Report 2: Inundation Hazard

Gippsland Lakes/90 Mile Beach Local Coastal Hazard Assessment Project

April 2014

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Cover Photo: Lakes Entrance, June 2007 Flood (East Gippsland Catchment Management Authority)

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GLOSSARY

Australian Height Datum (AHD)	A common national plane of level corresponding approximately to mean sea level
ARI	Average Recurrence Interval
AEP	Annual Exceedance Probability: The measure of the likelihood (expressed as a probability) of an event equalling or exceeding a given magnitude in any given year
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
Calibration	The process by which the results of a computer model are brought to agreement with observed data
Chart Datum	Common datum for navigation charts. Typically relative to Lowest Astronomical Tide
Eustatic Sea Level Rise	A rise in mean sea level at the global scale, for example as a result of melting ice-caps
Exceedance Probability	The probability of an extreme event occurring at least once during a prescribed period of assessment is given by the exceedance probability. The probability of a 1 in 100 year event (1% AEP) occurring during the first 25 years is 22%, during the first 50 years the probability is 39% and over a 100 year asset life the probability is 63%
Hydrodynamic Model	A numerical model that simulates the movement of water within a defined model area
Isostatic Sea Level Rise	A rise in sea level relative to a fixed position, for example as a result of land subsidence.
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).
Residual Water Level	The residual water level is the non-astronomical tidal component of a water level. Residual water levels can be either positive or negative, and can occur through a range of processes such as catchment inflows, coastally trapped waves, wind setup and the inverse barometric effect
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
Tidal Planes	A series of water levels that define standard tides, eg. 'Mean High Water Spring' (MHWS) refers to the average high water level of Spring Tides

Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides

1. INTRODUCTION

1.1 Overview

This report details the analysis undertaken to identify and predict inundation hazards associated with large flood events in the Gippsland Lakes. Inundation hazards have been determined under existing conditions and for a number of projected mean sea level rise scenarios over the course of the next century.

A number of townships adjacent to the shorelines of the Gippsland Lakes are located at relatively low elevations and are therefore vulnerable to inundation associated with flooding. Water levels in the Gippsland Lakes are influenced by a combination of different physical forcings and hydrodynamic processes including:

- Catchment generated streamflows (including floods);
- Coastal driven water levels (including tides and sea-storms); and
- Wind setup (lake levels elevated by the force of wind on the lake surface).

Detailed hydrodynamic modelling is required to integrate these processes and enable estimates of extreme water levels to be determined under various sea level rise scenarios. A sensitivity analysis has also been undertaken, assessing how hazards may vary with respect to changes in key system inputs such as river inflows or coastal erosion.

It is noted that the purpose of this study is to define potential coastal hazards under existing and future climate change scenarios. Whilst this report will provide insights to likely future planning levels around the Gippsland Lakes, it does not redefine these levels. A further detailed and targeted flood study will be required to revise flood planning levels for the Gippsland lakes under future climate change scenarios.

1.2 Reporting

This document is part 2 of a series of 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: Lake Shoreline Erosion Susceptibility
- Report 5: Coastal Monitoring

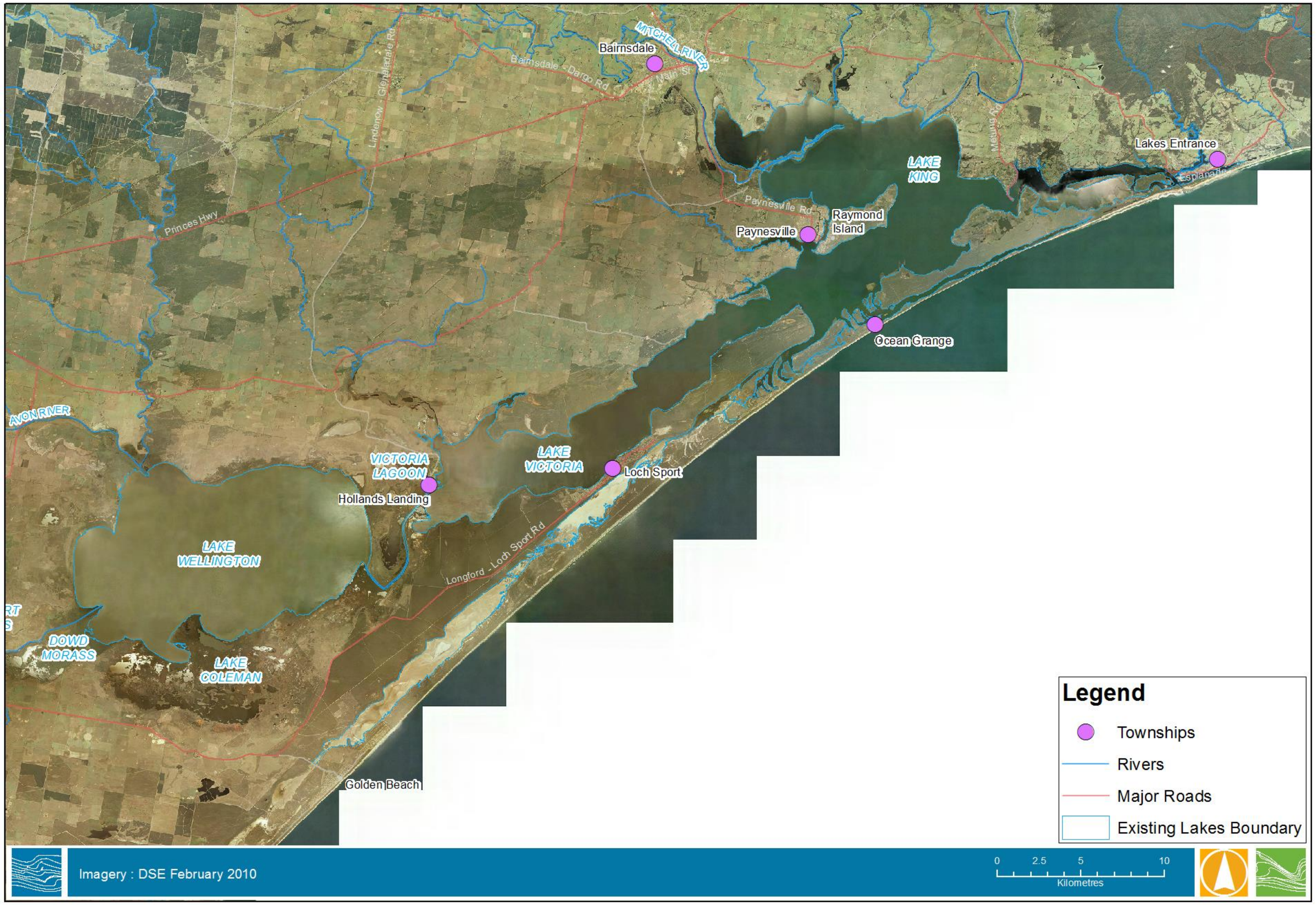


Figure 1-1 Gippsland Lakes Overview Map

1.3 Hazard Scenarios

The inundation hazard scenarios were developed by the Project Steering Group in consultation with the Technical Advisory Panel. The inundation hazard scenarios modelled in this study are shown in Table 1-1 below. These represent a selection of events spanning the range of potential SLR scenarios up to 2100 and consistent with the Victorian Hazard Guide (DSE, 2012) and the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, Working Group 1. It is noted that Scenario 2a was added to the list of scenarios specified in the brief in order to provide an indication of the response of the Lakes under a more extreme flood level than the 10% AEP case. Further guidance on the methods and approach to determine coastal hazard is provided in *Chapter 8 - Risk Assessment* of the Victorian Coastal Hazard Guide, (DSE, 2012).

Table 1-1 Scenario and Event Combinations Considered in Inundation Hazard Assessment

Scenario	SLR Likelihood at different timeframes				SLR (m)	Gippsland Lakes Flood (AEP%)[1]
	Current	2040	2070	2100		
1	Likely	Virtually certain			0	10%
2	About as likely as not	Likely	Virtually certain		0.2	10%
2a	About as likely as not	Likely	Virtually certain		0.2	1%
3	Unlikely	About as likely as not	Likely	Virtually certain	0.4	10%
4		Exceptionally unlikely	Unlikely	About as likely as not	0.8	10%

[1] Note that flood level frequency in the Gippsland Lakes may result from a combination of river inflows, wind, storm surge and tide.

It was decided by the PSG that modelling of the 1% AEP flood scenario with +0.4 and +0.8 m of sea level rise should not be undertaken for the following reasons:

- The uncertainties around future climate change projections, particularly in regard to rainfall, runoff and resultant changes in the estimated 1% AEP flood volumes entering the lakes; and
- The potential to confuse model outputs from this study with the declared flood levels presently used in the Gippsland Lakes.

1.4 Reporting

This document is part 2 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 Hazard**
- Report 3: Outer Barrier Coastal Erosion Hazard
- Report 4: Lakes Shoreline Erosion Hazard
- Report 5: Coastal Monitoring

This report is structured as follows:

- Background into the physical processes and dynamics that cause extreme water levels in the Gippsland Lakes;
- Overview of the historical impact of flooding within the Gippsland Lakes and overall flood vulnerability of representative locations within the Gippsland Lakes;
- Discussion of the analysis undertaken to identify representative design flood case scenarios for the Gippsland Lakes;
- Documentation of the development of the hydrodynamic model and calibration;
- Modelling analysis of the impact of sea level rise on the ambient hydrodynamic processes in the Gippsland Lakes;
- Modelling analysis of the impact of sea level rise on extreme water levels in the Gippsland Lakes; and
- Modelling analysis of major sources of uncertainty that could impact the inundation hazard assessment

2. BACKGROUND

2.1 Flood Drivers

Water levels in the Gippsland Lakes are a result of a complicated interaction between a number of physical forcings and hydrodynamic processes. The following summarises the main physical drivers of water levels in the Gippsland Lakes:

Catchment Generated Stream Flows

Catchment generated stream flows are the dominant forcing affecting extreme water levels in the Gippsland Lakes (Grayson R, 2004). Major floods in the river basins draining to the Gippsland Lakes can increase mean water levels by over one metre for periods of two to five days. The number and scale of the contributing catchments (over 20,000 km^2 in total) is such that variability in the synoptic rainfall systems can result in large variations in the streamflow contributions from each river basin. Subsequently, the Gippsland Lakes has complicated flood hydrology.

