considered when assigning the physical susceptibility score.

Fabric

Fabric of the shoreline refers to the hardness or softness of the shoreline material, which implies a differing susceptibility to erosion or mobility. The fabric component for this assessment has been developed from DPI's Geology mapping of the region and refined using geomorphology mapping of the lakes region by Bird (1978). The following *fabric* classes were mapped based on the characteristics described in Table 4-1:

- Soft – muddy
- Soft – sandy
- Soft Rock
- Hard Rock

Form

Form is a descriptor of the landform of the shoreline, as summarised in Table 4-1. For this assessment, the form was derived using a quantitative measure of the horizontal distance from the mapped shoreline to the 0.3 m and 0.9 m contours. This measure provides a means to quantify the form of the coastline as either:

- Flat or gently sloping
- Gently to moderately sloping
- Moderate to steeply sloping shoreline
- Very steep to cliff backed

Artificial

The third component of the physical shoreline is the presence of artificial structures. This information was derived from mapping using detailed aerial photography and cross-referenced to the Coastal Asset Information GIS dataset[2] (DSE, 2012).

Structures were incorporated in the Fabric and Form score, as where they exist they effectively represent the shoreline. Where a structure was present (such as seawalls) the physical score was overridden to become the score for the structure if it was lower than that of the fabric / form score. For the sea level rise scenario, any erosion hazard mitigating effects due to the presence of the structures were neglected. This approach was adopted as without modification any structures would not be effective under the 0.8 m sea level rise scenario. For this scenario the Physical score was purely the revised Fabric / Form score based on the 0.9 m AHD contour.

[2] Gippsland Lakes Protections Structures data set provided 23 November 2012.

Table 4-1 Description of Physical Characterisation (adapted from Table 1 in Sharples et al. (2009))

Fabric		Form	Stability Classes & Sub-Classes		Erosion Susceptibility Score
Soft Sediments	Dominantly Muddy	Flat to gently sloping shores	Muddy Intertidal flat e.g. mangrove flats (complex, significant instability likely)	Backed by bedrock or soft sediment	5
				On open coast or in coastal re-entrants (inlets)	
		Gently to moderately sloping shores	Narrow muddy shores e.g. many estuarine shores (instability likely)	Backed by bedrock or soft sediment	4
				On open coast or in coastal re-entrants (inlets)	
	Dominantly Sandy	Flat to moderately sloping shores	Sandy shores or beaches ± tidal flats (complex but prone to erosion and retreat)	Backed by bedrock or soft sediment	5
				On open coast or in coastal re-entrants (inlets)	
		Dunes, windblown sheets, beach ridge backshores exposed to wind	Sand dunes, ridges or sheets (prone to increased mobility: some may stabilise)	Isolated from or exposed to wave attack.	4

Fabric		Form	Stability Classes & Sub-Classes		Erosion Susceptibility Score
	Dominantly Coarse	Gently to moderately sloping shores	Shingle to boulder – grade beaches – wave deposited coarse sediment (instability likely, but response to SLR may be complex)	Backed by bedrock or soft sediment	4
		Moderately to steeply sloping shores & backshores	Dominantly colluvial (talus) shores where not significantly cliffed or dominated by protruding in situ bedrock (unstable shores, ongoing slumping likely)	Backed by bedrock or soft sediment (generally backed by bedrock rather than extensive soft sediment)	3
	Undifferentiated soft sediment	Undifferentiated	Undifferentiated soft sediment shores (instability likely but style unknown)	Backed by bedrock or soft sediment	4
				On open coast or in coastal re-entrants (inlets)	
Soft Rock	Various types sharing similar coast stability styles, e.g.: - semi-lithified or inherently soft sedimentary rocks (e.g. clayey-gravelly semi-lithified	Flat to gently sloping backshore	Low profile soft-rock shores (potential progressive erosion and shoreline retreat)		4
		Moderately to steeply sloping backshore (may include sub-ordinate colluvium)	Moderate to steep profile soft-rock shores (progressive erosion, slumping and shoreline retreat)		4
		Very steep to cliffed backshore (may include sub-ordinate	Very steep to cliffed soft-rock shores (comparatively rapid progressive erosion, slumping, rock-falls, slab collapses and		5

Fabric		**Form**	**Stability Classes & Sub-Classes**		**Erosion Susceptibility Score**
	sediments, soft limestones; or - weathered bedrock & regolith (laterites, residual materials)	colluvium)	shoreline retreat).		
Hard Rock	Hard lithified bedrock or coastal precipitates dominant, not deeply weathered	Gently to moderately sloping shore and backshore	Low to moderate profile hard-rock shores (robust physically stable shores, negligible likely retreat over human time-frames)		1
		Steep to cliffed shore (may include sub-ordinate colluvium)	Steep to cliffed hard-rock shores (progressive erosion, slumping, rock-falls, slab collapses and shoreline retreat)		4
Artificial		Landfill, reclamation			3
		Coastal defence structures (seawalls, revetments)	Good condition	If condition unknown, assume poor.	1
			Poor condition		3
		Groynes & Breakwaters			1
		Wharves & Port structures			1
		Jetties			2
		Other built structures			3
		Excavation			4
		Unclassified			4

Note: the susceptibility rating from the artificial structures only overrides the form / fabric rating if it is lower (provides a greater level of protection).

4.2 Environmental Characterisation

4.2.1 Introduction

Wave and current processes have a significant effect on shoreline morphology, as they provide the driving forces for sediment erosion and deposition. An example of the impact of waves on a section of shoreline between Paynesville and Eagle Point is shown Figure 4-2. Here the shoreline is being actively eroded. Waves and currents are also particularly important for biological processes in estuarine systems due to their influence on water levels and salinity distribution.

The impacts of waves and currents were defined along the shoreline in terms of a Wave Exposure and Current Exposure score, which were then combined to give an overall Environmental Score. The overall Environmental Score is the average of the two component scores. Various ways of combining these ratings were tested, including adopting the maximum value, the average of the two scores and providing a weighting factor for each score. It was found when benchmarking the data that the average score result was more representative of the likely erosion susceptibility conditions along the shoreline.

Figure 4-2 Erosive Section of Shoreline between Paynesville and Eagle Point

4.2.2 Wave Exposure

Wave Conditions

Waves inside the Gippsland Lakes are solely driven by wind blowing over the lakes surface, due to the sheltering of open ocean swell by the barrier on the coastal side of the system. The wave climate inside the lakes was assessed using a spectral wave model of the Gippsland Lakes, which is briefly described in Appendix C. For further details refer to Report 3 of this project.

Wave action predominately impacts the eastern edges of the lakes due to the prevailing westerly wind conditions. The largest waves also occur on the eastern edge of Lake Wellington and the eastern lakes edge, between Lake King and Lake Victoria, as these two shorelines are subjected to the longest fetches during the prevailing westerly / south-westerly winds.

The resultant wave exposure assessment and criteria used for the shoreline erosion susceptibility assessment are described below.

Wave Exposure Criteria

The method used for characterising the impact of wave processes on the shoreline was to develop an index of wave exposure. Wave exposure is based on consideration of shoreline wave power, which has been determined through analysis of the results of the spectral wave model of the Gippsland Lakes. The model simulates the growth, transformation and decay of wind-generated waves, taking into account dissipation due to bottom friction, white capping and depth induced breaking, shoaling and refraction.

The wave model is driven by wind data from the East Sale Airport. A 1 year period of wind was chosen as representative of the long-term average wind conditions, allowing average shoreline wave power to be calculated.

The wave power values along the shoreline are then translated into five wave exposure categories which correlate to a particular erosion susceptibility score (Table 4-2). These five categories are based on the average shoreline wave power for each individual stretch of shoreline relative to the rest of the lakes shoreline and reflect the likely impact of waves on shoreline deposition or erosion. The resultant wave exposure throughout the Gippsland Lakes is shown in Figure 4-3 for all of the five categories.

This analysis assumed present mean sea level conditions. It was repeated for the +0.8 m sea level rise scenario with the wave exposure categories revised to reflect the associated impacts of changes in wave fetch on shoreline wave power in particular.

Table 4-2 Definitions of wave exposure categories

Category		Explanation (wave power value or range)	Wave Exposure Score
VP	Very protected	Average shoreline wave power is in the 75-100% exceedance range relative to all other sections of shoreline. Shorelines within this category experience small and infrequent wave events and usually are the location of all-weather anchorages, marina and harbours (< 40 Nm/s).	1
P	Protected	Average shoreline wave power is in the 50-75% exceedance range relative to all other sections of shoreline. Wave conditions are limited to short fetches, from a narrow distribution of directions (40 – 125 Nm/s).	2
SP	Semi-protected	Average shoreline wave power is in the top 25-50% exceedance range relative to all other sections of shoreline. Shorelines in this category are subjected to increasing fetches, but limited to a narrow distribution of directions. (125 – 225 Nm/s).	3
SE	Semi-exposed	Average shoreline wave power is in the top 10-25% exceedance range relative to all other sections of shoreline. Shorelines are subjected to increasing fetches and a range of directional distributions. (225 – 350 Nm/s).	4
E	Exposed	Average shoreline wave power is in the top 0-10% exceedance relative to all other sections of shoreline. Shorelines are exposed to long unimpeded fetches and experience the largest shoreline wave power conditions within the lakes system (> 350 Nm/s).	5

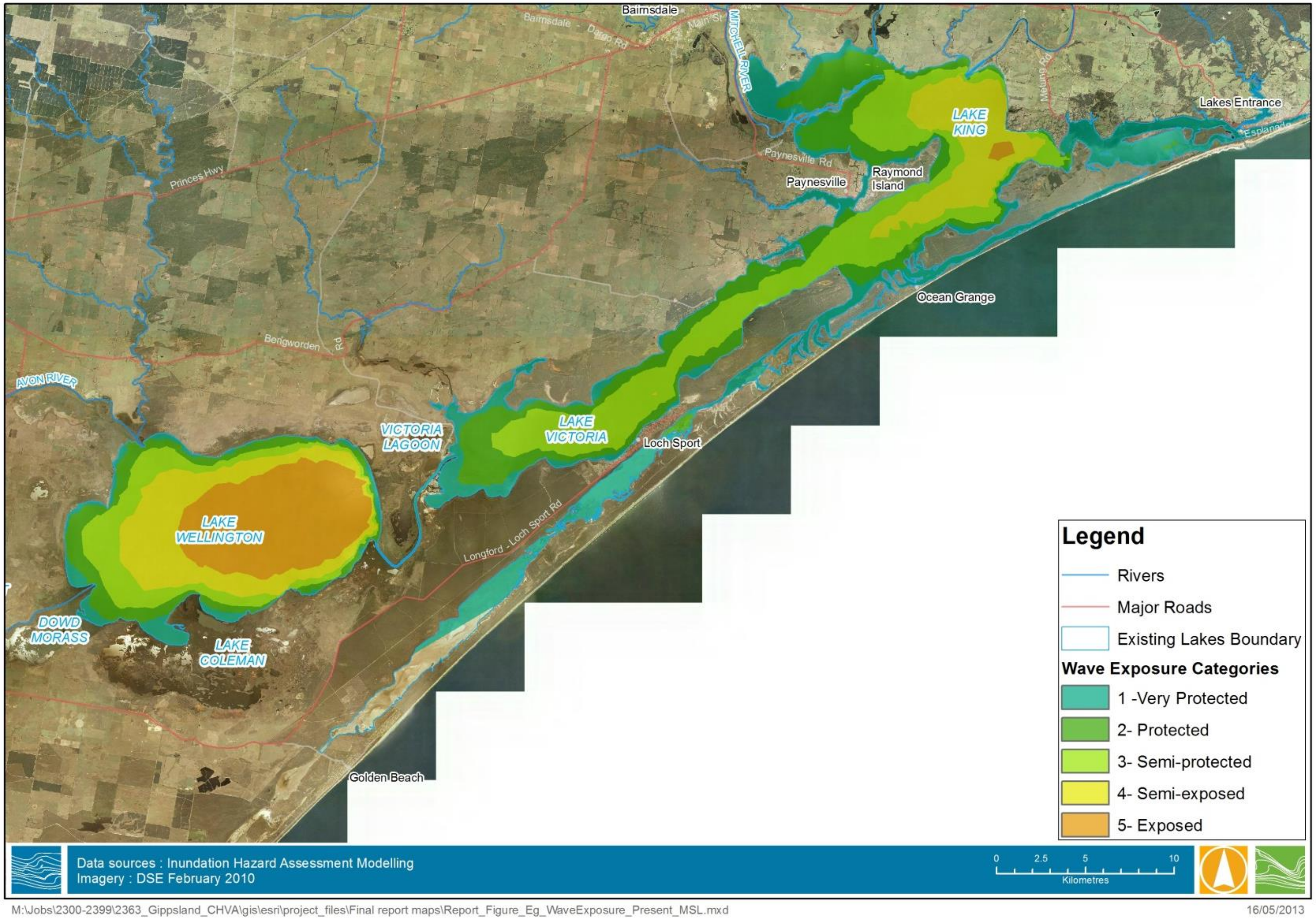

Figure 4-3 Wave exposure (ambient conditions) – present mean sea level

4.2.3 Current Exposure

Currents vary throughout the Gippsland Lakes and comprise, either individually or in combination, the tidal movement of water, wind driven circulations and freshwater inflows, depending on the location. A description of the tides and currents along with the current exposure criteria, across the Gippsland Lakes is described below.

Tide Conditions

The effect of tides on water levels and current speeds varies throughout the lakes. At Lakes Entrance, Cunninghame Arm and North Arm the tidal range is typically ±0.3 m about mean sea level. This reduces with distance from the entrance westward, giving a tidal range of around ±0.2 m about mean sea level at Metung, and only around ±0.03 m in Lake Wellington. The Entrance Channel, Reeve Channel and Hopetoun Channel are reasonably constricted and result in significant attenuation of the tidal signal. Moreover, the volume of water that can pass through the entrance and these channels is limited and once distributed over the area of the lakes, results in a small change in water level (Water Technology, 2005). For a more detailed discussion of tidal water levels simulated in this project refer to Report 2: Inundation Hazards.

In general, current flows between the Entrance and Metung can be described as "tidal" as there is a strong reversal of flow over a tidal cycle. Current speeds in this area range from a maximum of 0.3 m/s at Metung, 0.7 m/s to 0.9 m/s along Reeve Channel, to 2.4 m/s through the Entrance. Over the remainder of the lakes system the tidal currents are generally low (< 0.2 m/s) under ebb and flood conditions, although through McLennan Strait currents are locally higher (maximum of 0.6 m/s).

Wind Driven Circulations

Wind driven circulations are currents induced by wind shear on the surface of the lakes. This typically sets up a three-dimensional flow pattern where surface currents will flow in the direction of the wind whilst a return flow, deeper in the water column, will flow in the opposite direction, in order to maintain continuity. In order to resolve wind driven circulations, a three-dimensional hydrodynamic model is required, which was outside the scope of this project. Notwithstanding this, wind driven circulations are generally weak in magnitude and are not expected to have a significant impact on erosion susceptibility in the Gippsland Lakes.

River Inflow Conditions

As well as tidally driven currents, current speeds within the lakes can also be elevated where there is a river inflow. These current speeds typically range from 0.2 m/s to 0.5 m/s for non-flood river conditions.

Flow speeds in and around the inflowing river mouths and through the Entrance Channel can be elevated significantly under catchment generated flood conditions. The peak current speed associated with riverine flooding is dependent on the magnitude of the flood event.

Current Exposure Criteria

Current exposure is a measure of the erosion or deposition potential of the water current (also often termed "velocity") along a section of shoreline. Similar to a riverine environment, within an estuary there are often channelized sections where currents are high and therefore potential for erosion of the shoreline through entrainment of the sediment is increased. In a tidal environment like an estuary, the pattern of flow through sections of the system can also be dependent on the ebb and/or flood tide conditions, which can differ.

A hydrodynamic model of the Gippsland Lakes has been used to generate maps of current speed throughout the lakes system (refer to Report 2, Appendix A, for further model details). The current speed statistics were calculated from a 3 month simulation period which can be described as "ambient" conditions. This means that the values were calculated over a number of spring/neap tidal cycles, typical sea level surge events and typical river inflows (small discharges when compared to riverine flood flow conditions).

The current speeds have been translated into five current exposure categories based on the mapped model outputs of average current speed throughout the lakes (Table 4-3 and Figure 4-4). These categories then correlate to a particular erosion susceptibility rating, and reflect the likely impacts of the particular current speed(s) on shoreline erosion potential.