Coastal Driven Water Levels

The Gippsland Lakes experience water level variations caused by meteorological forcing of coastal water levels in Bass Strait that propagate through the entrance and penetrate all major water bodies within the Lakes. The water level variations are caused by a combination of the inverse barometric pressure affect, coastally trapped waves and astronomical tides. Extreme coastal driven water level events are generally referred to as storm surges. Coastally driven water level fluctuations generally vary over periods of two to five days and can frequently increase water levels by up to approximately 0.5 m with extreme storm surge events exceeding approximately 0.7 m (McInnes, Macadam, Hubbert, Abss, & Bathols, 2005) in the Gippsland Lakes. Higher frequency diurnal (once daily) and semi-diurnal (twice daily) astronomical tides propagate through the ocean entrance, although attenuated, and influence water levels in the vicinity of Lakes Entrance. Due to narrow channels and high friction losses, tides are more significantly attenuated further from the entrance such that the spring tidal range is less than 0.1 m and 0.05 m in the central and western lake basins respectively.

Wind Setup

The action of wind on the water surface creates shear stresses that drag water in the downwind direction within the Lakes. In shallow depths and confined waterways, the rate at which water is transported downwind exceeds the rate at which it can return under gravity and a super elevation of water levels is observed at downwind locations. In the Gippsland Lakes this generally occurs along a SW-NE axis. Wind setup can elevate water levels over periods of several hours to a day by up to approximately 0.5 m.

2.1.1 Existing Flood Characteristics

A number of townships, adjacent to the Lakes shoreline, are located at relatively low elevations and are therefore vulnerable to inundation associated with elevated water levels in the Gippsland Lakes.

The largest recorded flood events in the Gippsland Lakes were in 1893 and 1952. Available accounts suggest that these two floods were of similar magnitude (State Rivers and Water Supply Commission, 1981), although there is limited flood level information or flood damage reports from these events. Over recent decades, the Gippsland Lakes and associated townships and communities have experienced a number of minor to moderate flooding events. The following section summarises the historical impact of flooding at the critical study area locations and the overall flood vulnerability of these locations under existing sea level conditions.

Lakes Entrance

Lakes Entrance is particularly vulnerable to flooding due to the intensity of the development in the township, low elevations and proximity to the ocean entrance and associated tidal influence which can amplify flood levels locally. The estimated Annual Exceedance Probability (AEP) flood levels from the Gippsland Lakes Flood Modelling Project (GLFMP) (Grayson, et al., 2004) for Lakes Entrance in comparison to historical flood events are displayed in Table 2-1. Table 2-1 also displays the estimated number of properties impacted or isolated for different flood levels in Lakes Entrance.

The 1% AEP flood level for Lakes Entrance was calculated as 1.8 m AHD as part of the GLFMP. It is estimated approximately 597 properties are at risk of inundation in a flood of this magnitude at Lakes Entrance, with an additional 211 properties isolated (East Gippsland Shire Council, 2012).

The most significant recent historical flood event at Lakes Entrance was the June 2007 flood. This flood peaked at 1.4 m AHD at Lakes Entrance. A flood of this magnitude would be expected to have an Average Recurrence Interval (ARI) of approximately 30-40 years.

The next most significant flood recent flood event was in 1998 when levels peaked at approximately 1.3 m AHD at Lakes Entrance. A flood of this magnitude would be expected to have an average recurrence interval (ARI) of approximately 20 years.

The potential extent of inundation at 0.1 m flood level increments for Lakes Entrance has been derived from the LiDAR survey and is displayed in Figure 2-1. As can be seen from Figure 2-1, the flood level vulnerability of Lakes Entrance is such that flooding of roads and properties begins at around 0.9 – 1.0 m AHD. Low level inundation hazards begin primarily through surcharging of the stormwater network. Large increases in flood inundation extents and numbers of properties impacted occurs at flood levels above approximately 1.0 m AHD at Lakes Entrance.

Table 2-1 Historical Flood Magnitudes and Impacts at Lakes Entrance

AEP (ARI) Flood	Historical Floods	Level (m AHD)	Impacted Properties[1]	
			Flooded	Isolated
1% (100 yr)		1.8	597	211
	1952	1.7	561	211
2% (50 yr)		1.6	505	211
	2007	1.4	409	194
5% (20 yr)		1.3	329	173
	1998	1.3	-	-
10% (10 yr)		1.2	-	-
	1990	1.06	83	0
	2012	0.88	32	0

[1]Property Information sourced from the East Gippsland Shire Flood Emergency Plan (East Gippsland Shire Council, 2012).

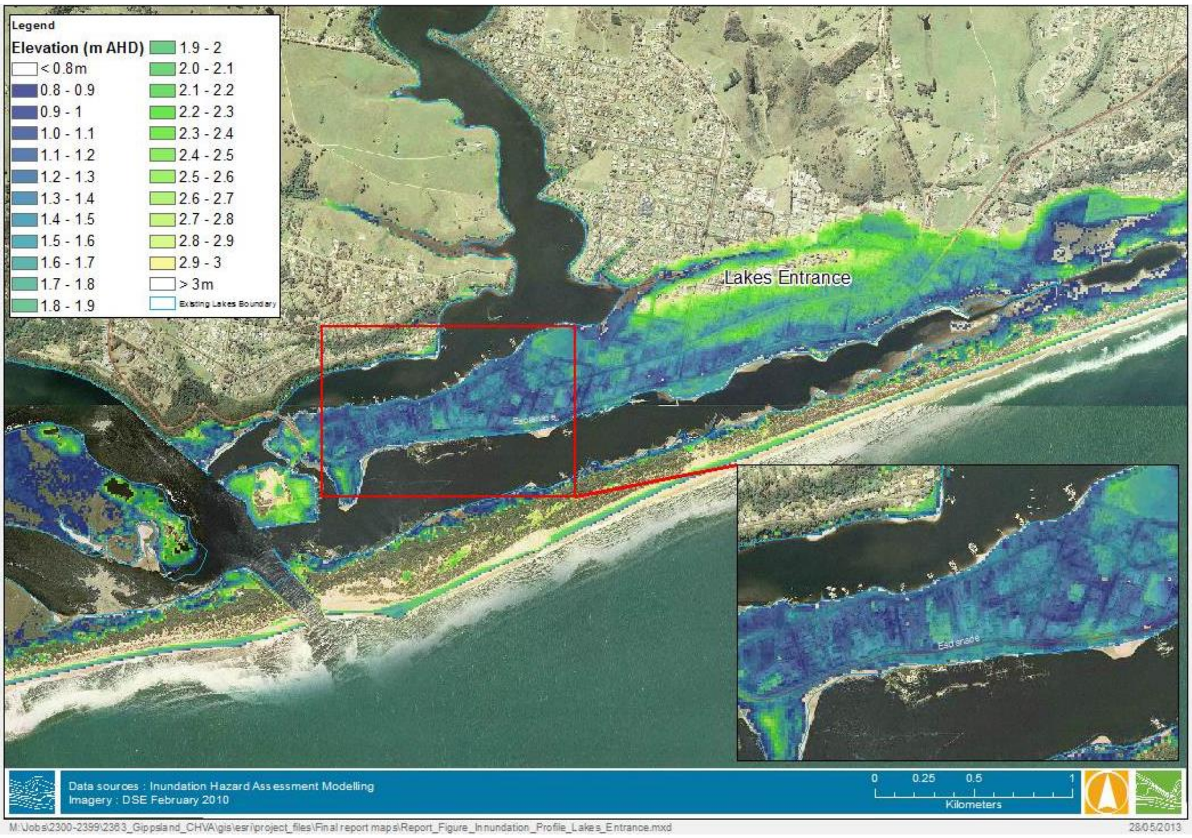


Figure 2-1 Inundation Profile for Lakes Entrance

Paynesville & Raymond Island

The communities of Paynesville and Raymond Island are vulnerable to flooding. Raymond Island is particularly vulnerable as the island becomes isolated at relatively low elevations due the inability of the ferry to operate during periods of Lake water levels above 0.725 m (East Gippsland Shire Council, 2012). The isolation of Raymond Island can typically last for up to two weeks. The estimated AEP flood levels from the GLFMP for Paynesville and Raymond Island in comparison to historical flood events are displayed in Table 2-2. Table 2-2 also displays the estimated number of properties impacted or isolated at for different flood levels at Raymond Island and Paynesville

The 1% AEP flood level at Paynesville was calculated as 2.0 m AHD as part of the GLFMP. In excess of 300 properties at Paynesville and Raymond Island combined are subject to inundation during a 1% AEP flood event (East Gippsland Shire Council, 2012).

The most significant recent historical flood event was the June 2007 flood. This flood peaked at approximately 1.5 m AHD at Paynesville. A flood of this magnitude would be expected to have an average recurrence interval of approximately 20 years at Paynesville.

The flood vulnerability profile at Paynesville and Raymond Island is given in Figure 2-2. Large increases in inundation extents and number of properties impacted occurs at approximately 1.3 m AHD.

Table 2-2 Historical Flood Magnitudes and Impacts at Paynesville & Raymond Island

AEP (ARI) Flood	Historical Flood (year)	Level (m AHD)	Impacted Properties[1]	
			Flooded	Isolated
1% (100 yr)		2.0	-	-
		1.8	292	264
2% (50 yr)		1.7	263	251
	1893	1.67	-	-
5% (20 yr)		1.5	174	251
	2007	1.5	174	251
	1998	1.35	-	-
10% (10 yr)		1.25	58	122
	2012	1.01	23	5

[1] *Property Information sourced from the East Gippsland Shire Flood Emergency Plan* (East Gippsland Shire Council, 2012).

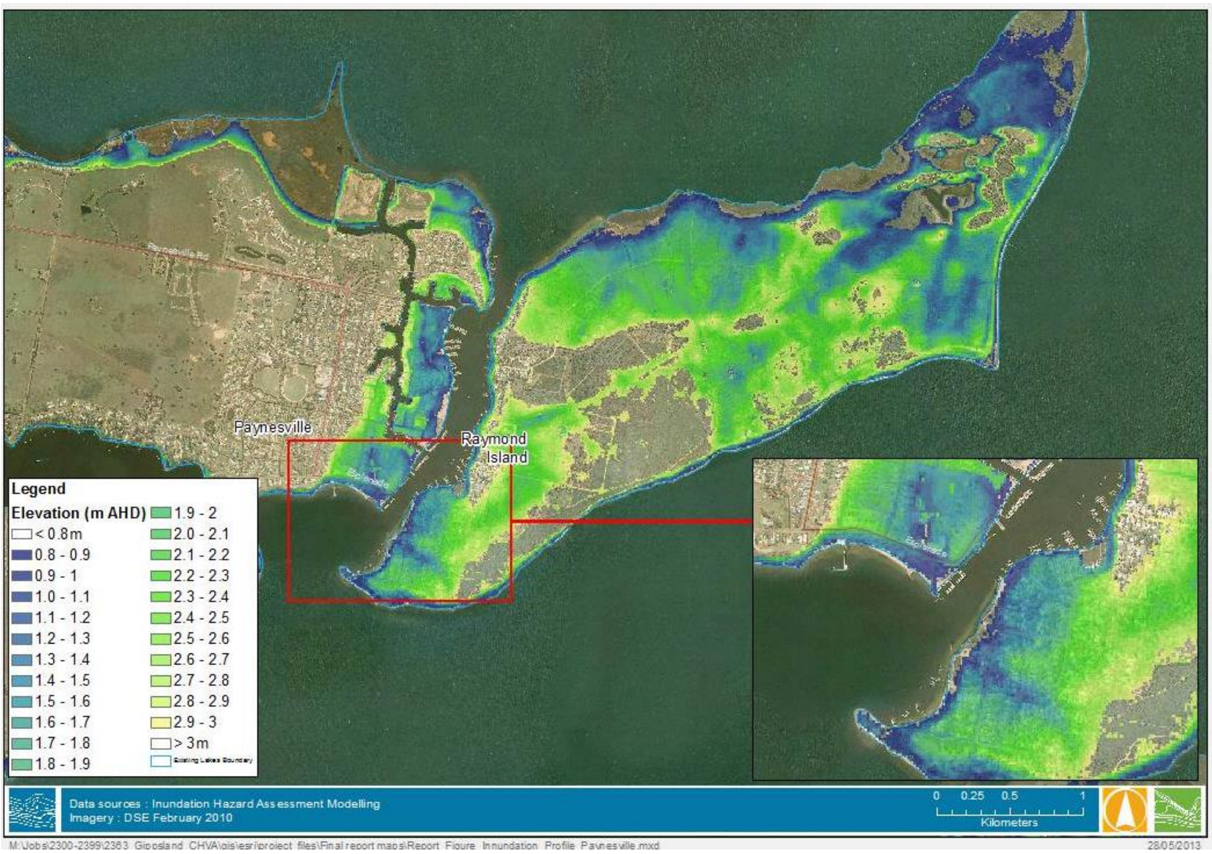


Figure 2-2 Inundation Profile for Paynesville

2.1.2 Previous Hydrodynamic Modelling

A major component of the technical investigations for this project involves numerical modelling of inundation and erosion processes. A number of previous hydrodynamic models have been developed for the Gippsland Lakes. These are listed and assessed according to relevant attributes in Table 2-3 below. As a result of this review it was confirmed that none of the existing models were appropriate for the present study and a new hydrodynamic and wave model should be developed for the Gippsland Lakes. For Bass Strait, Water Technology had an existing model that was appropriate to simulate offshore hydrodynamic and wave conditions.

Table 2-3 Main Previous Gippsland Lakes Hydrodynamic Models

Knowledge Source	Computation	Spatial Resolution	Modelled/ Measured Period	Simulations Run	Availability/Ownership	Applicability
Gippsland Lakes Second Entrance Study, hydrodynamic (RMA2)model, (Water Technology, 2005)	2D in horizontal, vertically integrated	Triangular and quadrilateral elements varying in size from less than 25 m to over 1500 m in length	Simulation periods of weeks to months. Calibration period Jan 2001	Existing conditions (average flow inputs) Second Entrance at Ocean Grange	Gippsland Coastal Board. Water Technology, model and output are readily available	• Topography does not include floodplain • Not suitable for flooding simulations as flood-dry process is inadequate
Gippsland Lakes Environmental Study (CSIRO, 2001), Hydrodynamic Model (MECO)	Full 3D hydrodynamics	500 m orthogonal grid, schematised McLennan Straits and Reeves Channel	Calibration to period July 1995 – June 1999, most scenarios computed over 4 year period, some for 32 years.	Existing conditions and 6 scenarios: • < flow 20% all rivers • < flow 20% in east rivers • > flow 20% west rivers • Entrance shallower • Entrance deeper • Second entrance	Gippsland Coastal Board/CSIRO, assume data is available	• 3D capability not required for this project, increases run times • Description too coarse for present purposes • Topography does not include floodplain
Gippsland Lakes Flood Level Modelling Project (Grayson, et al., 2004)(Sobek model)	One-dimensional hydrodynamic model	Bathymetry described by cross-sections at varying spacing from 10's to 100's of meters	Calibration period 1976 to 2000, focus was on high water levels. Design simulations based on a Monte Carlo method	Simulations based on existing conditions, 1000's of stochastically generated floods	Gippsland Coastal Board/CEAH/Cardno, assume data is available	• Simplified geometry, optimised for speed and computing peak flood levels • Limited details available at representative locations • Floodplain topography is out-of-date (before Lidar)

3. FLOOD HYDROLOGY

3.1 Background and Method

In order to integrate the complex combination of physical forcings that give rise to extreme water levels within the Gippsland Lakes, the previous GLFMP (Grayson, et al., 2004) study employed a stochastic modelling method that involved the simulation of 3,000 synthetic flood, coastal water level and wind cases. From these 3,000 cases, a total of 329 large cases were identified that were the focus of the analysis of the annual exceedance probability of extreme water levels in the Gippsland Lakes as displayed in Figure 3-1. The resulting design annual exceedance water levels for Lakes Entrance, along with level for other localities, are shown in Table 3-1.

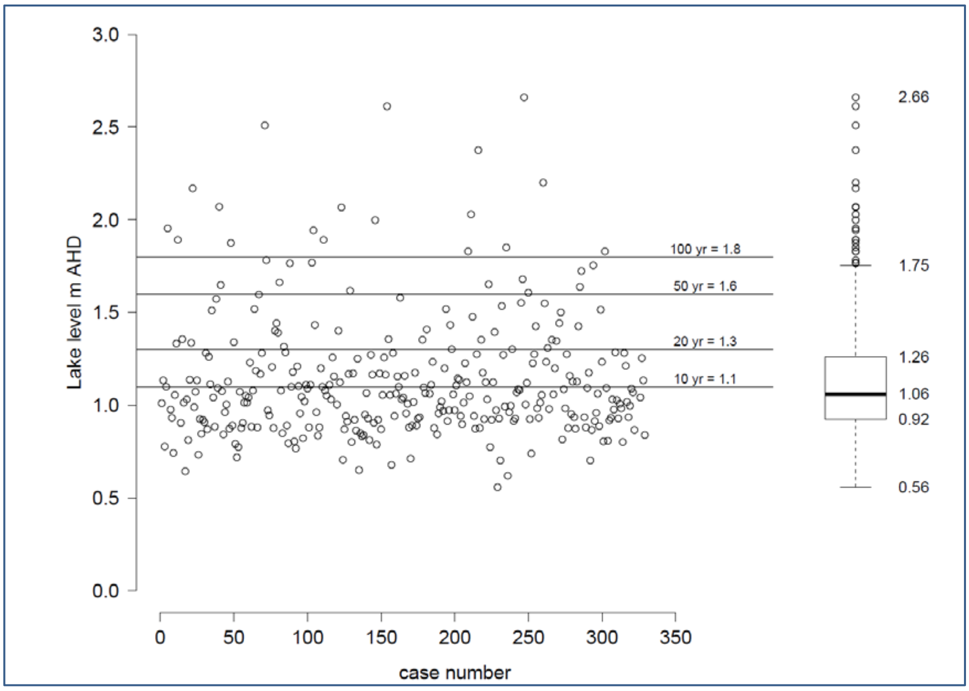


Figure 3-1 Peak Water Level at Lakes Entrance from the 329 Largest Stochastically Generated Flood Events in GLFMP study

Table 3-1 Estimated Annual Exceedance Levels for Gippsland Lakes

AEP (%)	ARI (Yrs)	Level (m AHD)		
		Lakes Entrance	Paynesville	Lake Wellington (west)
1	100	1.8	2.0	2.2
2	50	1.6	1.7	2.0
5	20	1.3	1.5	1.7
10	10	1.2	1.3	1.4

To identify representative streamflow, coastal water level and wind condition scenarios to support the modelling of the impact of sea level rise on extreme water levels in the Gippsland Lakes, analysis of the 329 large cases developed in the previous GLFLMP project was undertaken. The purpose of the analysis was to derive a set of forcings that produce modelled water levels throughout the Gippsland Lakes that approximate the current 10% and 1% AEP design water levels under existing sea level conditions. It should be noted that due to the size of the Gippsland Lakes and the multiple streamflow inputs and other physical forcings that contribute to extreme water levels, no single case/flood event can be expected to consistently reproduce the 10% or 1% AEP water levels throughout the entire system. Selection of the cases has therefore been undertaken to provide representative scenarios that show the relative impact of sea level rise on the existing 10% and 1% AEP water levels.

The main forcing variables that were analysed to characterise the design cases were as follows:

- Western Rivers inflow volume (Latrobe, Thompson and Avon Rivers)
- Eastern Rivers inflow volume (Mitchell, Nicholson and Tambo Rivers)
- Total inflow volume, including ungauged inflows
- Peak residual coastal water level at flood level peak
- The SW-NE wind velocity component at flood level peak

To identify the cases that most closely resembled the statistical averages of the main forcing variables listed above, the following method was undertaken:

- The median value of the main forcing variables for each case i.e. east volume, west volume, total volume, COL and wind was calculated along with 95% Confidence Intervals

- The distance of each case from the median value for each main forcing variable was calculated using the statistical measure of distance below:

$$d = \frac{(x_i - \text{median}(X))}{\text{median absolute deviation}(X)} \quad (1)$$

  Where

  d is a statistical measure of distance

  x_i is value of a descriptive variable for a particular case e.g. the value of the volume of the easterly inflows for case 152

  median(*X*) is the is the median of the descriptive variable for all cases e.g. the median of the volume of easterly inflows for all casts

  median absolute deviation(*X*) is the median of the absolute deviations from the median of (*X*)

- The total distance of each case from the median was calculated by summing the squares of the distance for each main forcing variable:

$$d_{tot} = \sum d_i^2 \quad (2)$$

  Where *i* is a descriptive variable e.g. east volume

- The cases were sorted in order of d_{tot}. Cases with the smallest value of d_{tot} were interpreted as most representative of the median forcings

The following sections summarise the results of the application of the above method to identify representative 10% and 1% AEP streamflow, coastal water level and wind cases.