This analysis assumed present mean sea level conditions. This process was repeated for the +0.8 m sea level rise scenario with the current exposure categories revised to reflect the associated impacts of changes in water depths on current speeds in particular.

Table 4-3 Definitions of current exposure categories

Category		**Explanation** **Note: U = current speed**	**Current Exposure Score**
VP	Very protected	Very low current speeds, little difference between ebb and flood tide conditions, or low tidal range. Depositional environment. U < 0.1 m/s	1
P	Protected	Low current speeds, little difference between ebb and flood tide conditions, or low tidal range. Limited sediment entrainment potential, predominantly depositional. 0.1 < U < 0.2 m/s.	2
SP	Semi-protected	Low to moderate current speeds. May be asymmetry between ebb and flood tide conditions. Entrainment (and deposition) of sediment may be observed under certain tide conditions. 0.2 < U < 0.3 m/s	3
SE	Semi-exposed	Moderate to high current speeds. May be associated with an inflow such as a river mouth or partly channelized section of shoreline. Entrainment of sediment observed. Deposition limited. 0.3 < U < 0.4 m/s	4
E	Exposed	High current speeds under all tide conditions. Widespread entrainment of sediment over a tidal cycle. U > 0.4 m/s	5

4.2.4 Environmental Characterisation Score

The individual wave and current exposure scores have been combined to develop the final environmental characterisation score along the entire length of the lakes shoreline. Various methods of combining the individual ratings were tested in the development of the method including individual weightings. The final method adopted applies the average of the wave and current scores and provides an Environmental Characterisation score of 1 to 5.

Refer to Section 5.2 for further discussion on why this weighting was adopted.

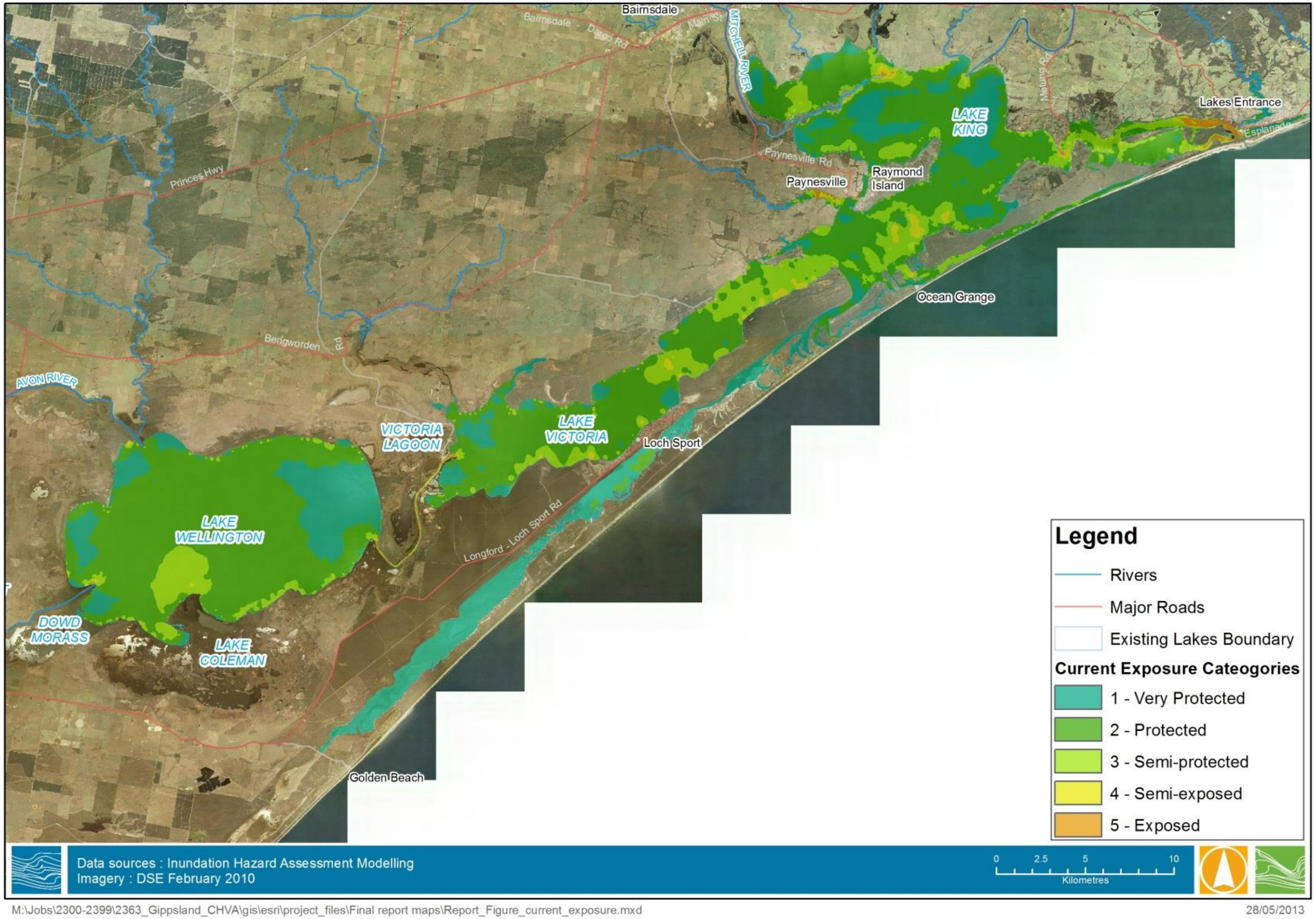

Figure 4-4 Current exposure (ambient conditions) – present mean sea level

4.3 Biological Characterisation

4.3.1 Introduction

Shoreline vegetation can influence the erosion susceptibility of a shoreline through processes such as binding of sediments, making them more resilient to erosion (Figure 4-5), or through buffering and dissipation of wave energy by semi-submersed vegetation such as reeds. The most common vegetation communities and plant species found throughout the Gippsland Lakes and their influences on erosion susceptibility are discussed in the following sections.

Figure 4-5 Vegetation aiding in the binding of sediment along a predominantly sandy shoreline within the Gippsland Lakes

4.3.2 Present Vegetation Communities

Vegetation communities around the shoreline of the Gippsland Lakes vary considerably. In order to describe the existing shoreline vegetation and provide input to the shoreline erosion assessment EVC categories have been adopted.

The EVCs present along the shoreline of the Gippsland Lakes are summarised in the Table 4-4 and Figure 4-6. These communities were assessed as being present within the first 50 m inland of the lakes shoreline.

Table 4-4 EVCs present along the Gippsland Lakes shoreline[3]

EVC	Description	% Area
EVC 53	Swamp scrub	40.6
EVC 9	Coastal Saltmarsh	30.8
EVC 3	Damp Sands Herb-rich Woodland	6.9
EVC 1/160	Coastal Dune Scrub/Coastal Dune Grassland Mosaic	5.9
EVC 15	Limestone Box Forest	3.5
EVC 48	Heathy Woodland	2.4
EVC 6	Sand Heathland	2.1
EVC 863	Floodplain reedbed	1.6
EVC 151	Plains Grassy Forest	1.6
EVC 681	Deep Freshwater Marsh	1.4
EVC 16/878	Lowland Forest/Damp Sands Herb-rich Woodland Mosaic	1.3
EVC 74	Wetland Formation	0.8
EVC 316	Shrubby Damp Forest	0.4
EVC 32	Warm Temperate Rainforest	0.3
EVC 2	Coast Banksia Woodland	0.2
EVC 144	Coast Banksia Woodland/Warm Temperate Rainforest Mosaic	0.2
EVC 10	Estuarine wetland	0.1
EVC 691/647	Aquatic Herbland/Plains Sedgy Wetland Mosaic	<0.1
EVC 689	Plains Grassy Woodland	<0.1
EVC 169/53/32	Dry Valley Forest/Swamp Scrub/Warm Temperate Rainforest Mosaic	<0.1

[3] EVC description derived from Davies et.al (2001) Ecological Vegetation Class Mapping at 1:25 000 in Gippsland

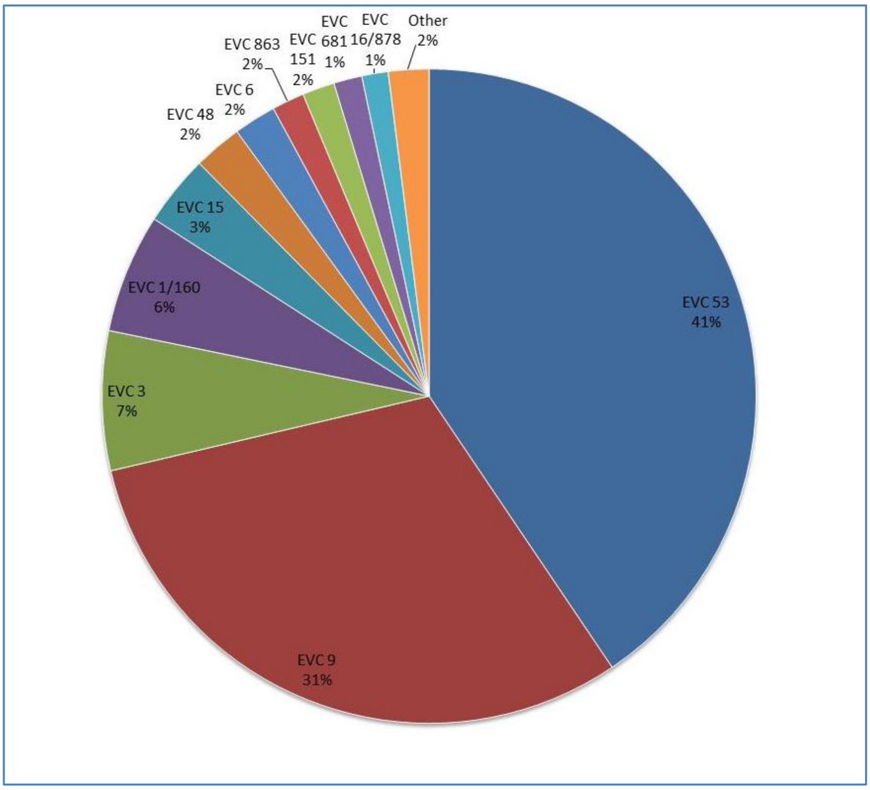

Figure 4-6 Shoreline EVCs by % area in the Gippsland Lakes

A short summary of the characteristics of key plant species with respect to shoreline erosion that are present within the different EVCs is provided below.

Phragmites australis

Phragmites australis once formed extensive fringing reedbeds around the Gippsland Lakes. The dense structure of these reedbeds forms an energy absorbing buffer for the adjacent shoreline against wave energy in particular. Changes in the extent and structure of these reedbeds throughout the Gippsland Lakes and the impact of this upon shoreline erosion have been discussed in detail by various authors (e.g. (Bird, 1961); (Bird, 1978); (Bird, 1983); and (Sjerp, Martin, Riedel, & Bird, 2002); among others). Much of this change has been attributed to changes in salinity regime in the lakes since the opening of the permanent entrance in 1889.

Melaleuca ericifolia

According to Sjerp et al. (2002), the most common shore type is *Melaleuca ericifolia* Swamp Scrub thicket along the water's edge. Bird (1978) noted that swamp land is extensive south of Lake Wellington, obtaining a maximum width of 6 kilometres, with narrower tracts on the northern and western shores; on the western shore of Lake Victoria either side of McLennan Strait; and on other more limited sections of the lake shore, particularly in embayments and along the side of narrow inlets and lagoons.

Sjerp et al. (2002) notes that where the *Melaleuca ericifolia* Swamp Scrub thicket is exposed along the water's edge there is either evidence of active erosion or it is fringed by a narrow sandy beach.

Juncus kraussii

Juncus kraussii is common towards the eastern end of the Lakes where it often forms a rushy fringe to a coastal saltmarsh complex or *Melaleuca ericifolia* thickets. However, *Juncus kraussii* does not offer the same level of wave attenuation as *Phragmites australis* due to its clumped tussock growth form (rather than distributed like reeds) and occurrence in the intertidal zone rather than out in open water (Sjerp, Martin, Riedel, & Bird, 2002).

Sarcocornia quinqueflora

The lowest and most frequently inundated zones of coastal saltmarsh are dominated by Beaded Glasswort *Sarcocornia quinqueflora*. It is a succulent perennial herb which has branches that reach 20 cm in height, and stems that creep along the ground. The stems are leafless and segmented, and set roots at the nodes (Sjerp, Martin, Riedel, & Bird, 2002).

While coastal saltmarsh plants like *Sarcocornia quinqueflora* can effectively colonise the shoreline around the Gippsland Lakes, due to their physical structure (i.e. low growing) they do not to offer the same resistance to wind/wave and current action as reedbeds such as *Phragmites australis* (Sjerp, Martin, Riedel, & Bird, 2002).

4.3.3 Assessment Description

The biological characterisation and potential impacts on shoreline erosion focuses on the mapped vegetation and land-use types along the shoreline. Previous reports, such as "A Geomophological Study of the Gippsland Lakes" by Eric Bird (1978), Sjerp et al. (2002) and Brizga et al. (2013) have identified a link between shoreline vegetation changes in the Gippsland Lakes and potential shoreline erosion.

To ensure a consistent biological characterisation along the length of the lakes shoreline, the EVC vegetation class mapping was used as the base dataset. Additional aerial photo interpretation was then undertaken to confirm the accuracy of the EVC classes, where information was known, or to apply EVC classes to areas where information was missing or did not match the shoreline defined for this study.

Each EVC was given an erosion susceptibility category and score. These categories (Table 4-5) have been developed considering the different vegetation types associated with the various EVCs and how the vegetation may provide protection against wave or current action. This biological categorisation and erosion susceptibility score does not incorporate the impacts of existing changes in or potential future changes in salinity levels in the lakes on the vegetation communities. It represents the present condition only.

As noted by various authors, such as Sjerp et al. (2002) and Brizga et al (2013), the changes in salinity within the Gippsland Lakes associated with construction of the permanent entrance have resulted in changes to vegetation communities, with formerly freshwater ecosystems dying back or changing as a result of the changed salinity regime. This is particularly relevant to reed beds (typically *Phragmites australis*) such as those fringing much of Lake Wellington, where increases in salinity during the recent (1996-2010) dry period resulted in considerable die-back of plants and exposure of the shoreline to increased wave and current action.

At present, die-back rates of shoreline reed beds due to elevated salinity in the Gippsland Lakes have not been quantified and the impacts of sea level rise on the future salinity regime within the lakes system is beyond the scope of this project. Therefore, the biological erosion susceptibility score represents the effect of present vegetation communities on erosion susceptibility assuming no change in extent or condition of those communities.

The analysis initially assumed present mean sea level conditions. The process was repeated for the +0.8 m sea level rise scenario, with the biological categories revised to reflect the change in vegetation community at the mean lake water level associated with a +0.8 m sea level rise. It was assumed that the rate of sea level rise was greater than the ability of the present shoreline vegetation community to response to the rise. This assumption was adopted due to the high level of uncertainty surrounding the ability of different vegetation communities to respond and adapt to changes in mean water level in the lakes, particularly the ability of these communities to move landward as water levels rise.

Table 4-5 Definition of biological characterisation categories

Category	Explanation	Biological Erosion Susceptibility Score
Highly Protective	Plant communities provide an effective buffer against wind, wave or current action. Reed beds below the normal water level are indicative of lower salinity environments. Reeds provide a buffer along the shoreline against current and wave action. Typical species: *Phragmites australis* Scrubland, located typically above the normal water level. Often protected by fringing reeds. Typical species *Melaleuca ericifolia*. Defined by the following EVCs: • EVC 53 - Swamp scrub • EVC 863 - Floodplain reedbed • EVC 10 -Estuarine wetland	1
Protective	Plant communities have the potential to provide some protection against wind or wave action. Defined by the following EVCs: • EVC 1/160 - Coastal Dune Scrub/Coastal Dune Grassland Mosaic • EVC 48 - Heathy Woodland • EVC 6 - Sand Heathland • EVC 681 - Deep Freshwater Marsh • EVC 74 - Wetland Formation • EVC 32 - Warm Temperate Rainforest • EVC 691 - Aquatic Herbland/Plains Sedgy Wetland Mosaic	2
Neutral	Plant communities provide coverage to shoreline but offer little buffering against wind or wave action. Defined by the following EVCs: • EVC 3 - Damp Sands Herb-rich Woodland • EVC 15 - Limestone Box Forest • EVC 151 - Plains Grassy Forest • EVC 16/878 - Lowland Forest/Damp Sands Herb-rich Woodland Mosaic • EVC 316 - Shrubby Damp Forest • EVC 2 - Coast Banksia Woodland • EVC 2 - Coast Banksia Woodland/Warm Temperate Rainforest Mosaic	3

Category	Explanation	Biological Erosion Susceptibility Score
	• EVC 689 - Plains Grassy Woodland • EVC 169 - Dry Valley Forest/Swamp Scrub/Warm Temperate Rainforest Mosaic	
Exposed	Plant communities offer little or no resistance to wind or wave action against the shoreline. Defined by the following EVCs: • EVC 9 - Coastal Saltmarsh	4
Highly exposed	Agriculture / Pasture or exposed soil (i.e. beach with no native vegetation backing)	5

Note:

- If no EVC vegetation was present an erosion susceptibility rating of 5 was applied.
- Land use is based on a 100m buffer of shoreline so sometimes native vegetation is backed by residential / agricultural land use. The potential for encroachment from the landward side on the vegetation has not been included in the susceptibility rating.