3.2 10% AEP Flood Scenario

A total of 55 cases with peak levels within 5 cm of the estimated 10% AEP (1.2 m AHD) level at Lakes Entrance were identified from the 329 large cases. This was used as the primary filter of cases, after which the 55 cases were analysed for their ability to replicate peak water levels at Lake Wellington, Paynesville and Metung as well as Lakes Entrance. Table 3-2 summarises the median and 95% confidence intervals for the main forcing variables characterising these cases. The following observations regarding the median characteristics of the cases displayed in Table 3-2 are provided:

- Of the 55 cases, 31 cases have inflow volume dominated from the western rivers and 24 cases where the eastern rivers volume dominate
- On average, there was negligible contribution to water levels due to wind setup within the Lakes for the 10% AEP cases
- Coastal water level residual influence at the flood peaks was generally modest, relative to other forcings

Analysis of the statistical measure of distance from the median for all 55 cases resulted in identification of 10 cases with the lowest sum of the square distances of the main forcing variables. Close examination of these 10 cases resulted in 2 cases being excluded due to unrealistic characteristics in the stochastic forcings they contained. An overview of the stochastic forcings for the 8 most representative cases is displayed in Figure 3-2. Of the 8 cases, the stochastic forcings provided by Case 259 provided the lowest sum of the square distances and was considered to provide the most representative median combination of forcings giving rise to 10% AEP water levels within the Gippsland Lakes.

Table 3-2 Median Characteristics of the 10% AEP Cases

Variable	Median	Confidence Interval	
		5%	95%
Western Rivers Inflow Volume (GL)	799	678	961
Eastern Rivers Inflow Volume (GL)	737	658	780
Total Inflow Volume (GL)	1,492	1,389	1,634
Peak Coastal Water Level Residual (m)	0.26	0.23	0.38
SW-NE Wind Velocity Component (m/s)	2.6	0	4.4

The 10% AEP design flood levels versus selected case levels at key locations around the Lakes are shown in Table 3-3 including the corresponding modelled levels from this study. This shows that the 10% AEP design level is closely matched at Lakes Entrance, but that modelled levels at Paynesville and Lake Wellington are 300 mm higher than the design values. This difference in level is due to the way the design levels were obtained by combining statistics from hundreds of runs. Hence no single model run will reproduce the exact design levels at all locations. Whilst the differences at Paynesville and Lake Wellington are significant, they are considered to be reasonable in terms of providing comparative hazard results for current and future conditions.

Table 3-3 Comparison of 10% AEP Design Flood Levels with Adopted Case 259

Location	10% AEP Design Level (m AHD)	[1]Case 259 Sobek (m AHD)	Modelled Case 259 (m AHD)
Lakes Entrance	1.2	1.1	1.2
Paynesville	1.3	1.5	1.6
Lake Wellington	1.4	1.6	1.7

[1] Levels modelled as part of the Gippsland Lakes Flood Level Modelling Project (Grayson R, 2004)

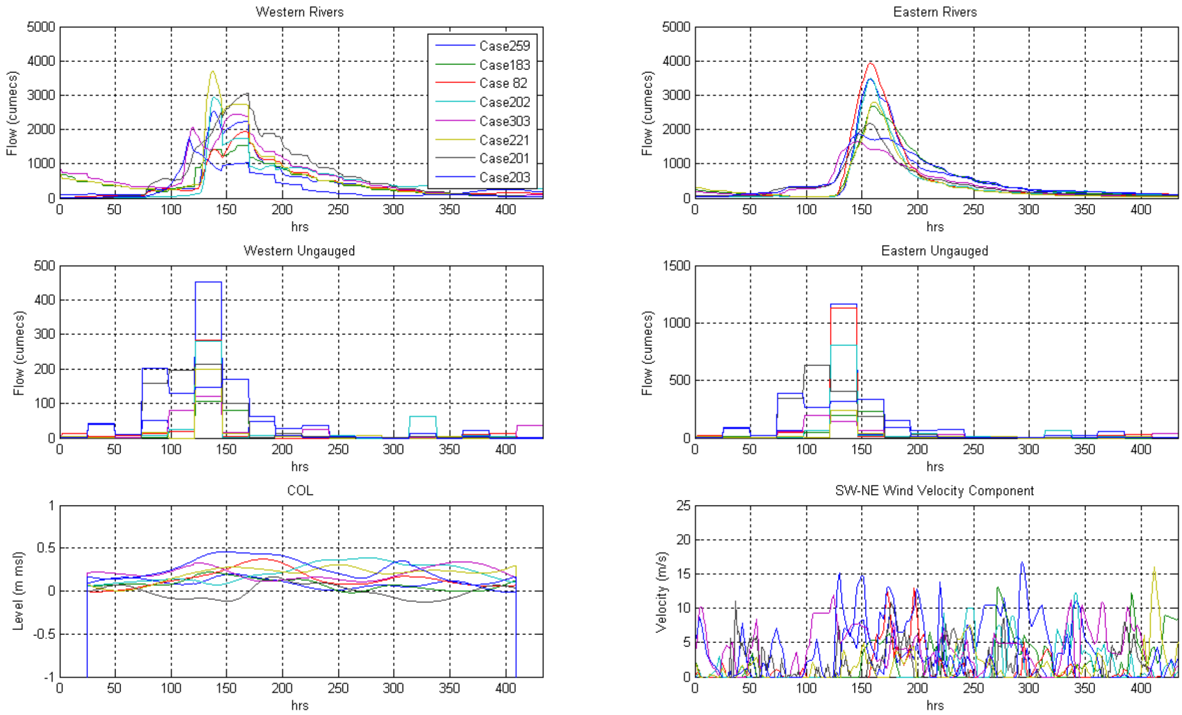


Figure 3-2 Representative Stochastic Forcing Cases for the 10% AEP Scenario

3.3 1% AEP Flood Scenario

A total of 11 cases with peak levels within 10 cm of the 1% AEP (1.8 m AHD) level at Lakes Entrance were identified from the 329 large cases. This was used as the primary filter of cases, after which the 11 cases were analysed for their ability to replicate peak water levels at Lake Wellington, Paynesville and Metung as well as Lakes Entrance. Table 3-4 summarises the median and 95% Confidence Intervals for the main variables characterising these cases. The following observations regarding the median characteristics of the cases displayed in Table 3-4 are provided:

- Both west and eastern river dominant cases can result in 1% AEP peak levels
- Wind speeds are noticeably stronger for the 1% AEP cases than for the 10% AEP cases
- Coastal water level residual influence at the flood peaks was, in generally, relatively modest for the 1% AEP cases

Analysis of the statistical measure of distance from the median for the 11 cases resulted in identification of 6 cases with significantly lower sum of the square distances of the main forcing variables. Close examination of the 6 cases showed that the stochastic forcings contained within these cases were all considered reasonable. An overview of the stochastic forcings for the 6 most representative cases is displayed in Figure 3-3. Of the 6 cases, the stochastic forcings provided by Case 302 provided the lowest sum of the square distances and was considered to provide the most representative median combination of forcings giving rise to 1% AEP water levels in the Gippsland Lakes.

Table 3-4 Median Characteristics of the 1% AEP Cases

Variable	Median	Confidence Interval	
		5%	95%
Western Rivers Inflow Volume (GL)	913	648	1,141
Eastern Rivers Inflow Volume (GL)	856	726	1,278
Total Inflow Volume (GL)	1,752	1,481	2,636
Peak Coastal Water Level Residual (m)	0.34	0.21	0.37
SW-NE Wind Velocity Component (m/s)	10	5	11

The 1% AEP design flood levels versus selected case levels at key locations around the Lakes are shown in Table 3-5 including the corresponding modelled levels from this study. This shows that the 1% AEP design level is closely matched at Lakes Entrance, but that modelled levels at Paynesville and Lake Wellington are 300 mm lower than the design values. As described for the 10% AEP case, these differences are due to the way the design levels were obtained by combining statistics from hundreds of runs. Hence no single model run will reproduce the exact design levels at all locations. Whilst the differences at Paynesville and Lake Wellington are significant, they are considered to be reasonable in terms of providing comparative hazard results for current and future conditions.

Table 3-5 Comparison of 1% AEP Design Flood Levels with Adopted Case 302

Location	1% AEP Design Level (m AHD)	[1]Case 302 Sobek (m AHD)	[2]Modelled Case 302 (m AHD)
Lakes Entrance	1.8	1.8	1.8
Paynesville	2.0	1.5	1.7
Lake Wellington	2.2	1.8	1.9

[1] Levels modelled as part of the Gippsland Lakes Flood Level Modelling Project (Grayson R, 2004).
[2] The boundary conditions for the eastern rivers were adjusted by increasing flow by 20% to better match levels in the mid-lakes area as represented by the modelled level at Paynesville.

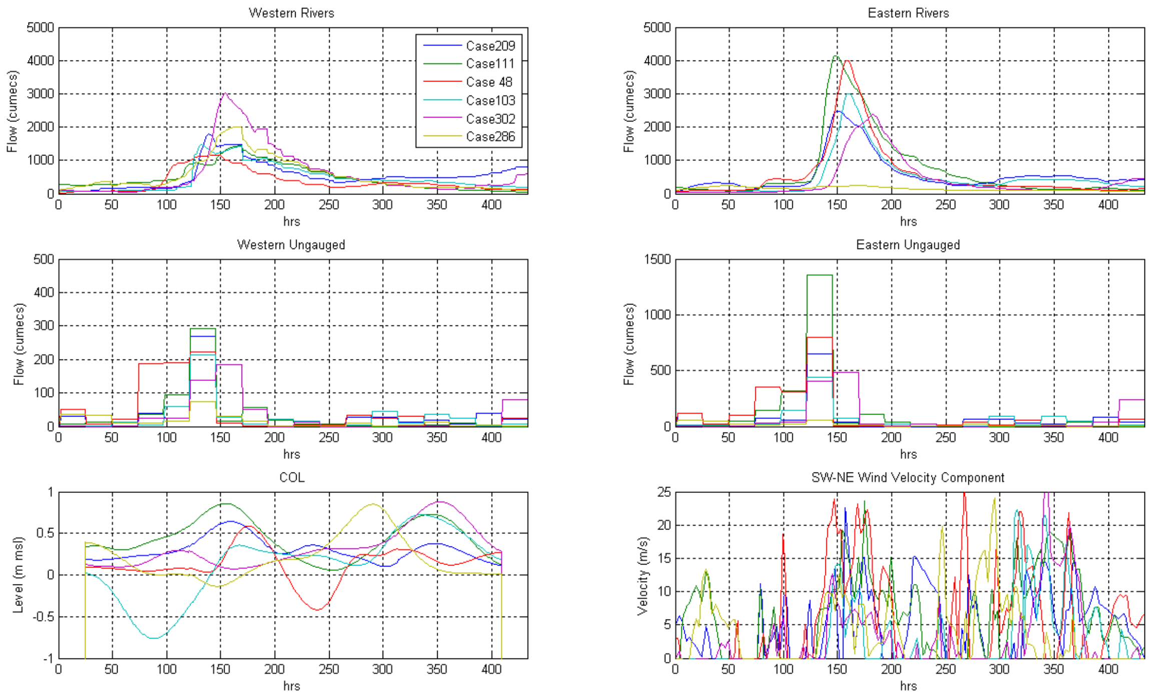


Figure 3-3 Representative Stochastic Forcing Cases for the 1% AEP Scenario

4. HYDRODYNAMIC MODEL

4.1 Model Development

4.1.1 Model System

The Danish Hydraulic Institute's (DHI) MIKE21 Flexible Mesh (FM) hydrodynamic model was used to simulate the impacts of sea level rise and climate change on the extent of inundation hazards within the study area. MIKE21 FM is a two-dimensional model based on the two-dimensional shallow water equations; the depth-integrated incompressible Reynolds averaged Navier-Stokes equations.

The discretization of the governing equations is performed using a cell-centred finite volume method, with an unstructured mesh in the geographical domain. An explicit scheme was used for the time integration.

4.1.2 Domain Schematisation

The extent of the hydrodynamic model of the Gippsland Lakes is shown in Figure 4-1. The model domain extends to all areas within the Gippsland Lakes basin up to an elevation of 3.0 m AHD. The coastal boundary extends approximately 4 km offshore in the vicinity of Lakes Entrance. The model topography and bathymetry are derived from a number of different survey data sets including the following:

- Terrestrial Coastal LiDAR survey captured as part of the Coordinated Imagery Program between 09/2007 – 09/2009, provided by DSE
- A number of recent bathymetric survey data sets of the entrance channel and tidal channels in the vicinity of the entrance, provided by Gippsland Ports
- Bathymetry survey data sets of the Gippsland Lakes compiled as part of the previous GLFLMP (Grayson, et al., 2004) and provided for this project as part of Gippsland Lakes Data Assimilation Project. This DEM contained contour data derived from photogrammetry collected in the 1980s, area specific hydrographic surveys and spot depths from other source maps
- Bathymetric LiDAR survey, offshore of Ninety Mile Beach, collected for the Future Coasts Program between 26/11/2008 – 03/04/2009, provided by DSE.

The different survey data sets were projected to GDA Zone 55 coordinates and all elevations were reduced to AHD. A prioritisation routine was used during the computational mesh interpolation to utilise more recent and or more detailed survey data sets where appropriate within the study area.

The computational mesh consisted of both triangular and quadrilateral elements, and varied in size depending on the complexity of the terrain and the need to resolve the hydrodynamic processes of interest at different locations within the Lakes. Figure 4-1 displays an overview of the model domain and computation mesh, whilst Figure 4-2 displays a zoomed–in view of the model mesh at Lakes Entrance. These figures show the flexibility of the model mesh, with relatively coarse mesh elements in areas with limited change in bed levels or coastline geometry (such as middle of Lake Wellington, where triangular elements up to approximately 1500 m x 1500 m were specified), whilst areas with complex geometry or hydrodynamics are resolved with fine mesh elements (such as Lakes Entrance, where quadrangular elements of approximately 10 m x 25 m were specified).

The geometry of the entrance, between the training walls and just inside and outside of the entrance itself, is subject to change over time due to sand movement by strong currents under typical tidal conditions as well as flood. For example the entrance would be expected to scour on the rising limb and then refill on the falling limb of a flood hydrograph. In addition to this pattern, there are intertidal variations in sediment transport with the rising and falling tide.

The variations in bed form around the entrance are also influenced by regular dredging undertaken by Gippsland Ports which is required to maintain safe navigation to the Port of Lakes Entrance from Bass Strait.

The interactions between sediment and flow dynamics at the entrance are clearly complex and were outside the scope of this investigation. For the purposes of this study, the most recent entrance geometry survey was used and calibration to various flow events has shown that the results are satisfactory for the prediction of peak flood levels.

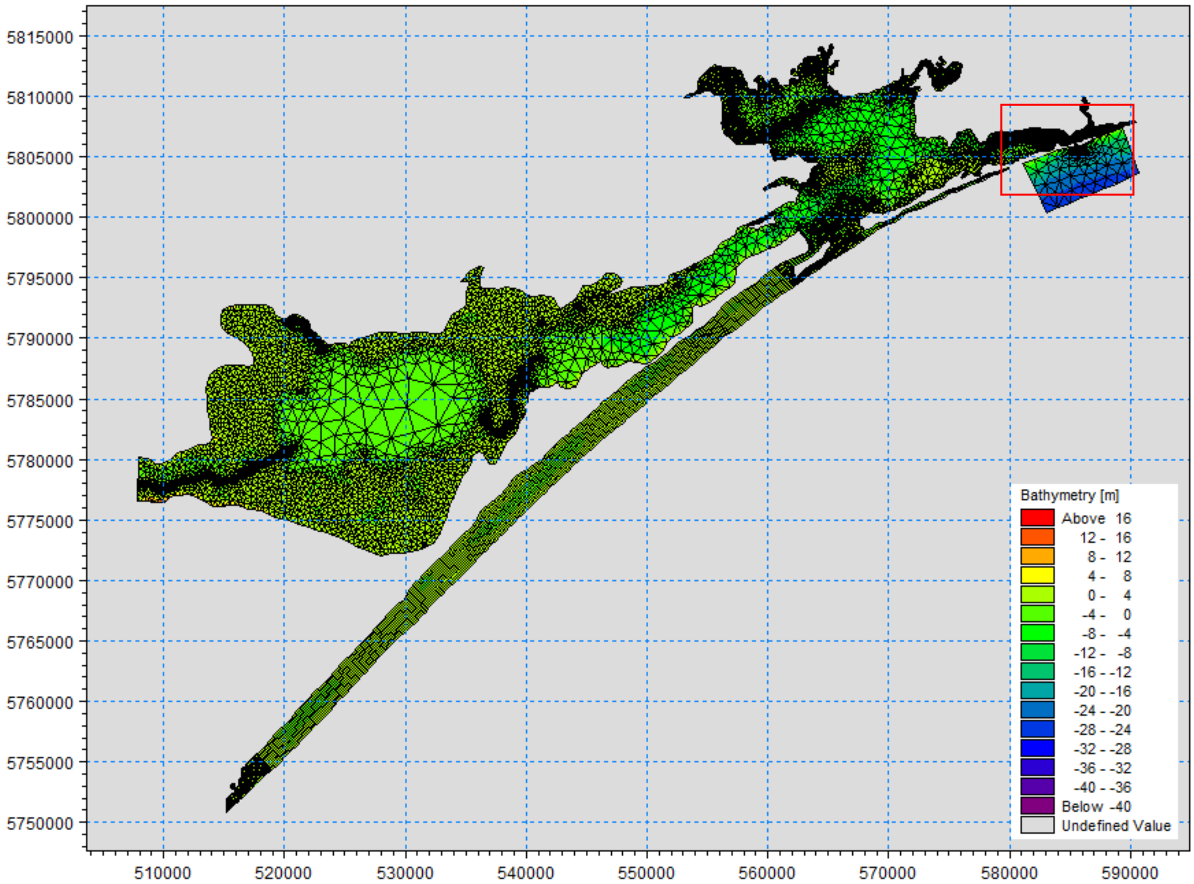


Figure 4-1 Gippsland Lakes Hydrodynamic Model Domain and Computational Mesh Schematisation

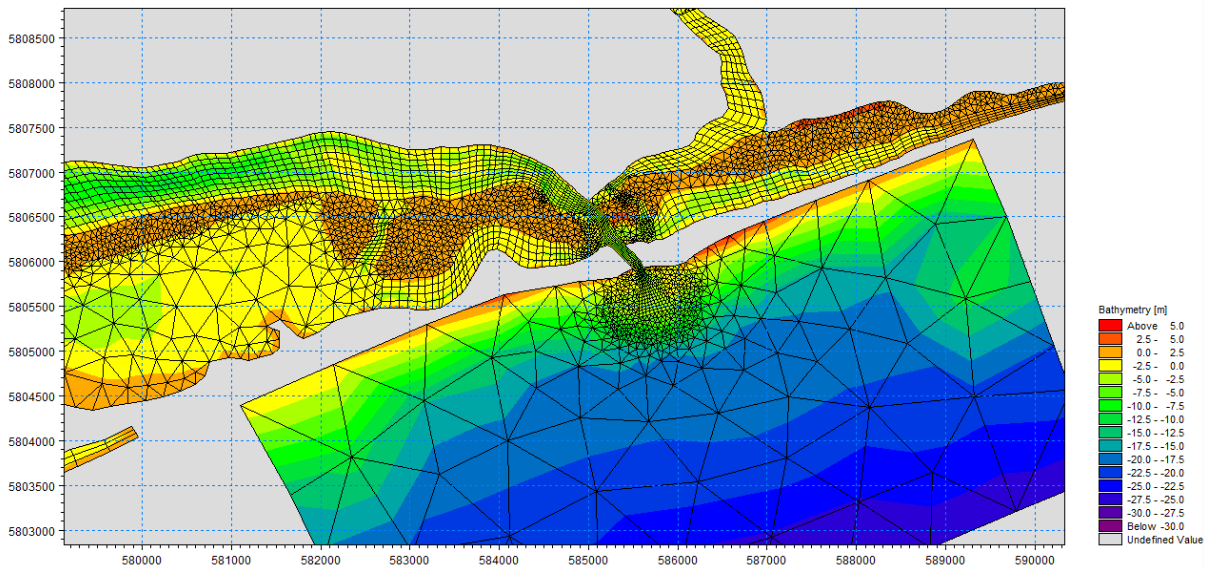


Figure 4-2 Zoomed in Section of the Hydrodynamic Mesh and Computational Domain at Lakes Entrance

4.1.3 Boundary Conditions

Due to the multiple physical forcings giving rise to water level variations in the Gippsland Lakes, the hydrodynamic model contains a number of different boundary condition specifications. The hydrodynamic model boundary conditions and source data used to force the model are discussed below.

Astronomical Tides

An open tidal boundary was defined along the offshore coastal boundary in Bass Strait. The astronomical tide boundary was derived from published astronomical tidal constituents (Hinwood & Wallis).

Coastal Residual Water Levels

Estimates of the meteorological components of coastal water level variations associated with barotropic effects (changes in atmospheric pressure), coastal trapped waves and local wind setup were developed from a number of sources depending on the available data.

Where streamflow inputs to the Gippsland Lakes were minimal and available data existed, the Lakes Entrance Breakwater (LEB) water level gauge operated by Gippsland Ports was decomposed into the tidal harmonic components and the remaining residual water level variations were applied at the model ocean boundary. Previous analysis (Water Technology, 2008) showed that mean sea levels in Bass Strait over moderate time scales (1 week or more) correlated well with mean water levels in Lake King and Lake Victoria.