4.4 Land Use

Land management practices and foreshore grazing contribute to loss of shoreline vegetation such as the fringing reed beds and hence enhance shoreline erosion susceptibility. Where the shoreline is pasture, this has been identified and mapped. The potential effect of this on shoreline erosion is captured in the risk scored assigned, Table 4-5.

Land use and management also encompasses aspects such as erosion protection measures along the shoreline. A range of structures have been identified in the Gippsland Lakes and include sea-walls, rock rubble and timber groins which have been established along sections of the shoreline often to protect against erosion (Sjerp, Martin, Riedel, & Bird, 2002). These artificial structures and their effects on shoreline erosion susceptibility are captured in the physical characterisation of the shoreline, Table 4-1.

5. EROSION SUSCEPTIBILITY RESULTS – GIPPSLAND LAKES

5.1 Introduction

Shoreline erosion within the Gippsland Lakes is a function of a wide range of forcing factors, including geomorphology and physical form, environmental aspects such as waves and currents, and biological character which includes vegetation communities and land use. This section describes the results of the erosion susceptibility assessment throughout the lakes system.

5.2 Benchmarking

The individual erosion susceptibility scores for the different components were combined within the project GIS for each section of shoreline within the Gippsland Lakes. The weighting factors applied to the components (physical, environmental and biological) as well as the individual scores (form and fabric, wave and currents, EVCs) were then reviewed against previous information (Sjerp et al. (2002); Brizga et al. (2013)) and field data obtained during this project.

5.2.1 Category and Rating Sensitivity

The categories and associated scoring used to characterise the different factors such as sediment types or wave exposure can have a significant impact on both the erosion susceptibility ratings and ultimately the overall shoreline erosion hazard.

During the refinement of the study method and then when comparing outputs to field data the impacts of the different categories and scoring was analysed. The outcomes of this analysis are discussed further below.

Physical

The physical characterisation comprised the Fabric and Form components as detailed in Table 4-1. The overall erosion susceptibility score is weighted towards these components as they describe the physical form of the shoreline. Therefore, the score given to this component has a significant effect on the overall score for any section of shoreline.

It was found that for the Gippsland Lakes shoreline, the score applied to the flat to moderately sloping dominantly sandy shores was critical to describing the physical characterisation score. The originally proposed score for these areas was increased from 2-3 to 4-5 depending on the slope of the shoreline (i.e. form).

Environmental

The environmental characterisation comprised the Wave and Current Exposure components. The overall score therefore had to consider both components and their relative importance for a given section of shoreline. For instance, for the Entrance and Reeve Channel, along with McLennan Strait the impact of currents on erosion potential is more critical than waves; whereas conversely for the broad shallow waters of Lake Wellington wave impacts dominate.

Different methods of combining the individual wave and current components were tested. The final adopted approach takes the average of the two component scores. This was found to provide the best presentation of wave and current behaviour along the shoreline of the Lakes.

Biological

The biological characterisation describes the present EVC communities along the Gippsland Lakes shoreline and how they may provide protection against wind, wave or current action.

Generally the use of EVCs to define the biological character of the shoreline was considered to provide good results and none of the individual EVC ratings were altered during the benchmarking process. The key limitation of this approach was the ability to distinguish vegetation types within EVC 53 Swamp Scrub. For instance, it was not possible to differentiate between shorelines fringed by reed beds (*Phragmites australis)* or those where reed beds were no longer present and the backing scrubland (*Melaleuca ericifolia)* was exposed to wave and current action. Where there are fringing reed beds the erosion protection afforded against waves and currents is higher than where the swamp scrub is directly exposed. The erosion susceptibility rating could have been modified to account for this if the data was available.

There was data from other sources (e.g. Sjerp et al. (2002); Water Technology (2013)) which did provide information to enable these vegetation types to be differentiated in some areas but the information was not available consistently across the system.

By differentiating between reed beds and the scrubland it may be possible to assess the impact of changes to reed bed extent, as a potential indicator of the impacts of a changing salinity regime. As stated previously, the impact of changes in salinity regime either past, present or future are not within the scope of this study and so have not been incorporated into this analysis.

5.2.2 Comparison to Previous Work

Sjerp et al. (2002) undertook a detailed assessment of shoreline erosion in the Gippsland Lakes and Table 1 of their report provides a detailed assessment of numerous locations including information of the erosion status and rate of erosion for each site. For this project the information contained in Table 1 (Sjerp, Martin, Riedel, & Bird, 2002) has been converted into a GIS layer and each site has been mapped in terms of its stability status. The stability status was defined as one of seven categories; from eroding, erosion and accretion sequences through to stable, or unknown.

For each location the stability status was compared to the erosion susceptibility rating. Where there was a notable difference between the observed erosion conditions for a location compared to that predicted by the present assessment, the individual scores along with how the various components were brought together and the assumed weightings were reviewed.

This lead to an increase in the original susceptibility score of the physical components associated with sandy shorelines (described previously).

The overall comparison between the two different assessments shows good agreement over the majority of the shoreline. There are minor differences at some locations which are predominantly due to the following:

- Accuracy of the site co-ordinates, as stated in Sjerp et al. (2002). In some instances it is unclear which section of shoreline is being referred to.
- Accuracy of mapping inputs for present study, such as EVC and geology layer mapping. The resolution of the mapping is variable between data sets and sometimes local scale variations are not accurately captured.

The following general summaries, along with Figure 5-1, Figure 5-2 and Figure 5-3 provide an overview of the comparison between the results of the present study with those of Sjerp et al. (2002). The overall shoreline erosion susceptibility rating shown has been categorised as high and very high, as discussed in 3.4. Ratings below this are not reported as they represent stable or accreting areas.

Lakes Entrance

Results for the Lakes Entrance peninsula shoreline are typically low, which is consistent with Sjerp et al. (2002). The southern shore of Cunninghame Arm is rated as mobile by Sjerp et al. (2002) which is consistent with a rating in the present study of 2 to 3, which falls below the high erosion rating category. Results in the north of Cunninghame Arm are more varied in both datasets, particularly as the Arm turns to the north. The present study data typically shows ratings of 2 to 3 in this area (below the High category) whilst the spot ratings of Sjerp include “stable?” and “minor erosion”. These suggest that the over ratings are similar.

Paynesville-Raymond Island

Through Newlands Arm and McMillan’s Strait there is little erosion susceptibility shown in the present study results which corresponds well with the Sjerp et al. (2002) data. Point Fullarton is an area of localised increase in susceptibility which corresponds to the point data. Most of the northern shore of Raymond Island is not shown as susceptible to erosion, matching with the majority of point classifications (stable). The north-east tip of Raymond Island (Point King) has a High to Very High susceptibility rating which matches well with the point assessments at this location. The southern shore of Raymond Island has mixed ratings in both data sets.

Lake Victoria

The results for Lake Victoria show a mix of stable and eroding sites in the Sjerp et al. (2002) data that correspond to the change in conditions at different sites. These are reflected in the susceptibility ratings that also demonstrate the variability along the northern and southern shoreline of Lake Victoria.

Lake Wellington

Most of the site assessments by Sjerp et al. (2002) indicate an eroding shoreline in Lake Wellington, apart from the eastern shore, north of Plover Point where accretion was observed. The susceptibility ratings generally correspond well with this assessment. Potentially the ratings in the present study could be refined further for Lake Wellington, as discussed in 5.2.1.

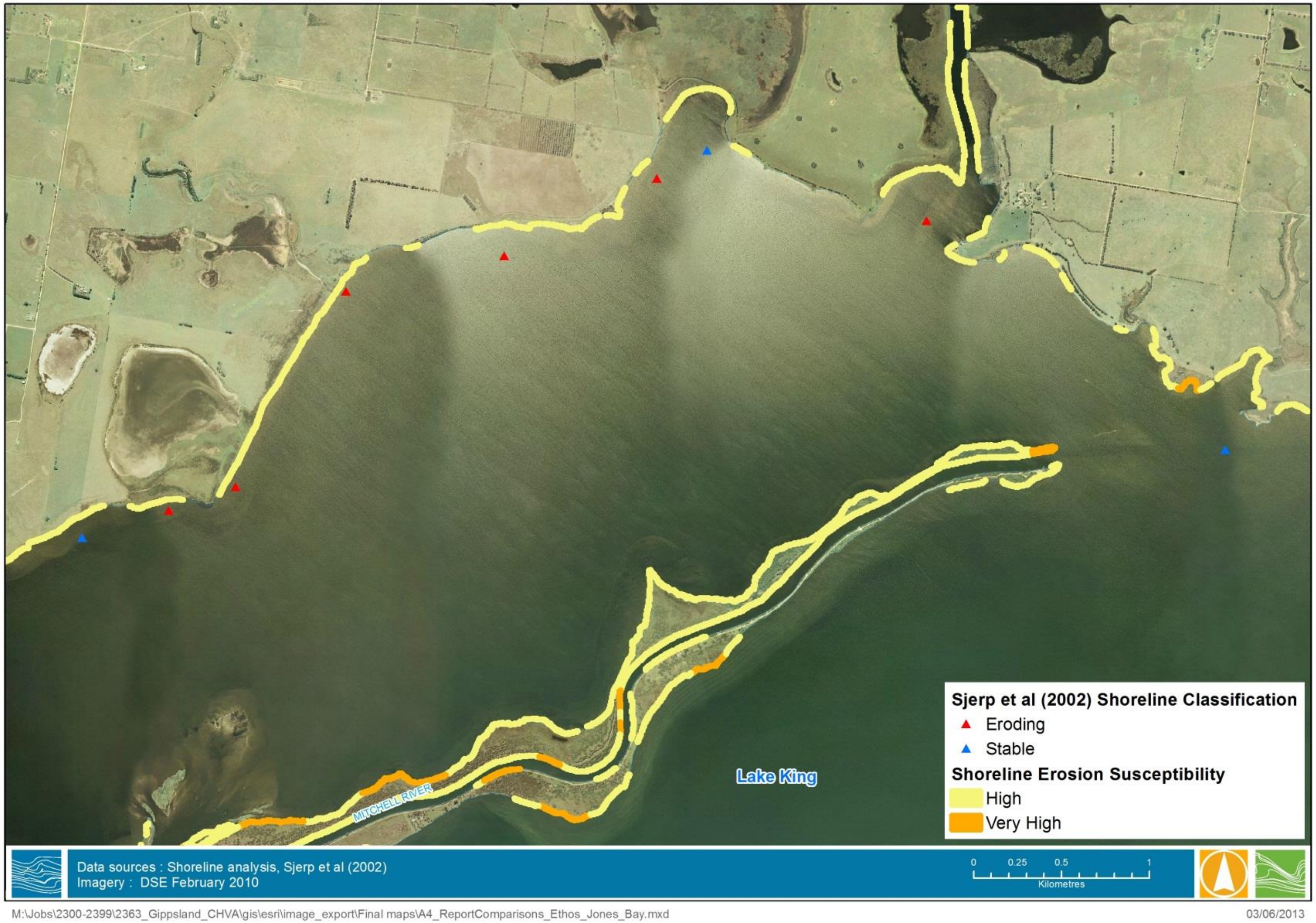

Figure 5-1 Comparison between stability status (from Sjerp et al. (2002)) and erosion susceptibility score - Jones Bay

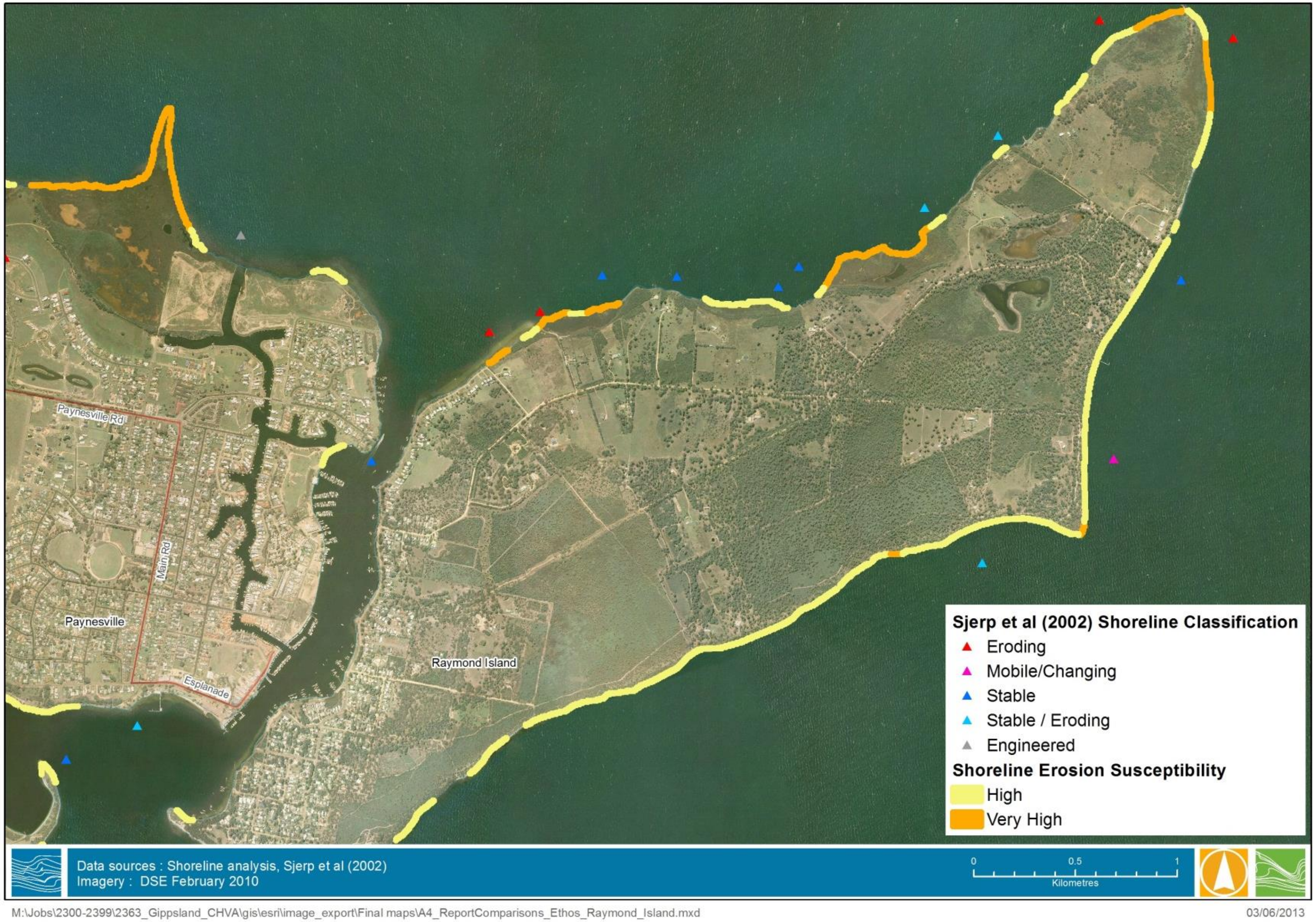

Figure 5-2 Comparison between stability status (from Sjerp et al. (2002)) and erosion susceptibility score - Northern end of Raymond Island

Figure 5-3 Comparison between stability status (from Sjerp et al. (2002)) and erosion susceptibility score - Sperm Whale Head

In addition to the previous erosion assessment work by Sjerp et al. (2002), a series of shoreline photos have been collected at various locations around the lakes for comparison with the analysis results. There is also on-going shoreline profile monitoring being undertaken.

Lake Wellington

An example of where the analysis results were able to identify a clear change in erosion susceptibility related to fabric and form is shown on the eastern shoreline of Lake Wellington, Figure 5-4. This section of shoreline north of the entrance to McLennan Straits shows a transition between high erosion susceptibility (yellow) to a more stable system (no rating applied). This transition aligns with changes in the sediment type from silt to sand, with the yellow zone associated with the silty area where the swamp scrub vegetation encroaches to the shoreline while areas to the north are sandy with sections of beach backed by swamp scrub. The ground surface slope, away from the shoreline, is also different for these sections.

Raymond Island

The sandy, flat to moderately sloped eastern shoreline of Raymond Island is shown as having high erosion susceptibility. This shoreline type matches well with the observed shoreline morphology as shown in Figure 5-5.

Reeve Channel

Figure 5-6 shows the erosion susceptibility along Reeve Channel and associated areas immediately north of Lakes Entrance. The ratings shown match well with the morphology and vegetation communities observed.

Figure 5-4 Shoreline erosions susceptibility – Lake Wellington, eastern shore

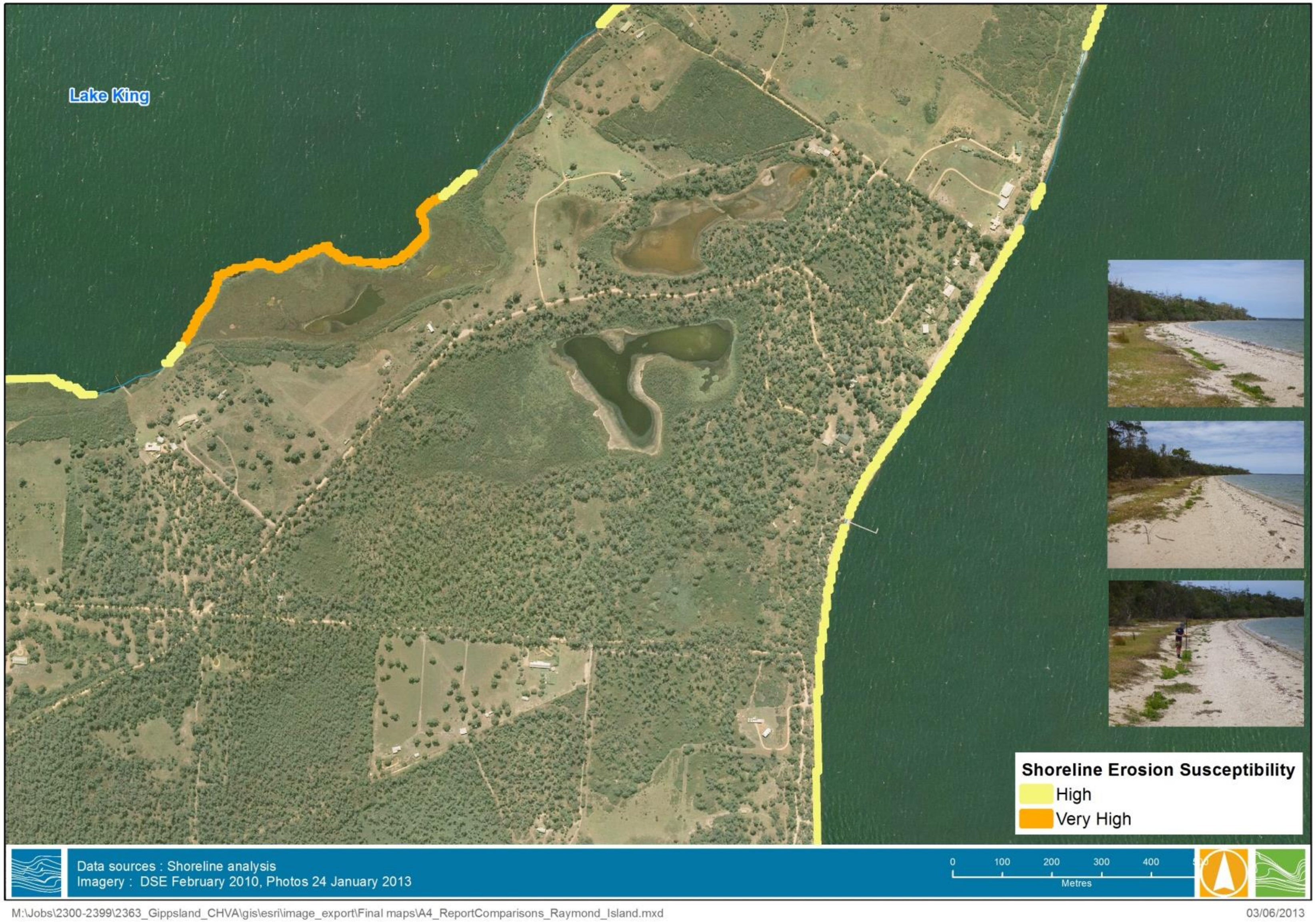

Figure 5-5 Shoreline erosions susceptibility – Raymond Island

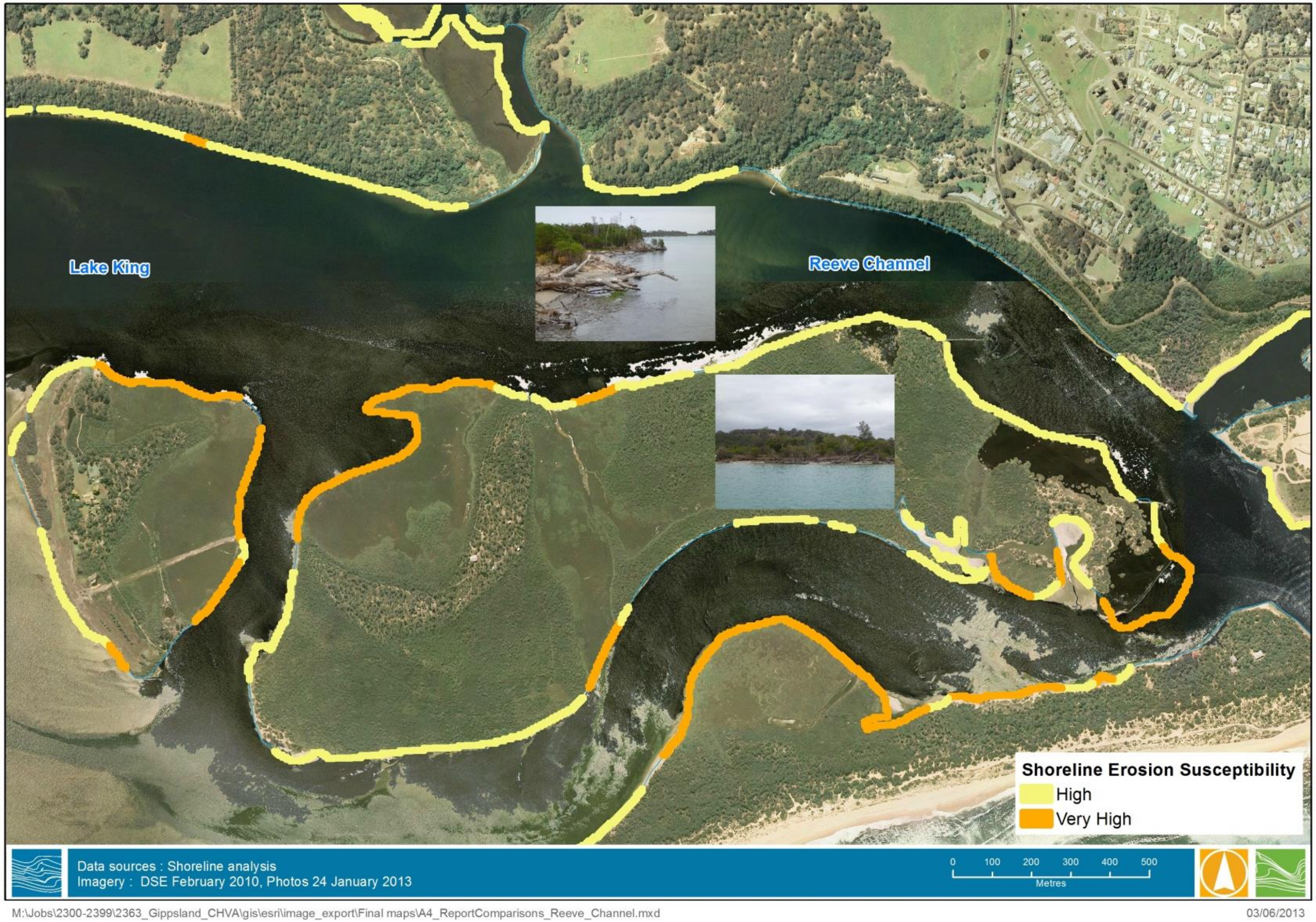

Figure 5-6 Shoreline erosions susceptibility – Reeve Channel

5.3 Existing Conditions

The erosion susceptibility rating of the Gippsland Lakes shoreline at the study-area scale is shown in Figure 5-7. Clearly much of the current shoreline has the potential to erode under present mean sea level conditions. There are far fewer areas identified as Very Highly susceptible to erosion which would indicate active erosion.

These results should be considered in the context of the current vegetation communities and that the past, present or future impacts of salinity on these communities have not been incorporated.

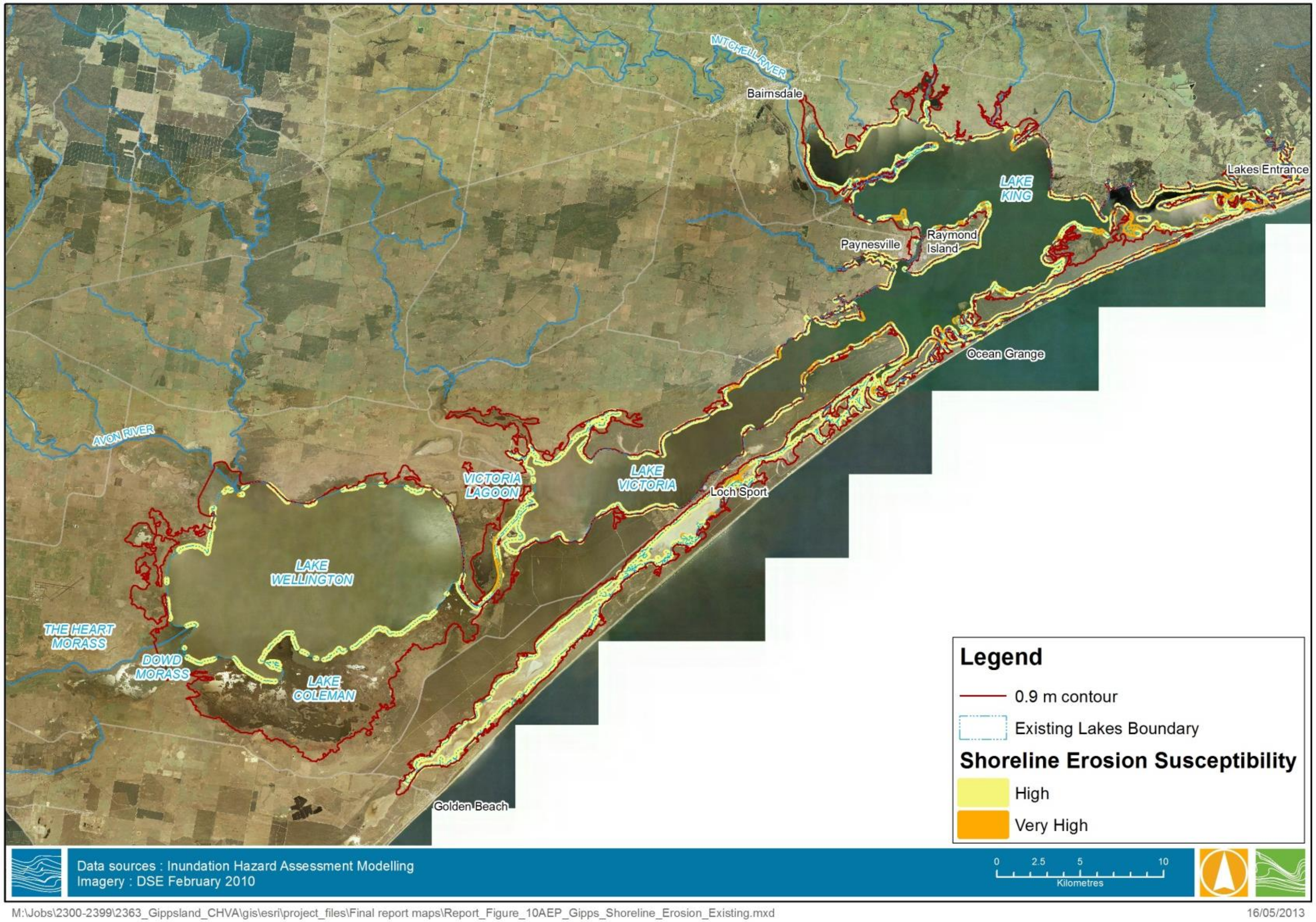

Figure 5-7 Overview of Shoreline Erosion Susceptibility for the Gippsland Lakes Shoreline

5.4 Sea Level Rise Impacts

The shoreline erosion susceptibility ratings discussed previously represent present conditions in terms of the physical, environmental and biological characterisation. Under predicted sea level rise conditions there are likely to be changes to these components as a result of higher mean water levels in the Gippsland Lakes. To assess how an increase in mean water level may alter the erosion susceptibility of the shoreline, the scores associated with each component were reassessed for the +0.8 m sea level rise scenario.

5.4.1 Key Parameters and Assumptions

Physical

The key physical change tested for the +0.8 m sea level rise scenario was the removal of all artificial structures. This is considered a conservative assumption as it is likely that many structures throughout the Lakes will be maintained and adapted as sea level rises.

The other aspect of the physical characterisation was the application of the shoreline fabric and form values at the 0.9 m AHD contour[4]. This captured any change in shoreline sediments or slope associated with +0.8 m sea level rise. This is particularly relevant to areas of low relief such as the shoreline of Lake Wellington.

Environmental

The wave and current exposure along the shoreline under a sea level rise scenario of +0.8 m were based on hydrodynamic model results of this scenario, as described in Section 4.2.

Biological

The biological score is based on the EVC at the shoreline. For the sea level rise scenario the biological score was based on the current land use and EVC present at the 0.9 m AHD contour. This resulted in some instances where the vegetation communities were unchanged; while in other locations there was a change from Swamp Scrub or similar type vegetation to agricultural or other land uses. Retreat or adaptation of the shoreline vegetation communities with sea level rise was not considered.

5.4.2 Erosion Susceptibility Changes

Overall, the sea level rise assessment indicates a generally increased level of shoreline erosion susceptibility throughout the Gippsland Lakes as indicated by the pink lines shown in Figure 5-8. Those areas most affected by sea level rise related increases in erosion susceptibility are the shoreline of Lake Wellington, the Lake Reeve lagoon system behind the outer coastal barrier south of Sperm Whale Head, the shoreline of Lake King from Paynesville to the Nicolson River, and the areas around Reeve Channel and Lakes Entrance.

Lake Wellington

The western shoreline of Lake Wellington is susceptible to erosion under present mean sea level and this is shown to increase and extend around the majority of the lake's shoreline under +0.8 m sea level rise. Much of this change on the western shoreline and around the Latrobe and Avon River mouths can be associated with a likely change in shoreline vegetation. Under the +0.8 m sea level rise scenario the mean water level in the lake will be approximately 0.9 m AHD. The 0.9 m AHD contour is shown on Figure 5-8 and Figure 5-9 along with the change in erosion susceptibility (in

[4] Note that present mean water level in the lakes is approximately 0.1 m AHD due to tidal pumping (caused by increased resistance through the entrance during ebb tide compared to flood tide) and river inflows to the lakes. Hence we have assumed a mean lake level of 0.9 m AHD under 0.8 m sea level rise conditions.

pink). The vegetation communities currently present at the 0.9 m AHD contour are associated with agricultural land uses (pasture) rather than the predominantly Swamp Scrub EVC53 along the present shoreline.

Lake Reeve

The existing shoreline along Lake Reeve under present mean sea level is considered to have high erosion susceptibility due to its physical characterisation (fabric and form). This increases under the +0.8 m sea level rise scenario in many locations predominantly due to changes in vegetation communities, Figure 5-10. For instance, at Loch Sport the 0.9 m AHD contour along the Lake Reeve shoreline is approximately aligned with the current residential property extent.

Lake King/Jones Bay

Much of the change under the sea level rise scenario along the shoreline of Lake King/Jones Bay is associated with a move from a current susceptibility rating of moderate (i.e. likely to be stable) to high. As for the other locations, much of this change is associated with changes to the vegetation communities along the 0.9 m AHD contour. In this area the land-use type at the 0.9 m AHD contour is predominantly agricultural land which has a high erosion susceptibility score. The results are shown in Figure 5-11.