Where significant streamflow impacts existed on the water level record at LEB, such as during major flood events, the coastal residual water levels were predicted based on the equations developed by Tan (Tan & Grayson, 2002) as part of the GLFLMP (Grayson R, 2004).

Catchment Inflows

The five main catchment streamflow inputs to the Gippsland Lakes were derived from available streamflow gauge data for the catchments. Under low flow conditions, the most downstream available streamflow records were applied to the model boundary with no additional scaling or routing to the hydrodynamic model boundary.

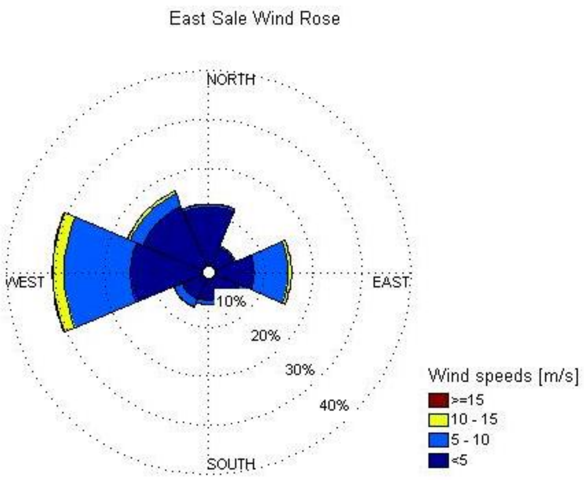
For significant streamflow conditions, the gauged data was scaled and routed based on the routing equations and parameters determined for each of the main river inflows as part of the Gippsland Lakes Flood Forecasting system (Sinclair Knight Merz, 2011). The catchment inflows for the June 2012 flood event were supplied by the Bureau of Meteorology, from their Gippsland Lakes model.

Wind Shear

Wind data provided by the Bureau of Meteorology for the East Sale Airport site was applied uniformly over the model domain. The wind drag coefficient was varied linearly with wind speed as follows:

$$C_D = \begin{cases} 7\ \frac{\mathrm{m}}{\mathrm{s}} & 1.255 \times 10^{-3} \\ 25\ \frac{\mathrm{m}}{\mathrm{s}} & 2.425 \times 10^{-3} \end{cases}$$

The magnitude and directional distribution of wind data from the East Sale Airport site and Lakes Entrance breakwater anemometer were compared in the form of wind roses, as shown in Figure 4-3. The plotted wind data suggests the two stations match closely, with the exception of slightly stronger and more frequent westerly winds at East Sale. Although the East Sale Airport anemometer is inland from the Gippsland Lakes in comparison to the Lakes Entrance breakwater site, it provided a much longer continuous record, and therefore was adopted for the hydrodynamic model. The relatively close match between the two datasets, and lack of appropriate continuous wind data from sites closer to the Lakes, confirmed the East Sale Airport wind data provided an appropriate representation of wind speed and directions occurring over the Gippsland Lakes.



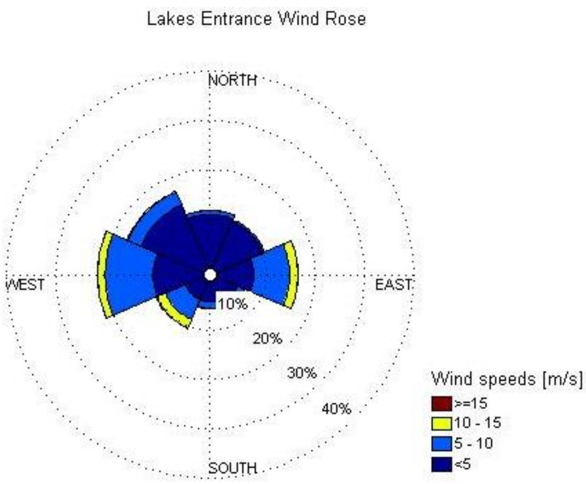


Figure 4-3 East Sale Airport and Lakes Entrance Breakwater Wind Roses for the Period 15th April 2008 - 31st December 2011

4.2 Model Calibration

4.2.1 Approach

In order to establish the hydrodynamic model was appropriate for use in the inundation hazard assessment, four hydrodynamic scenarios were selected based on available data for calibration of the model. The purpose of the model calibration was to achieve the following:

- Establish the ability of the model to reproduce the fundamental hydrodynamic behaviour of the lakes due to typical tide, wind and streamflow conditions; and
- Reproduce major flood behaviour across the lakes

The four calibration scenarios selected were:

- Typical flow conditions (June-July 2011)
- A large flood (June 2007)
- A series of minor flows (August 2011)
- A minor flood (June 2012)

The calibration process consisted of simulating the scenarios and reviewing the discrepancy between modelled and observed water levels at different locations within the lakes. Where significant differences were observed, the cause of the discrepancy was identified and changes made to the model configuration and parameterisation until a satisfactory level of agreement was achieved.

4.2.2 June – July 2011 Typical Conditions

The hydrodynamic model was calibrated to typical conditions over a three month period, June to August 2011. This period included two small freshwater inflows, periods of wind setup, and elevated coastal ocean levels. The boundary conditions used to force the hydrodynamic model during this time period are shown in Figure 4-4.

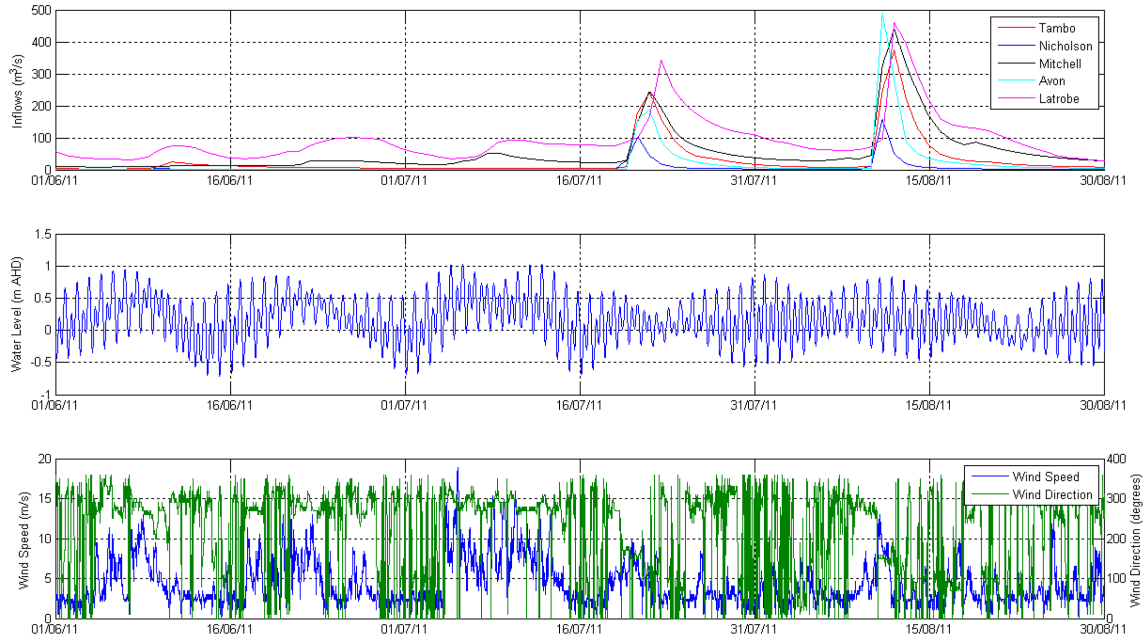


Figure 4-4 **Boundary Conditions Used to Force the Hydrodynamic Model for a 3 Month Period in 2011 during Ambient Conditions**

Measured water level data were available from seven different locations within the lakes during this period. Time series plots of measured and modelled total, tidal and residual water level data for the seven locations are given below in Figure 4-5 to Figure 4-11.

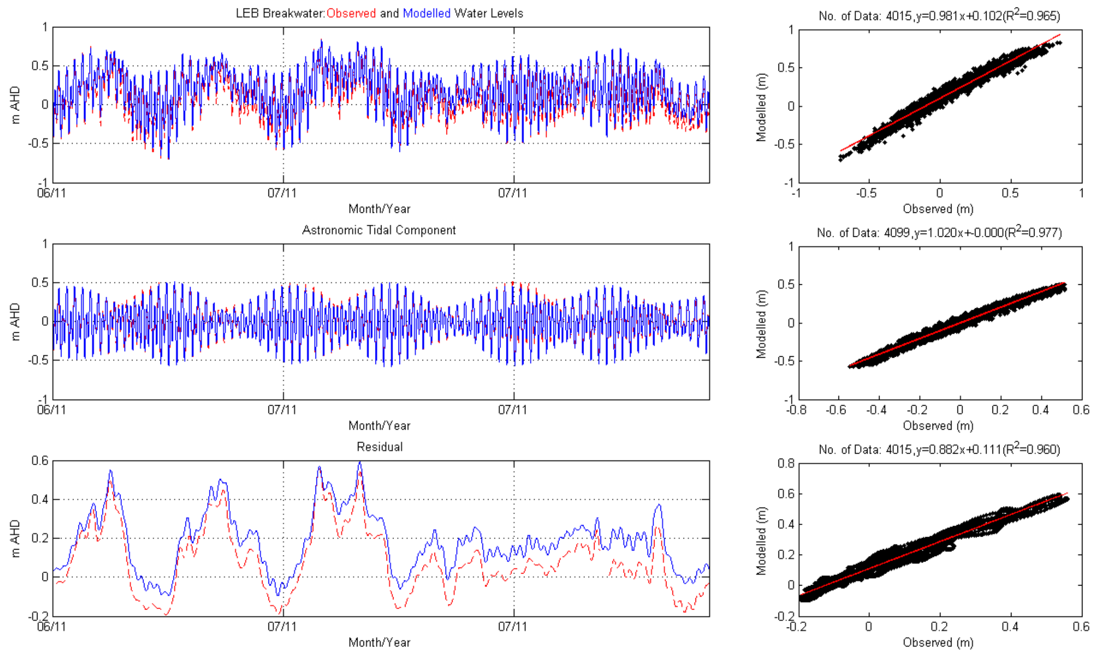


Figure 4-5 **Comparisons of Total, Tidal and Residual Water Level Data for the 2011 Ambient Conditions Simulation at Lakes Entrance Breakwater**