Reeve Channel

The key change in the area of Reeve Channel is the increase in erosion susceptibility along the cliffed section of the channel. This is associated with changes in wave and current exposure associated with the sea level rise scenario, Figure 5-12.

Lakes Entrance

The results of the sea level rise scenario analysis for Lakes Entrance are discussed further in the project inundation report. In this area, the inundation hazard impacts are significantly greater than the potential erosion hazards.

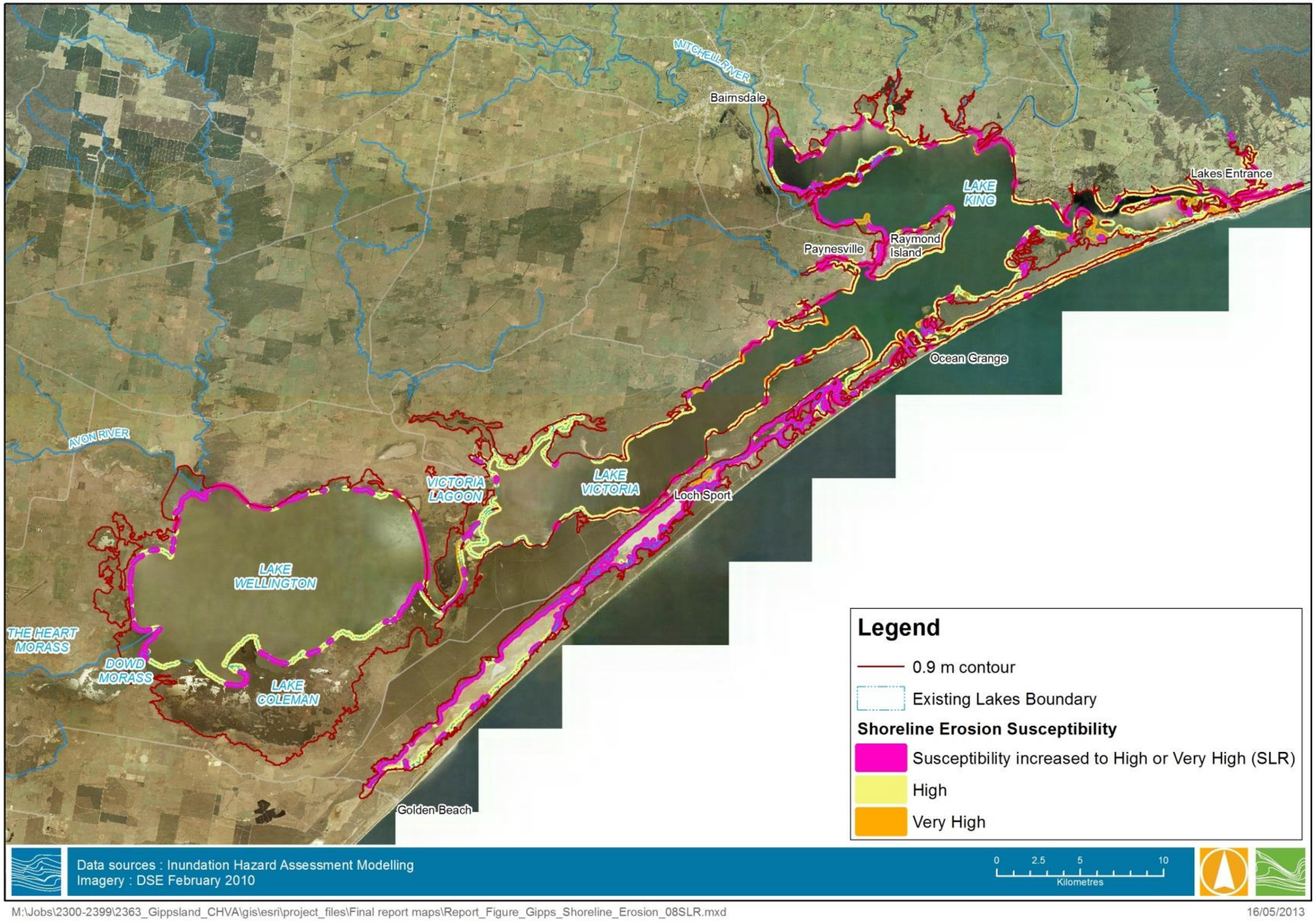

Figure 5-8 Example of shoreline erosion susceptibility under present mean sea level conditions and sea level rise of +0.8 m, whole Lakes

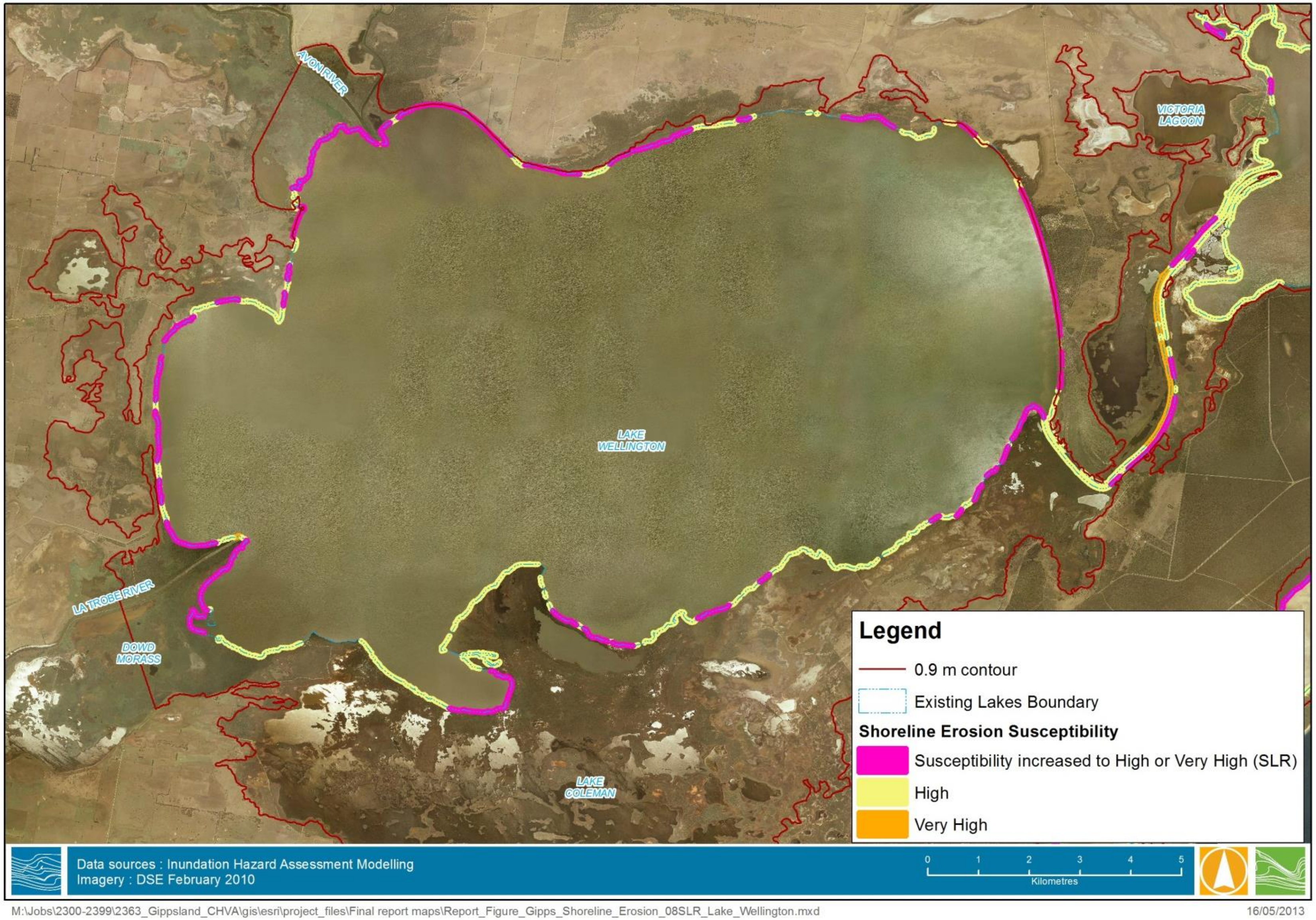

Figure 5-9 Example of shoreline erosion susceptibility under present mean sea level conditions and sea level rise of +0.8 m, Lake Wellington

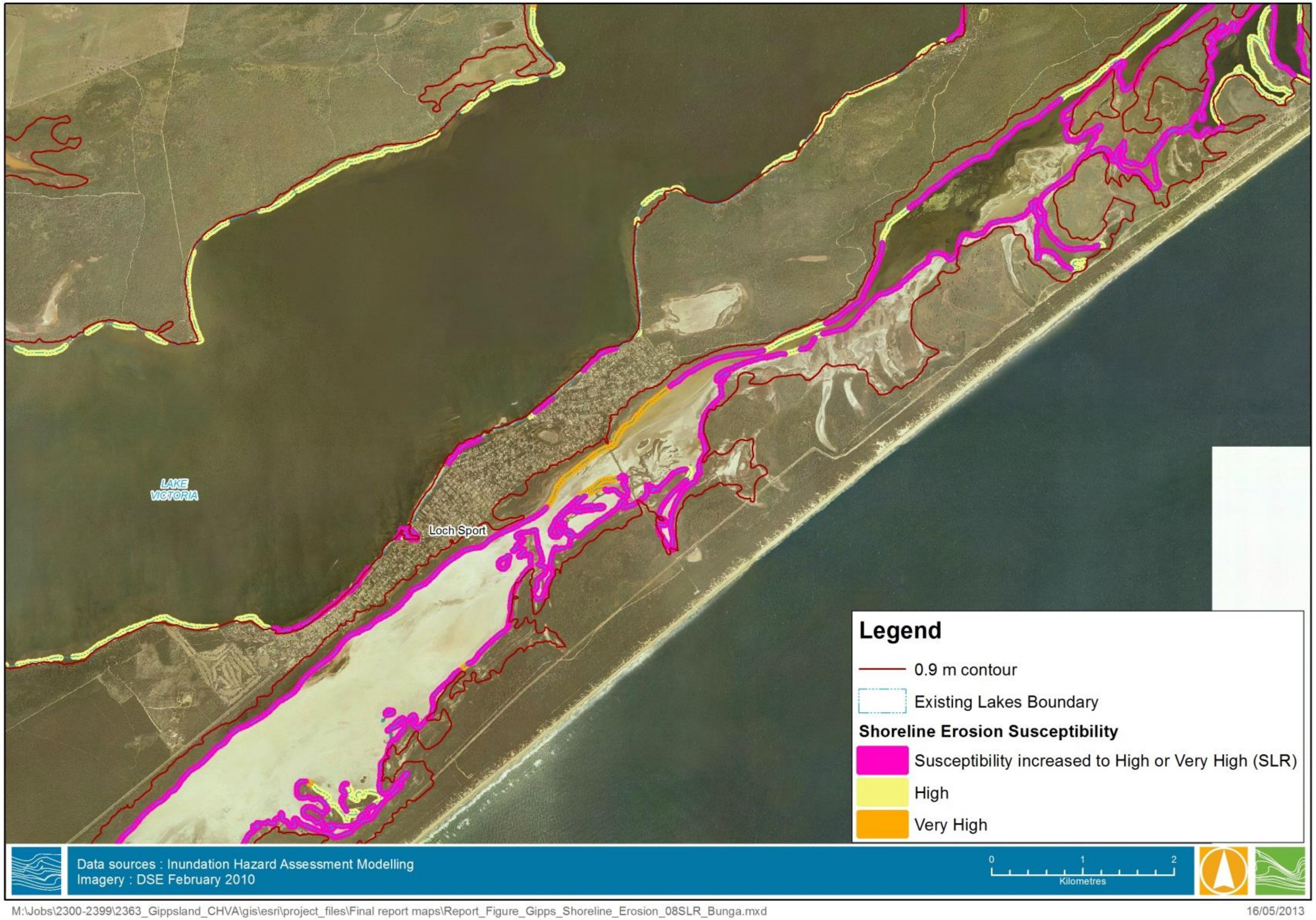

Figure 5-10 Example of shoreline erosion susceptibility under present mean sea level conditions and sea level rise of +0.8 m, Bunga Arm (south)

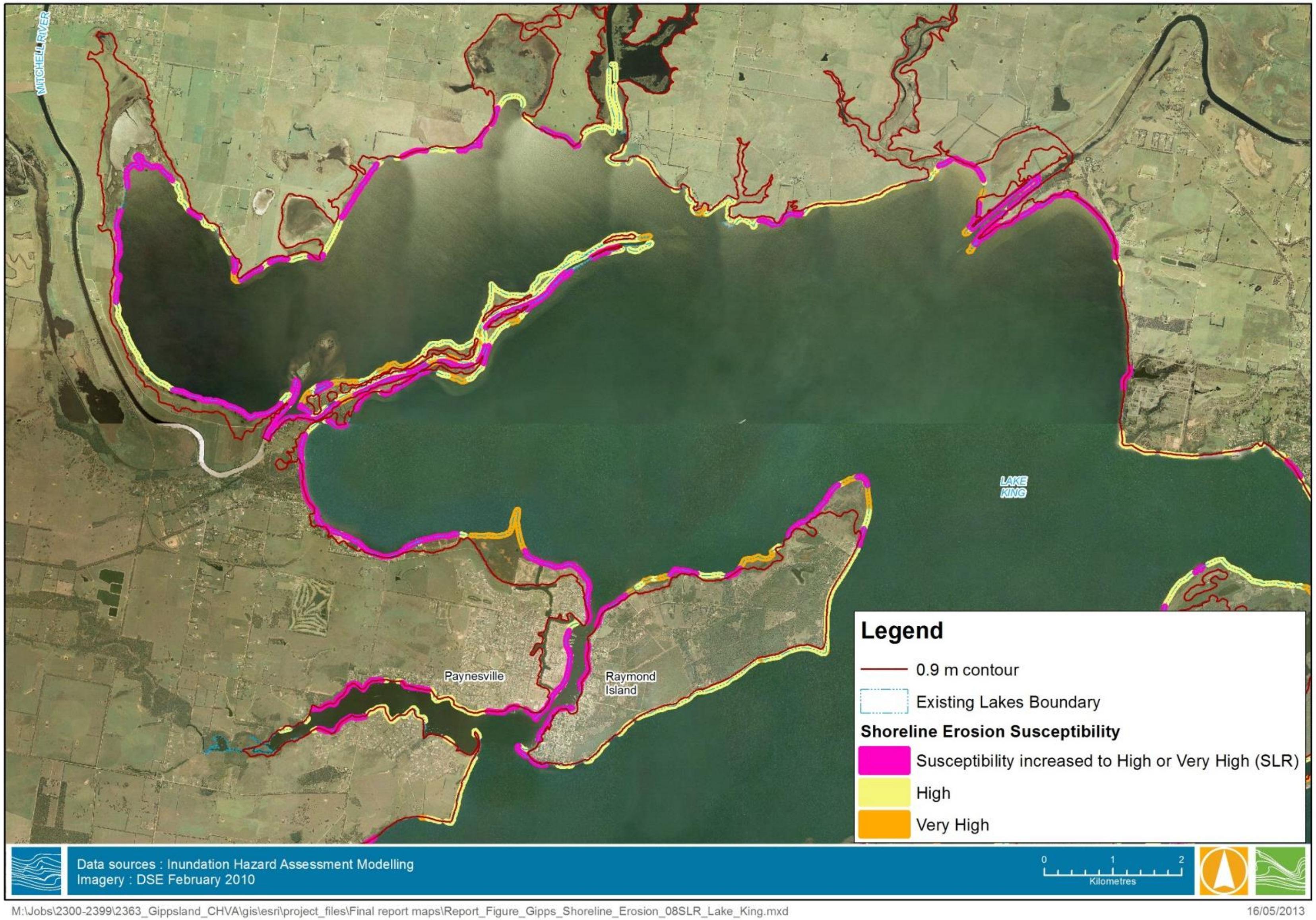

Figure 5-11 Example of shoreline erosion susceptibility under present mean sea level conditions and sea level rise of +0.8 m, Lake King/Jones Bay

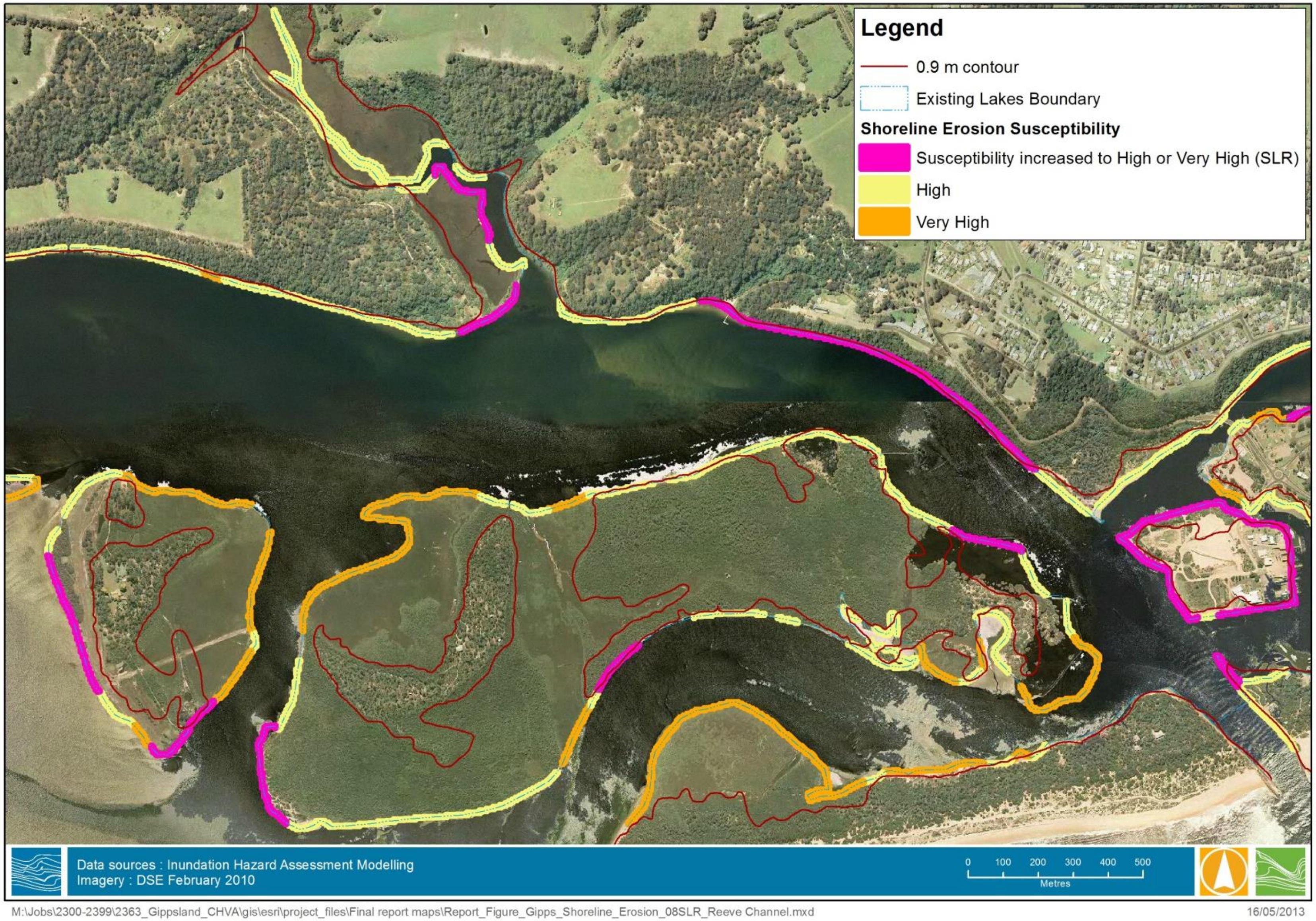

Figure 5-12 Example of shoreline erosion susceptibility under present mean sea level conditions and sea level rise of +0.8 m, Reeve Channel

6. EROSION SUSCEPTIBILITY RESULTS - REPRESENTATIVE LOCATIONS

6.1 Overview

Lakes Entrance, Paynesville/Raymond Island, Loch Sport, Bunga Arm and Seaspray were identified as representative locations for this project due to varying combinations of inundation and erosion hazards along with other local issues at each site. Apart from Seaspray, each of these locations is susceptible to lake shoreline erosion. The hazard assessment for Seaspray focusses on the coastal hazards associated with changes to the coastal barrier in this location. This is discussed further in Report 3: Outer Barrier Erosion Hazards. This location has not been assessed as part of the lakes shoreline erosion hazard assessment.

Discussion in the following sections relate to shoreline erosion susceptibility for these locations only.

6.2 Lakes Entrance

The shoreline erosion susceptibility and hence risk around the township of Lakes Entrance is to a significant extent mitigated by the presence of artificial structures, as shown in Figure 6-1. Should these structures not be maintained or removed then the majority of the Lakes Entrance shoreline becomes susceptible to erosion. The erosion hazard is therefore increased.

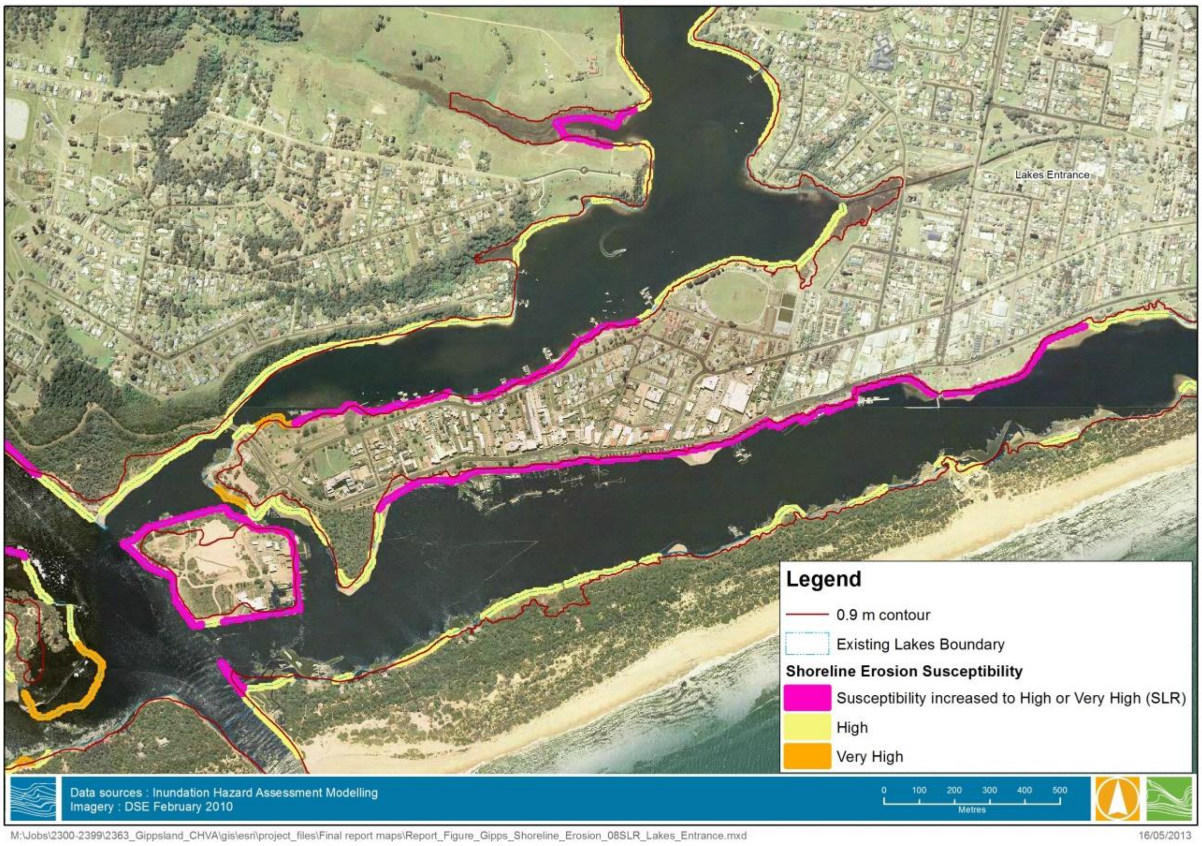

Figure 6-1 Comparison of shoreline erosion susceptibility under present mean sea level conditions and sea level rise of +0.8 m, Lakes Entrance

6.3 Paynesville – Raymond Island

As at Lakes Entrance, the presence of artificial structures along the shoreline reduces the susceptibility of the shoreline to erosion in these locations. However, the assessment also shows that the southern and eastern sides of Raymond Island are more susceptible to erosion, with a number of other low lying swampy sites on the northern shoreline showing increased susceptibility under the sea level rise scenario.

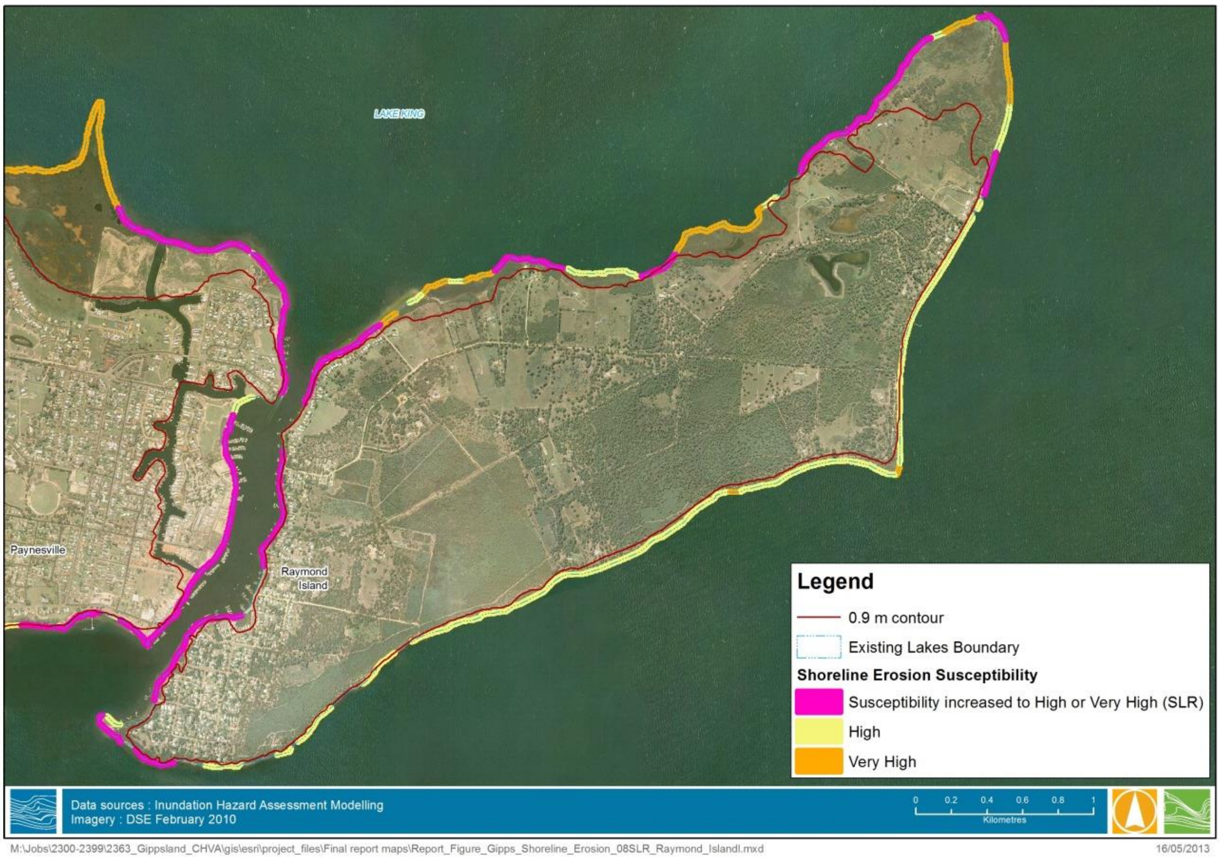

Figure 6-2 Comparison of shoreline erosion susceptibility under present mean sea level conditions and sea level rise of +0.8 m, Paynesville/Raymond Island

6.4 Loch Sport

The presence of beach protection measures such as groynes at Loch Sport indicate an eroding shoreline in some sections. These structures act to mitigate the potential for erosion under present mean sea level conditions. For this assessment it is assumed these structures are mitigating the erosion risk for this section of shoreline and therefore there is little erosion susceptibility.

Under the sea level rise scenario, particularly assuming these structures are not present, the shoreline erosion susceptibility rating increases.

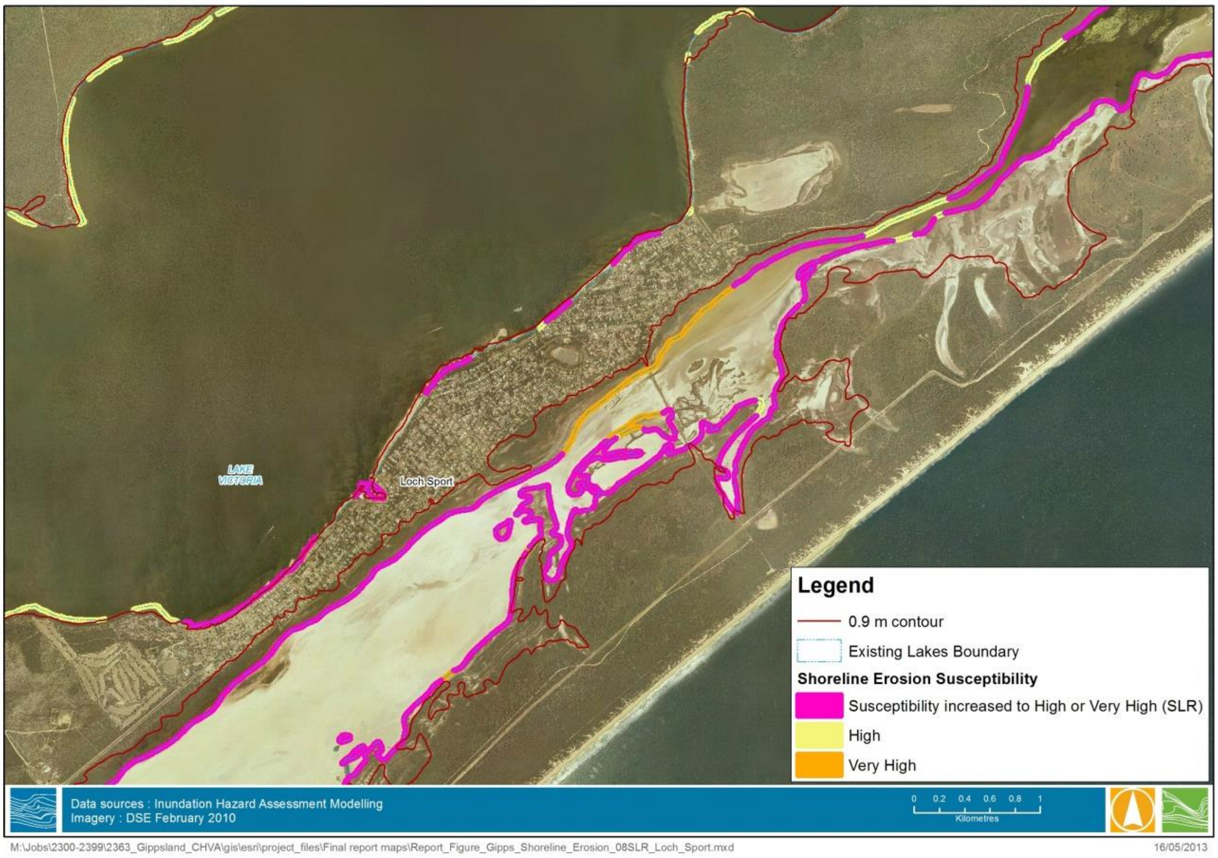

Figure 6-3 Comparison of shoreline erosion susceptibility under present mean sea level conditions and with sea level rise of +0.8 m, Loch Sport

6.5 Bunga Arm

The erosion susceptibility for Bunga Arm is predominantly a function of the physical components, dominantly sandy areas in particular, along with the biological rating. The environmental components of wave and current exposure have less impact in this area.

Under the sea level rise scenario there is some increase in the spatial extent of shoreline erosion susceptibility (predominantly to the south of Sperm Whale Head) but as the majority of the area is currently erosion susceptible there is effectively little change.