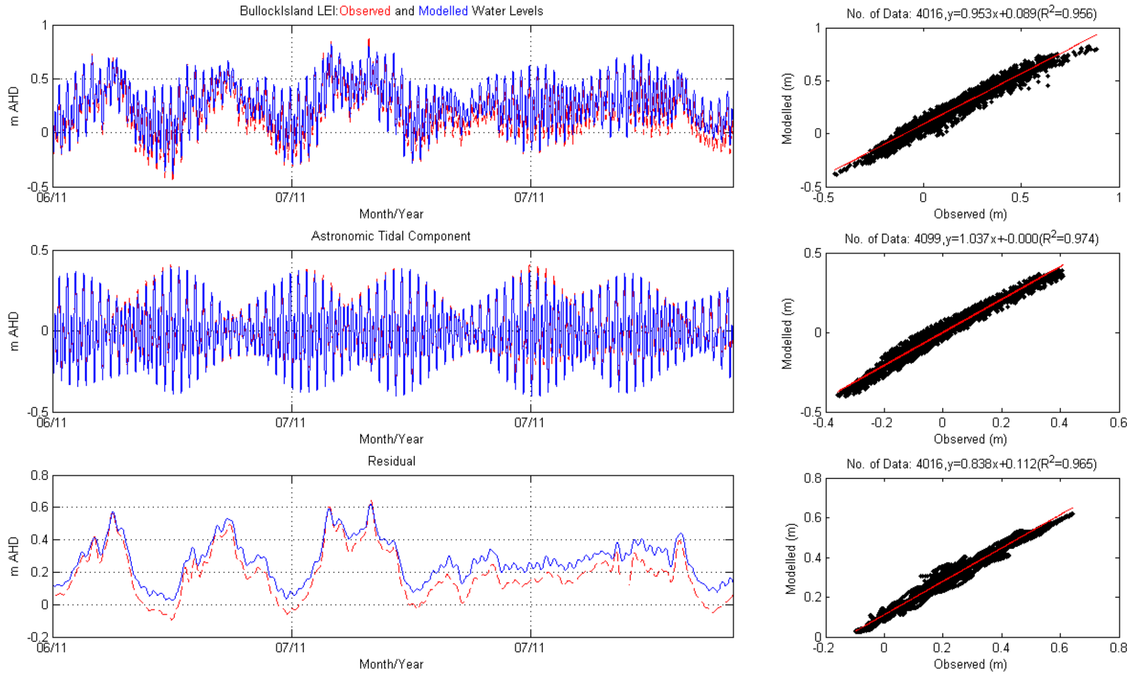


Figure 4-6 **Comparisons of Total, Tidal and Residual Water Level Data for the 2011 Ambient Conditions Simulation at Bullock Island**

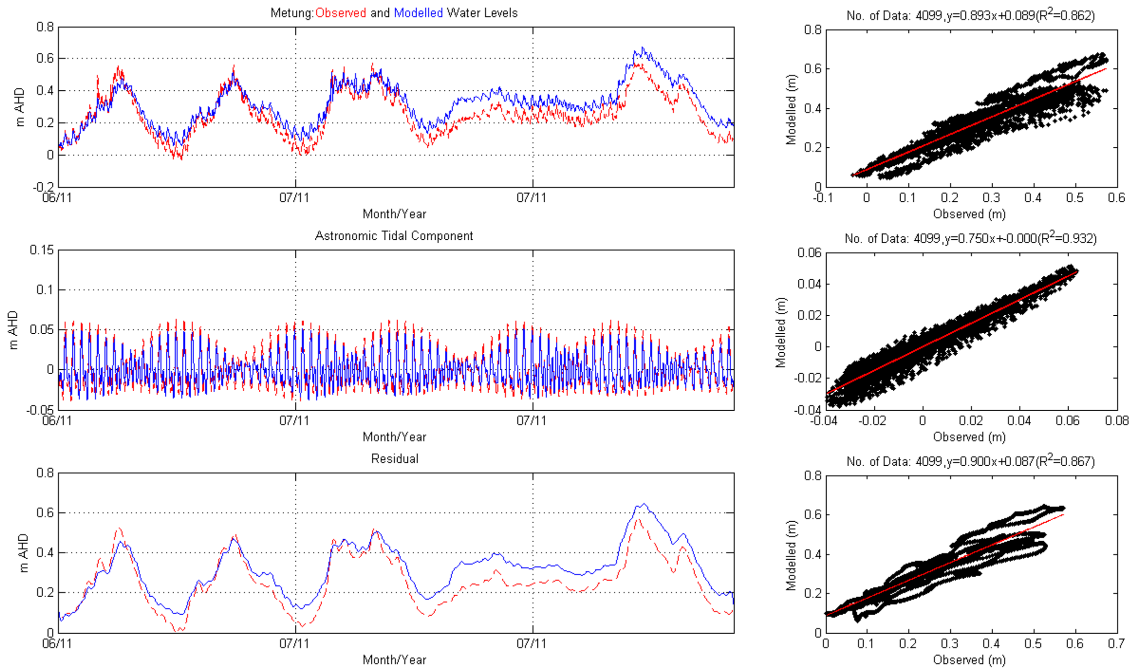


Figure 4-7 **Comparisons of Total, Tidal and Residual Water Level Data for the 2011 Ambient Conditions Simulation at Metung**

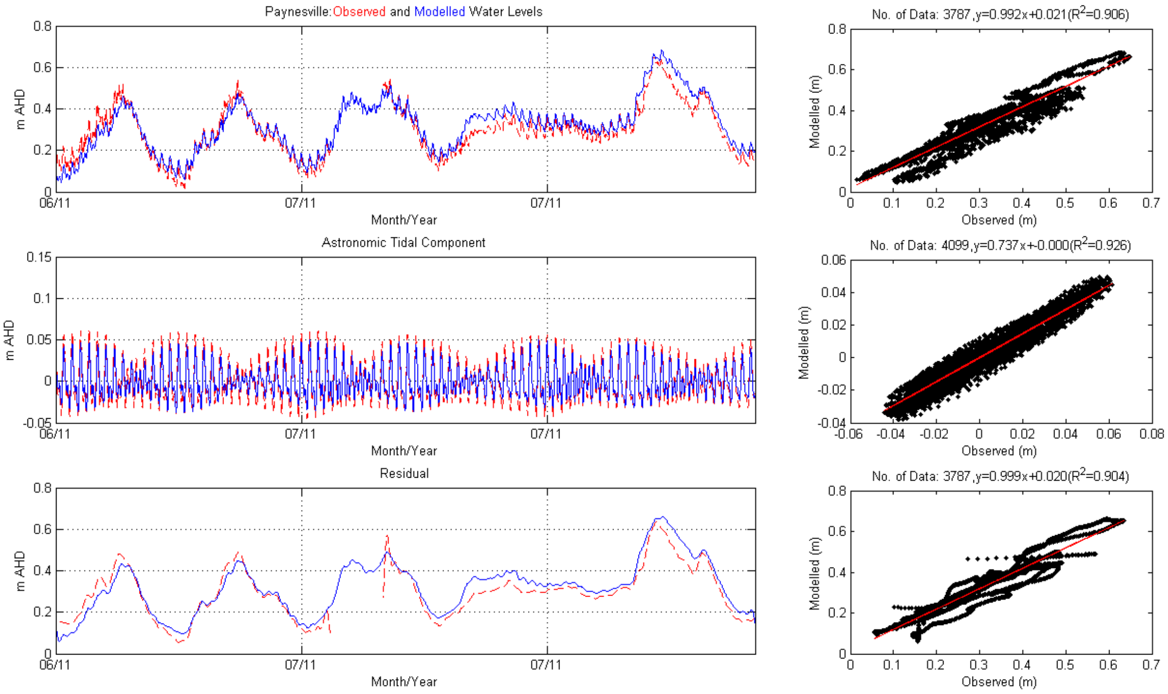


Figure 4-8 Comparisons of Total, Tidal and Residual Water Level Data for the 2011 Ambient Conditions Simulation at Paynesville

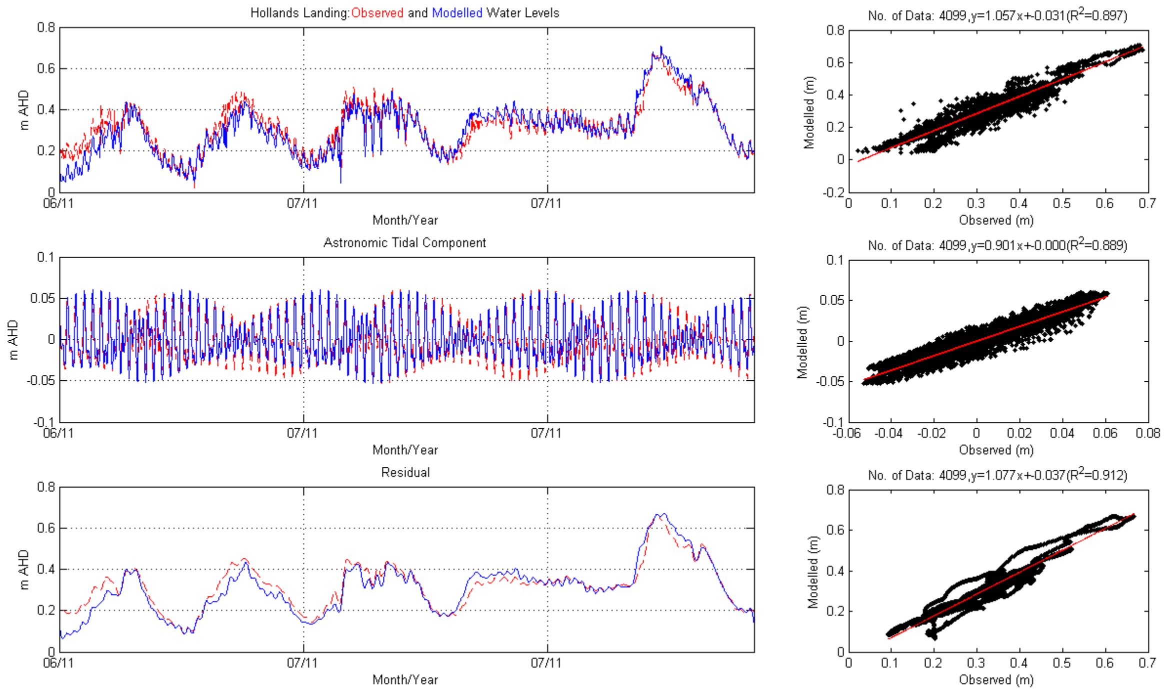


Figure 4-9 Comparisons of Total, Tidal and Residual Water Level Data for the 2011 Ambient Conditions Simulation at Holland's Landing