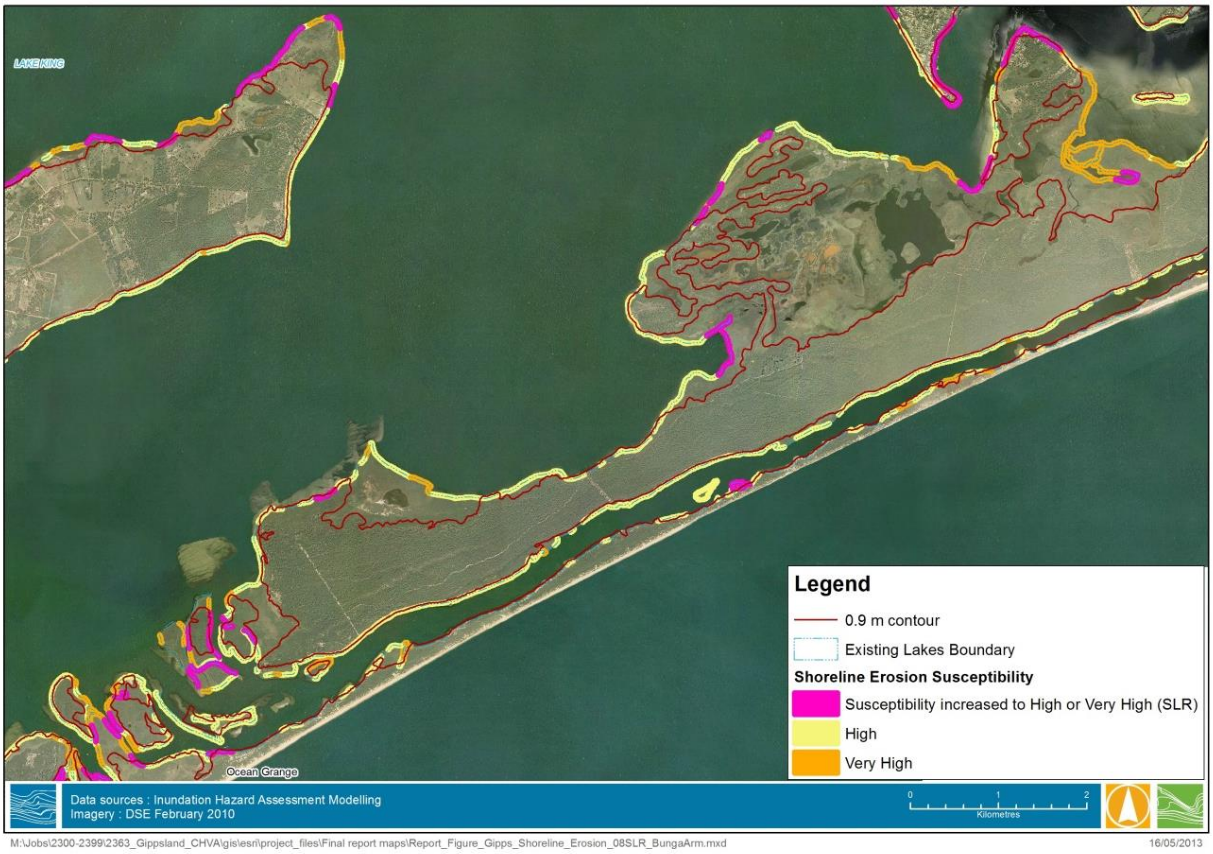

Figure 6-4 Comparison of shoreline erosion susceptibility under present mean sea level conditions and with sea level rise of +0.8 m, Bunga Arm

7. SHORELINE HAZARD ZONE MAPPING – GIPPSLAND LAKES

7.1 Mapping Methodology

The shoreline hazard mapping of the Gippsland Lakes is based on the estimates of potential shoreline erosion over the period of the scenarios analysed in the present study (to 2100) as well as the effect of sea level rise on the mean water level in the lakes and the resultant general inundation of the shoreline. Details of the methodology used to define the shoreline erosion and inundation extent is provided in Section 3.5.

There are a number of engineered sections of shoreline and other structures throughout the Gippsland Lakes. Depending on their standard of construction, maintenance and the ownership arrangements associated with these structures they are likely to result in localised changes to the potential rates of shoreline change predicted. It has been considered prudent to assess the potential extent of coastal hazards assuming these structures would not be adapted for future sea levels.

For major engineered shorelines associated with port and harbour facilities it is likely these engineered shorelines would be upgraded/adapted to future sea level rise and the hazard extents can be modified in these areas in the future to reflect adaptation decisions.

7.2 Shoreline Hazard Mapping

An overview of the shoreline hazard mapped across the Gippsland Lakes is displayed in the following figures. In many instances, for example around Lake Wellington and McLennan Strait, the hazard extent is dominated by the extent of inundation as a result of an increase in the mean water level in the lakes.

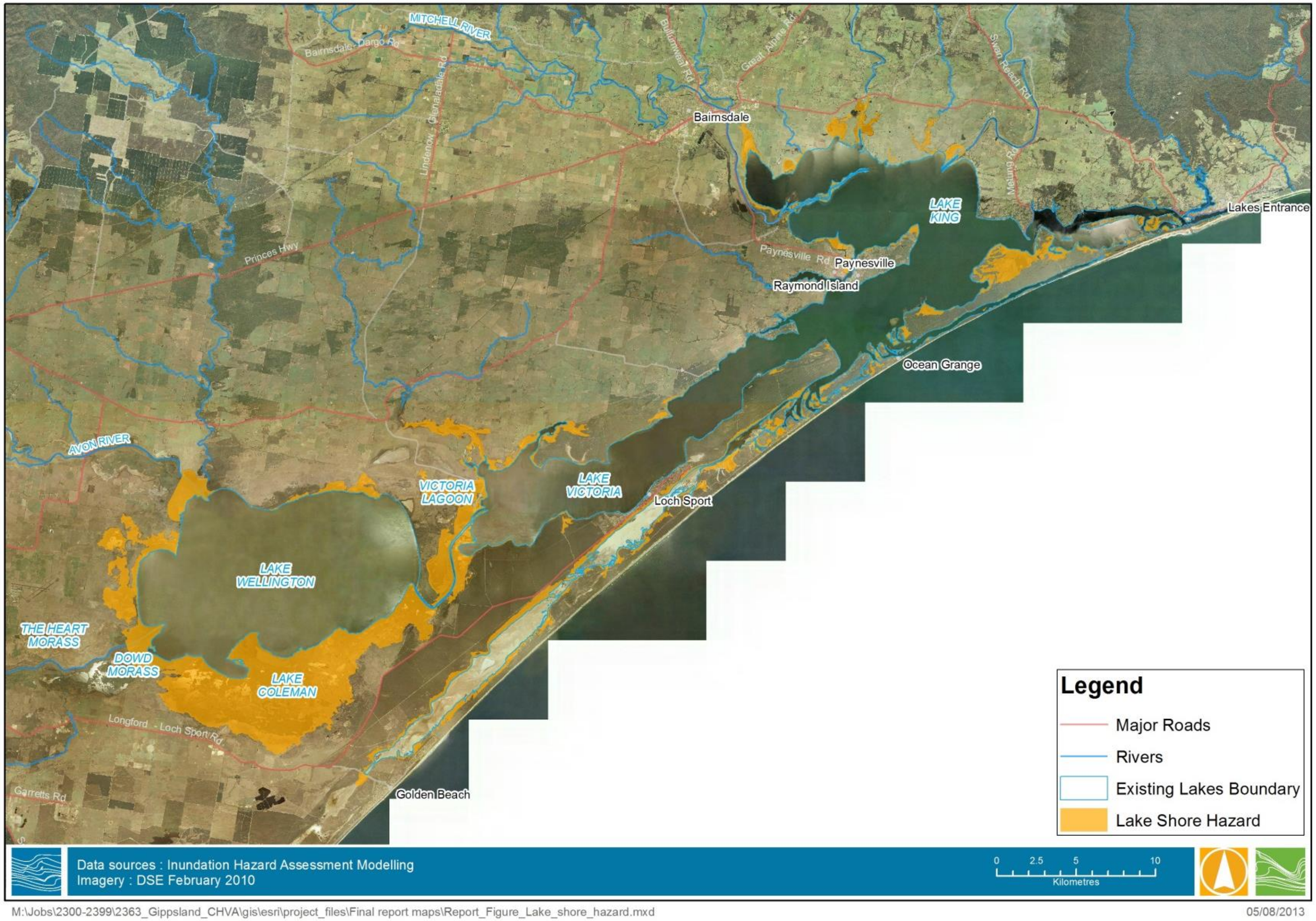

Figure 7-1 Gippsland Lakes Shoreline Hazard Extent

Figure 7-2 Bunga Arm Shoreline Hazard Extent

Figure 7-3 Lakes Entrance Shoreline Hazard Extent

Figure 7-4 Loch Sport Shoreline Hazard Extent

Figure 7-5 Paynesville – Raymond Island Shoreline Hazard Extent

8. EVALUATION OF UNCERTAINTY

The analysis of the potential extent of shoreline erosion hazards along the Gippsland Lakes has a number of significant potential sources of uncertainty. These require evaluation to understand the sensitivity that these sources of uncertainty may have on the findings.

8.1 Data Sets

The following uncertainties relate to the input data sets.

- Accuracy of mapping inputs for present study, such as EVC and geology layer mapping is variable between data sets ranging from 1:25,000 to 1:250,000 and thus local scale variations are not accurately captured.
- Accuracy of the site co-ordinates, as stated in Sjerp et al. (2002). In some instances it is unclear which section of shoreline is being referred to.
- The analysis results have been generalised to represent features at least 50 m in length as features less than 50 m is beyond the scale of resolution of many of the input data sets and are likely to be result of incorporating multiple data sets with differing resolution and dates of capture.
- The input data sets had different geometry for the lake shoreline. A single shoreline was captured using the Vicmap Coast25 shoreline and current aerial imagery and applied for consistency. The source data was extrapolated or clipped as required to meet the project defined shoreline.

8.2 Physical Characterisation

8.2.1 Fabric and Form

A reasonably high level of accuracy was available in the data sets (predominantly LiDAR survey) used to develop the physical characterisation of the Gippsland Lakes shoreline. The key area of uncertainty was in the erosion susceptibility score applied to the data, particularly given the dominance of this parameter on the overall assessment outcome. Based on the benchmarking process and the good agreement with available field information it is considered that the uncertainty in the scores applied has been minimised as much as possible. Further refinement of the GIS model could be undertaken for specific sites if detailed site information (form and fabric) is incorporated into the assessment.

8.2.2 Artificial Structures

For the climate change scenario it has been assumed that the present artificial structures along the shoreline are no longer present. This assumption was adopted due to uncertainty as to which structures and what adaptations may occur in different locations throughout the lakes as a result of sea level rise. Sensitivity of the results to the presence or absence of specific structures could be tested within the model in the future.

8.3 Environmental Characterisation

8.3.1 Catchment Flood Events

Short term changes in wave or current exposure due to catchment generated flood events have not been incorporated in the erosion assessment. It is considered that any erosion due to elevated currents under these conditions is likely to be of short duration and limited to predominantly those areas in and around the inflowing river mouths.

However, there is potential for significant short term changes at the Entrance Channel where there are high velocities under normal tidal conditions and catchment flood events in the past have been associated with scouring of the entrance channel. How this may affect bank stability further into Reeve Channel is uncertain and has not been investigated as part of this project.

The impact on the environmental characterisation associated with specific catchment flood events could be tested within the GIS model by incorporation and analysis of specific hydrodynamic model results in the future.

8.3.2 Climate Change

The climate change scenario applied in this project does not incorporate changes to catchment inflows due to climate change. It is likely that changes to rainfall frequency and intensity may occur which would alter the river inflow regime for the inflowing rivers. However there is considerable uncertainty as to the magnitude and timescale of such changes.

Potential impacts associated with such changes could be incorporated into the GIS model through modifications to the river inflows to the hydrodynamic model.

An additional potential impact of climate change which has even greater uncertainty surrounding it is the potential for changes in wind speeds and directions. There is currently no reliable guidance available on such changes and therefore this has not been considered as part of this project.

8.4 Biological Characterisation

8.4.1 Vegetation and Salinity

The biological categorisation and erosion susceptibility score used for this study does not incorporate the impacts of existing changes or potential future changes in salinity levels in the lakes on vegetation communities. It represents the present extent and condition of the vegetation only.

As noted by various authors, such as Sjerp et al. (2002) and Water Technology (2013), the changes in salinity within the Gippsland Lakes associated with construction of the permanent entrance have resulted in changes to vegetation communities, with formerly freshwater ecosystems dying back or changing as a result of increased salinity. This is particularly relevant to reed beds (typically *Phragmites australis*) such as those fringing much of Lake Wellington, where increases in salinity during the recent (1996-2010) dry period resulted in considerable die-back of the plants and exposure of the shoreline to increased wave and/or current action.

At present, die-back rates of shoreline reed beds due to elevated salinity in the Gippsland Lakes have not been quantified and the impacts of sea level rise on the salinity regime within the lakes system is beyond the scope of this project. Therefore, the biological erosion susceptibility score represents the effect of present vegetation communities on erosion susceptibility assuming no change in extent or condition of those communities.

8.4.2 Vegetation Communities

EVCs were used to define the biological character of the shoreline and provided generally good results during the benchmarking process. The key limitation of this approach was the ability to distinguish vegetation types within EVC53 Swamp Scrub. For instance, it was not possible to differentiate between shoreline fringed by reed beds (*Phragmites australis)* or those where reed beds were no longer present and the backing scrubland (*Melaleuca ericifolia)* was exposed to wave and current action. Where there are fringing reed beds, the erosion protection afforded against waves and currents is higher than where the swamp scrub is directly exposed. The erosion susceptibility rating could have been modified to account for this if the data was available.

There was data from other sources (e.g. Sjerp et al. (2002); Water Technology (2013)) which did provide information to enable these vegetation types to be differentiated in some areas but the information was not available consistently across the system.

By differentiating between reed beds and the scrubland it would have been possible to assess the impact of changes to reed bed extent, as a potential indicator of the impacts of a changing salinity regime. This could be readily incorporated into the project GIS and updated erosion susceptibility scores generated.

8.4.3 Sea Level Rise Constraints

The analysis initially assumed present mean sea level conditions. The process was repeated for the +0.8 m sea level rise scenario, with the biological categories revised to reflect the change in vegetation community at the mean lake water level associated with a +0.8 m sea level rise. It was assumed that the rate of sea level rise was greater than the ability of the present shoreline vegetation community to respond. This assumption was adopted due to the high level of uncertainty surrounding the ability of different vegetation communities to respond and adapt to changes in mean water level in the lakes, particularly the ability of these communities to move landward as the water level rises.

In the future the GIS data model could be used to further investigate the impacts of different assumptions regarding vegetation response to sea level rise by applying vegetation rules based on, for example, slope or rate of sea level rise.

8.4.4 Land Use Changes

Land use changes within the catchments will affect the vegetation communities along the shoreline and also potentially the catchment inflows. For the present study it has been assumed the land use remains the same under the climate change scenario. The impact of this assumption could be explored further using the GIS model.

8.5 Erosion Rates

As stated in Section 3.4 the overall erosion susceptibility rating is characterised as either High or Very High and specific erosion rates have not been applied to each individual section of shoreline along the lakes. An indicative estimate of the likely erosion rates under either a High or Very High rating are provided based on the work of Sjerp et al. (2002). However, there is considerable uncertainty on the specific mechanisms influencing erosion along the shoreline, such as salinity impacts on reed bed retreat. Given the lack of long term vegetation monitoring to understanding the response of some vegetation communities to salinity or other changes, and limited long-term erosion monitoring at different shoreline areas around the Gippsland Lakes, there is little justification for providing more detailed estimates of shoreline erosion rates at this time.

The erosion hazard zones defined in this study are therefore based on the available erosion rate data and represent a broad assessment of potential erosion risk across the Gippsland Lakes. Further site specific monitoring data could be used to refine these hazard zones further.

9. SUMMARY AND RECOMMENDATIONS

9.1 Overview

The Gippsland Lakes are a system of coastal lagoons sheltered behind sandy barriers. They include Lake Wellington (area 138 km^2; shoreline length 60 km), Lake Victoria (area 110 km^2; shoreline length just over 100 km), Lake King (area 92 km^2; shoreline length 160 km), and various other smaller lagoons with extensive swamps across a broad, low-lying coastal plain (Bird, The Geomorphology of the Gippsland Lakes Region, 1978).

The system is linked to the sea by an artificial entrance near the eastern end (Lakes Entrance), opened in 1889. Before 1889 the entrance moved position during floods or storms and became restricted during periods of low river flows (Ecos, unpublished).

Such a diverse system contains an equally diverse range of shorelines, in terms of the underlying geomorphology, the wave and current conditions, and the types of vegetation that are present. Each of these components impacts upon the ability of the shoreline to either accrete or erode and how it may respond to changes in conditions in the future due to sea level rise.

This study has attempted to assess the current susceptibility of the shoreline to erosion, and based on available information provide an indication of the potential shoreward extent of erosion that could occur over the period to 2100.

9.2 Methodology

In order to assess shoreline erosion hazard over the entire Gippsland Lakes system a spatially based assessment framework was developed. The framework comprised a spatial data model which combined both quantitative and qualitative descriptors of the key physical, environmental and biological characteristics of the Gippsland Lakes.

These characteristics were defined as follows:

- The Physical: the fabric, form, geology / geomorphology and artificial shore line data. This approach is based upon the Smart Line analysis methodology developed by Sharples et al. (2009).
- The Environmental: combining the wave / wind and current data derived from hydrodynamic modelling as part of this study.
- The Biological: information derived from EVC mapping and land use data.

The model then provided an assessment of the susceptibility of the lakes shoreline to erosion. The term “erosion susceptibility” was used to identify locations of potential erosion hazards as it represents the combination of individual erosion hazards or contributors to the hazard(s) and the relative impact of these different drivers or factors on the overall potential for shoreline erosion along any given section of the shoreline.

Erosion susceptibility results were then combined with available rates of shoreline erosion for the Gippsland Lakes to produce a mapped zone of potential for shoreline retreat associated with erosion on a Gippsland Lakes scale.

Hazard zones could be further refined for the representative locations should location specific erosion rate data become available for these areas.

9.3 Erosion Susceptibility

9.3.1 Existing Conditions

The erosion susceptibility rating of the Gippsland Lakes shoreline at the study-area scale is shown in Figure 5-7. Much of the current shoreline has the potential to erode under present mean sea level conditions. There are far fewer areas identified as Very Highly susceptible to erosion which would indicate active erosion.

These results should be considered in the context of the current vegetation communities and that the past, present or future impacts of salinity on these communities have not been incorporated.

9.3.2 Sea Level Rise Impacts

Overall, the sea level rise assessment indicates a general increase level of shoreline erosion susceptibility throughout the Gippsland Lakes as indicated by the pink lines shown in Figure 5-8. Those areas most affected by sea level rise related increases in erosion susceptibility are the shoreline of Lake Wellington, the Lake Reeve lagoon system behind the outer coastal barrier south of Sperm Whale Head, the shoreline of Lake King from Paynesville to the Nicolson River, and the areas around Reeve Channel and Lakes Entrance.

9.3.3 Representative Locations

Lakes Entrance, Paynesville/Raymond Island, Loch Sport, Bunga Arm and Seaspray were identified as representative locations for this project due to varying combinations of inundation and erosion hazards along with other local issues at each site. Apart from Seaspray, each of these locations is susceptible to lake shoreline erosion. The hazard assessment for Seaspray focusses on the coastal hazards associated with changes to the coastal barrier in this location. This is discussed further in Report 3: Outer Barrier Erosion Hazards. This location has not been assessed as part of the lakes shoreline erosion hazard assessment.

9.4 Shoreline Hazard Mapping

The shoreline hazard mapping of the Gippsland Lakes is based on the estimates of potential shoreline erosion over the period of the scenarios analysed in the present study (to 2100) as well as the effect of sea level rise on the mean water level in the lakes and the resultant general inundation of the shoreline.

The results indicate that in many instances, for example around Lake Wellington and McLennan Strait, the hazard extent is dominated by the potential extent of inundation as a result of an increase in the mean water level in the lakes rather than landward erosion of the shoreline itself.

9.5 Recommendations

There is uncertainty in both knowledge and data for different aspects of this assessment of shoreline erosion across the Gippsland Lakes. The following recommendations are made for further investigations and monitoring programs which would enable further refinement of the study outcomes, particularly the definition of the hazard zones along the shoreline.

9.5.1 Uncertainty in Knowledge

Salinity

The key knowledge gap for this study is the impact of salinity on the vegetation communities of the Gippsland Lakes shoreline and how this may impact on the current ability of these shorelines to mitigate erosion susceptibility.

As noted by various authors, such as Sjerp et al. (2002) and Water Technology (2013), the changes in salinity within the Gippsland Lakes associated with construction of the permanent entrance have resulted in changes to vegetation communities, with formerly freshwater ecosystems dying back or changing as a result of increased salinity. This is particularly relevant to reed beds (typically *Phragmites australis*) such as those fringing much of Lake Wellington, where increases in salinity during the recent (1996-2010) dry period resulted in considerable die-back of the plants and exposure of the shoreline to increased wave or current action.

At present, die-back rates of shoreline reed beds due to elevated salinity in the Gippsland Lakes have not been quantified and the impacts of sea level rise on the salinity regime within the lakes system is beyond the scope of this project.

In the future the GIS data model could be used to further investigate the impacts of different assumptions regarding vegetation response to sea level rise by applying vegetation rules based on, for example, slope or rate of sea level rise. However, the underlying knowledge as to how these communities are currently responding to salinity and what their trajectory may be into the future are unknown.

Coupling the impacts of changing salinity with vegetation response would require understanding of the changes to salinity regimes resulting from sea level rise as a prerequisite. This may be investigated in future through application of the hydrodynamic model, modified to resolve salinity dynamics.

Climate Change

It is likely that aside from sea level rise, climate change may result in changes to rainfall frequency and intensity which would alter the river inflow regime for the inflowing rivers. However there is considerable uncertainty as to the magnitude and timescale of such changes.

An additional potential impact of climate change which has even greater uncertainty surrounding it is the potential for changes in wind speeds and directions. There is currently no reliable guidance available on such changes.

The hydrodynamic models used for this study could be modified to test the sensitivity of the system to a wide range of potential climate change conditions, including the impact of salinity, changes to flows, and altered wind conditions.

9.5.2 Data Collection

The outcomes of this study could be further enhanced through the provision of additional data collection. Recommendations for data collection include:

- Mapping of shoreline EVCs that differentiates between reed beds and the scrubland to enable the impact of changes to reed bed extent to be quantified.
- Monitoring of the extent of specific high value reed beds (such as the western shore of Lake Wellington) along with salinity measurements to assess responses to salinity and enhance understanding of responses to these systems to change
- Erosion monitoring throughout the lakes system covering a range of shoreline types, environmental conditions (exposed to waves/currents), and vegetation communities.

This additional data could be readily applied to the spatial model to refine both the susceptibility and erosion risk zones.

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APPENDIX A PREVIOUS FORESHORE CLASSIFICATIONS

The following shoreline classification system was developed previous by Sjerp et al. (2002) to describe the susceptibility to erosion of the Gippsland Lakes shoreline. This information, along with the detailed descriptions of shoreline change detailed in the report has been used for the present study for benchmarking the analysis outputs.

Table A-1 Gippsland Lakes Foreshore Classification (from Sjerp et al. (2002))

Category	Example
1	**Low lying land which is rarely greater than 1 m above lake level, and which supports mainly salt marsh and swamp vegetation. There is little sand in the soil and the foreshore erodes rapidly once wave absorbing fringing vegetation is removed or dies.**
Lake Wellington	Bull Point to Tucker Point
	Tucker Point to Sheepwash Point
	Sheepwash Point to Crash Boat Landing
	Frawley Drain to Marlay Point
	Marlay Point Yacht Club to Strathfieldsaye
	Much of McLennan Strait
Lake Victoria	Spoon Bay to Bandin Bay
	McLennan Strait to Jones Bay (west)
	Blond Bay
	Gorcrow Point
Lake King to Lakes entrance	Point Fullarton and adjacent shoreline
	Jones Bay northern shore
	Old Nicholson River entrance
	Baines Swamp and Salt Lake entrance
	Point Jones
	Swamp area adjacent to Hopetoun Channel
	Salt marsh and swamp areas on Fraser and Rigby Islands
	Eastern Creek
2	**Low Lying vegetated land adjacent to the foreshore with sand soils that form beaches when the foreshore is eroded**
Lake Wellington	Bull Point
	Tucker Point
	Sheepwash Point
	Storm Point to Roseneath Point
	Point Plover to Bull Bay
Lake Victoria	Hybla Point to about 2km east of Thalia Pt
	Midway between Trouser Point and Green Hill Point
	On western side of Green Hill Point
	Shoreline backed by swamp between Green Hill Point and Point Wilson
	Rotamah, Rotten and Barton Islands

Category		Example
		Waddy Point and 1km west and north of Waddy Point
		Luff Point
3	**Low Lying farm land or recently revegetated farmland adjacent to the foreshore, marginally greater than 1m above sea level.**	
Lake Wellington		Crash Boat Landing to Frawley Drain
		Marlay Point to Marley Point Yacht Club
Lake Victoria		Between Jones Bay (west) and Blond Bay
Lake King to Lakes Entrance		Mitchell River silt jetties
		New Mitchell River Entrance, clockwise to Point Bolodun
		Broadlands
		Jones Island
		Tambo Bay and Swan Reach Bay adjacent to the Avon River entrance
		Flannagan Island
		Point Tyers and Mosquito Point
4	**Raised farm land with slowly eroding foreshore**	
Lake Wellington		Strathfieldsaye to Storm Point
Lake Victoria		Tannin, Terrace and Toms Point
		Bluff Head to Duck Arm
Lake King to lakes Entrance		Point Bolodun to Point Norgate
		Nicolson River to Slaughterhouse Creek
		Tambo Bay to Tambo Bluff
5	**Sandy accreting shoreline**	
Lake Wellington		Eastern Beach
Lake Victoria		Eastern side of Point Turner, Elbow Point, Terrace Point, Wattle Point, Waddy Point. Storm Point, Red Bluff, Pelican Point and Trouser Point
Lake King to Lakes Entrance		Eastern side of Point Scott and Jones Point
		West Metung between seawall and northern end of the Shaving Point reach
		Southern end of Beach in front of Baines Swamp
6	**Sandy eroding foreshore backed by high land**	
Lake Victoria		2km east of Thalia Point to start of Loch Sport
		Pelican Point to Point Wilson and the SE towards Rotomah Channel, except for low areas identified under Category 2
		Banksia Peninsula – eastern end
		South shore of Raymond Island
		Wattle Point to 2km west of Wattle Point
		Between Storm Point and Waddy Point
Lake King to Lakes		Eagle Point Bay at settlement

Category		Example
Entrance		West side of Shaving Point
		Southern shore of Hopetoun Channel up to the start of Bunga Arm
7	**Steeply sloping shoreline backed by high land**	
Lake King to Lakes Entrance		Tambo Bluff to Metung
		Bancroft Bay
		Bell Point through to Mount Barkly (Jemmy's Point)
		North Arm foreshore except for those areas previously identified as belonging to other categories.
8	**Shorelines modified by the placement of dredged sand**	
Lake King to Lakes Entrance		Point Scott
		Eastern end of Flannagan Island
		Rigby Island at various locations
		Bullock Island
		Southern shore of North Arm
		Cunninghame Arm – various locations

APPENDIX B DESCRIPTION OF NUMERICAL MODELS

GIPPSLAND LAKES SPECTRAL WAVE MODEL

A spectral wave model of the Gippsland Lakes was developed to assess shoreline wave power, and the relative changes in shoreline wave power with increasing mean sea levels, to provide an indicator of wave contributed shoreline erosion as part of the shoreline erosions susceptibility assessment described in this report.

The Danish Hydraulic Institute's (DHI), MIKE 21 Spectral Wave (SW) model was employed for this assessment. The model domain was created from the same topographic and bathymetric data sets as described for the hydrodynamic model in Report 2: Inundation Hazard Assessment. However, the mesh resolution and boundary were modified to better suit the requirements of the spectral wave model.

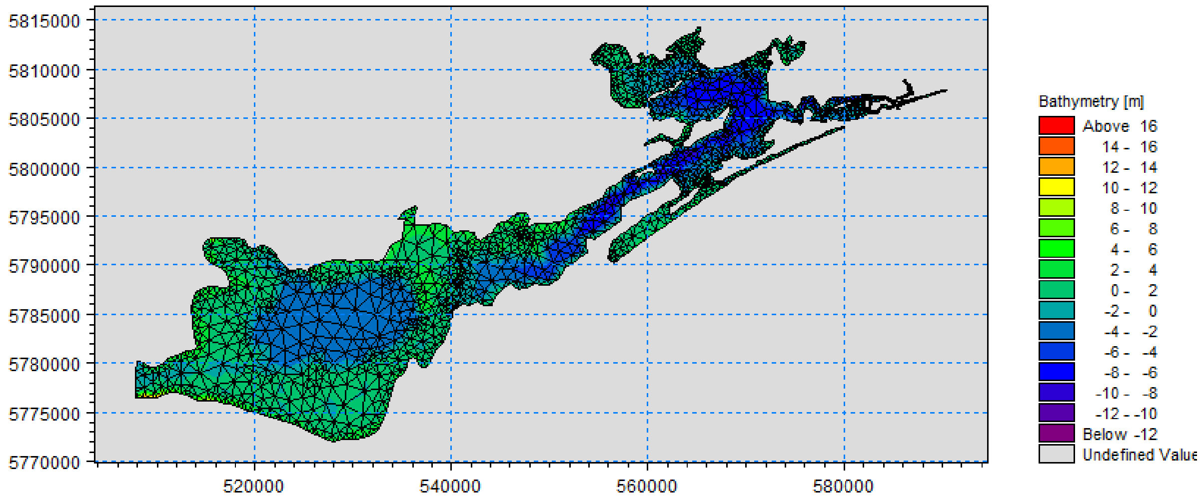

Figure B-1 **Gippsland Lakes Spectral Wave Model Domain and Computational Mesh Schematisation.**

Boundary Conditions

Waves inside the Gippsland Lakes are solely driven by wind blowing over the lake surface, due to the sheltering of open ocean swell by the barrier on the coastal side of the lakes. One year of representative wind conditions was determined through the analysis and comparison of annual wind rose plots and the long term wind rose plot, based on data from East Sale Airport. From this assessment 2005 was considered to provide the best representation of the long-term wind conditions at East Sale Airport.

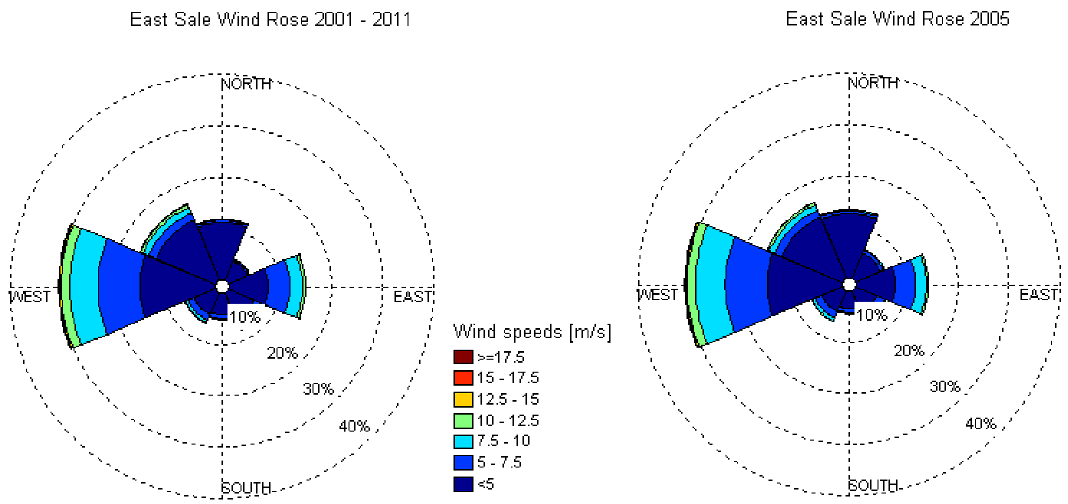

Figure B-2 **Rose Plot Comparisons of the 2001 - 2011 and 2005 Wind Conditions at East Sale Airport**

Model Set Up and Calibration

There were no wave data available inside the Gippsland Lakes which could be used to calibrate/validate the lakes spectral wave model, and therefore, the model was run using the recommended default parameters. Despite the above, the relative change in shoreline wave power under various sea level rise scenarios was of primary concern rather than absolute wave parameters, and thus rigorous calibration was not required. At the same time, the computational scheme used in the model is well developed and is known to produce reliable results in areas where the bathymetry is well defined. As such it is considered that the results of the spectral wave model should be quite representative of wave conditions within the Lakes.

GIPPSLAND LAKES HYDRODYNAMIC MODEL

A full description of the development, setup, calibration and validation of the hydrodynamic model used to assess the current exposure for the environmental characterisation of the shoreline cells is provided in Report 2: Inundation Hazard Assessment.