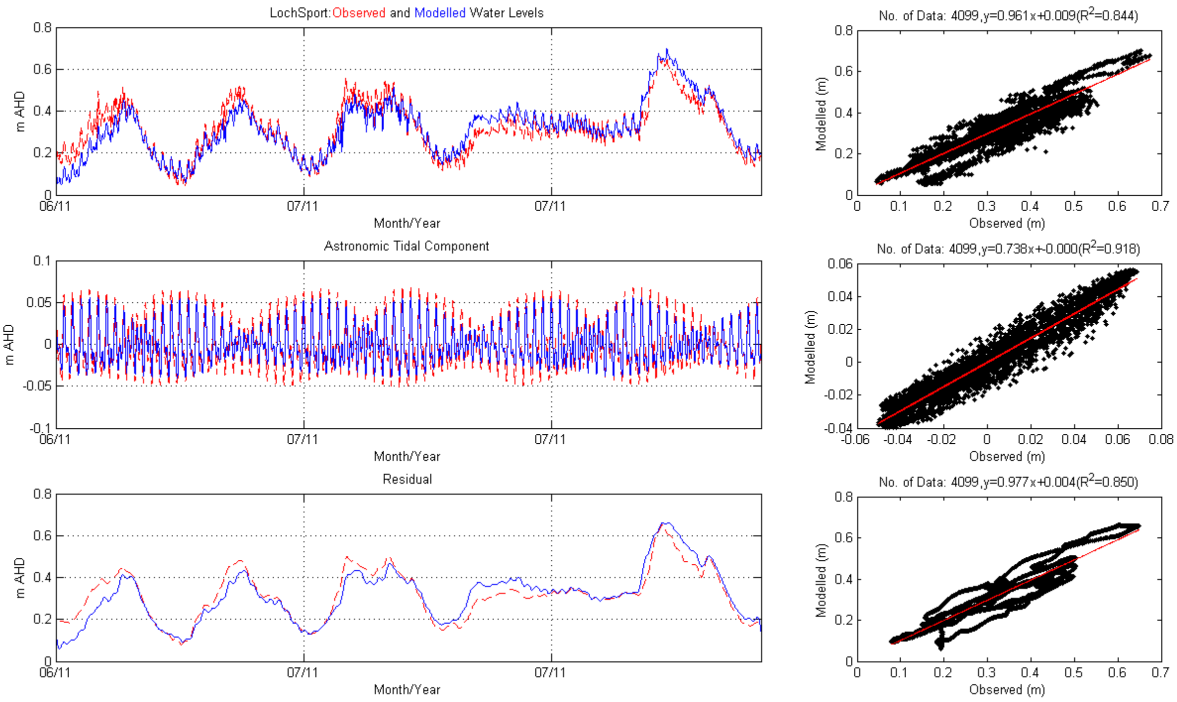


Figure 4-10 **Comparisons of Total, Tidal and Residual Water Level Data for the 2011 Ambient Conditions Simulation at Loch Sport**

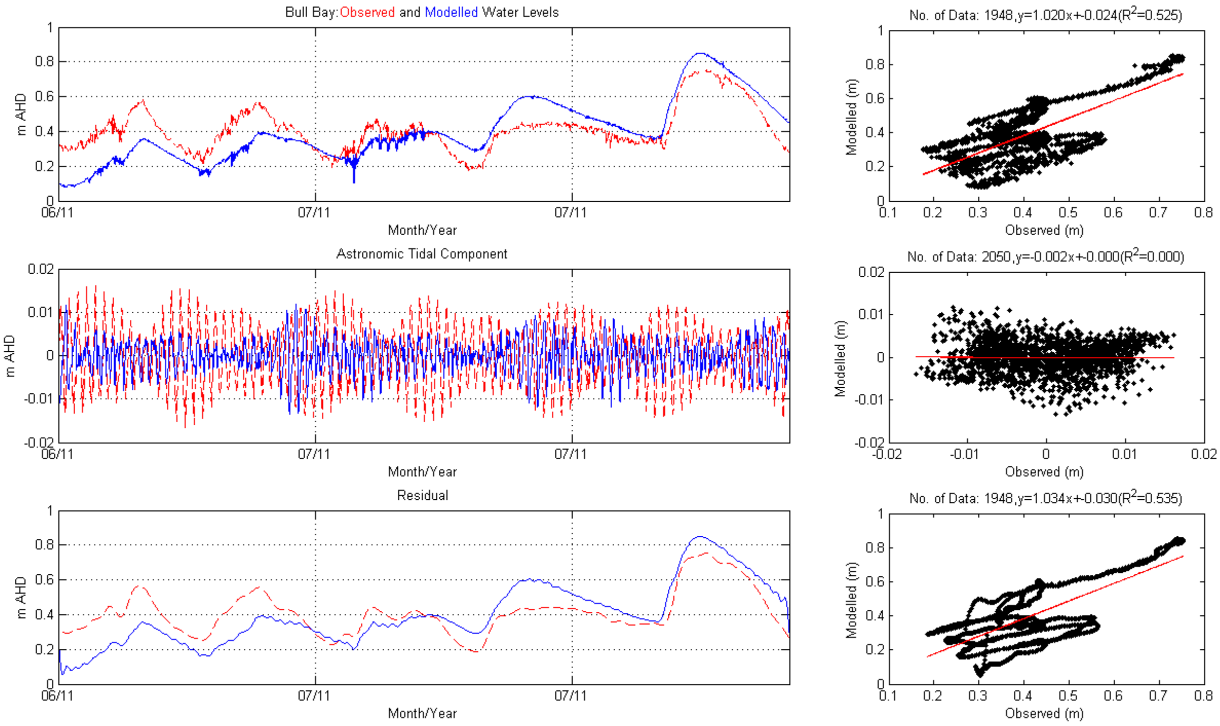


Figure 4-11 **Comparisons of Total, Tidal and Residual Water Level Data for the 2011 Ambient Conditions Simulation at Bull Bay**

Modelled and measured total, tidal and residual water levels at all sites, with the exception of Bull Bay, were shown to have a correlation coefficient (r^2) of 0.84 or greater, with Lakes Entrance Breakwater, Bullock Island and Paynesville having r^2 values higher than 0.9. The poor correlation at

Bull Bay, in Lake Wellington is considered largely a function of the poor quality of the streamflow boundary conditions

4.2.3 June 2007 Flood Event

The hydrodynamic model was calibrated to the June 2007 flood event, using routed catchment inflows and wind data, and tidal and coastal ocean level as shown in Figure 4-12.

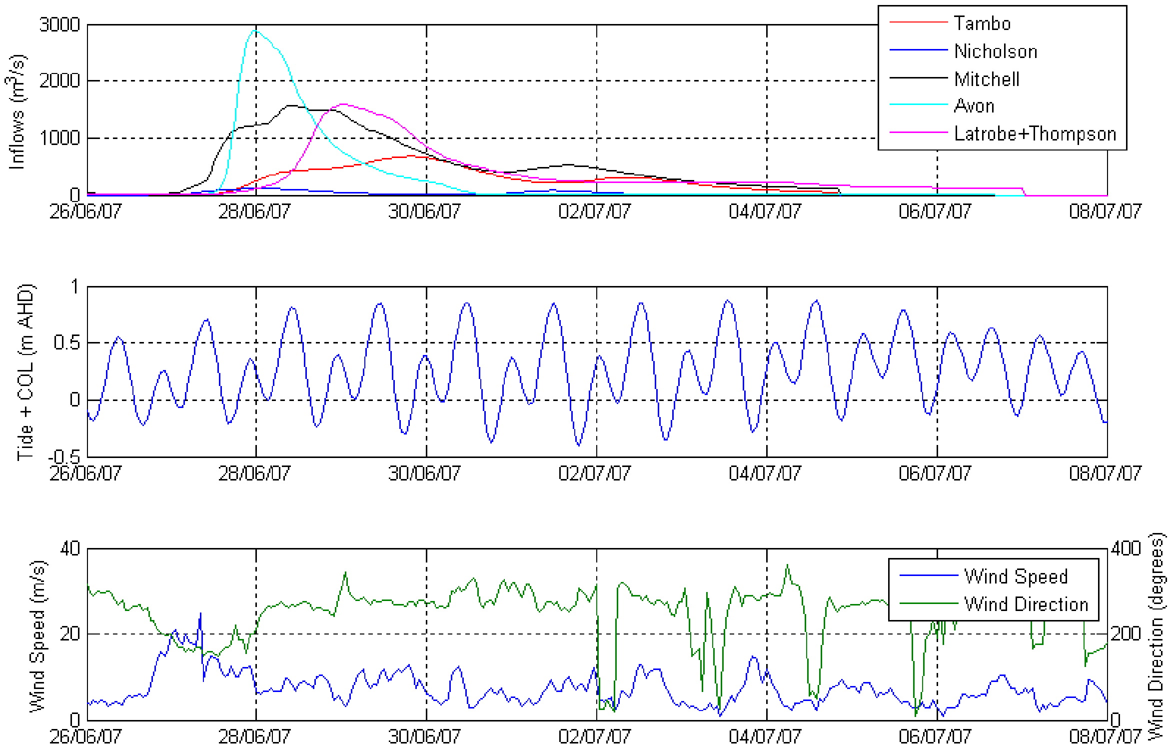


Figure 4-12 Data used to Force the Hydrodynamic Model for the 2007 Flood Event

Comparisons of modelled and measured water level data are displayed below in Figure 4-13 and Table 4-1. The model accurately predicted the timing and peak water levels at Bull Bay in Lake Wellington. Although, the peak water level was not achieved at Paynesville, the slow post flood recession in water levels was well represented. Peak water levels were successfully recreated at Lakes Entrance, although the low tide troughs were over predicted.

Water levels in Lake Wellington are strongly influenced by inflows from the Latrobe and Avon rivers, whereas levels at Paynesville are more dependent on inflows from the Mitchell and Tambo rivers. The variation in accuracy of reproduced levels between these two locations is attributed in part to uncertainties related to the inflow hydrographs for the Mitchell and Tambo rivers. The hydrograph in Figure 4-13 suggests there may have been some missing volume in the early part of the flood hydrograph coming into Lake King. This is plausible, given there is a considerable catchment area that is either downstream of the main river gauges or in entirely ungauged catchments.

The error in modelling of the tidal trough at Lakes Entrance is not clearly understood. The previous calibration case shows that ambient tides are well represented in the model. It is believed the most likely explanation for this result is a dynamic interaction between the tide and bed sediments within the entrance during floods. On the ebb (outgoing) tide, the water level gradient through the entrance will be at a maximum, as the ocean level lowers. This would result in a significant increase in velocity and bed shear through the entrance, causing scour that could reduce friction and lower levels close to the entrance. The investigation of this mechanism was not within the scope of the project, however this may be an important aspect for future flood studies of Lakes Entrance to address. Further, as the focus of this project is peak flood levels, this issue was not considered significant for the study outcomes. Given the project scope is related to extreme water levels, the model results for this event were considered appropriate for the project.

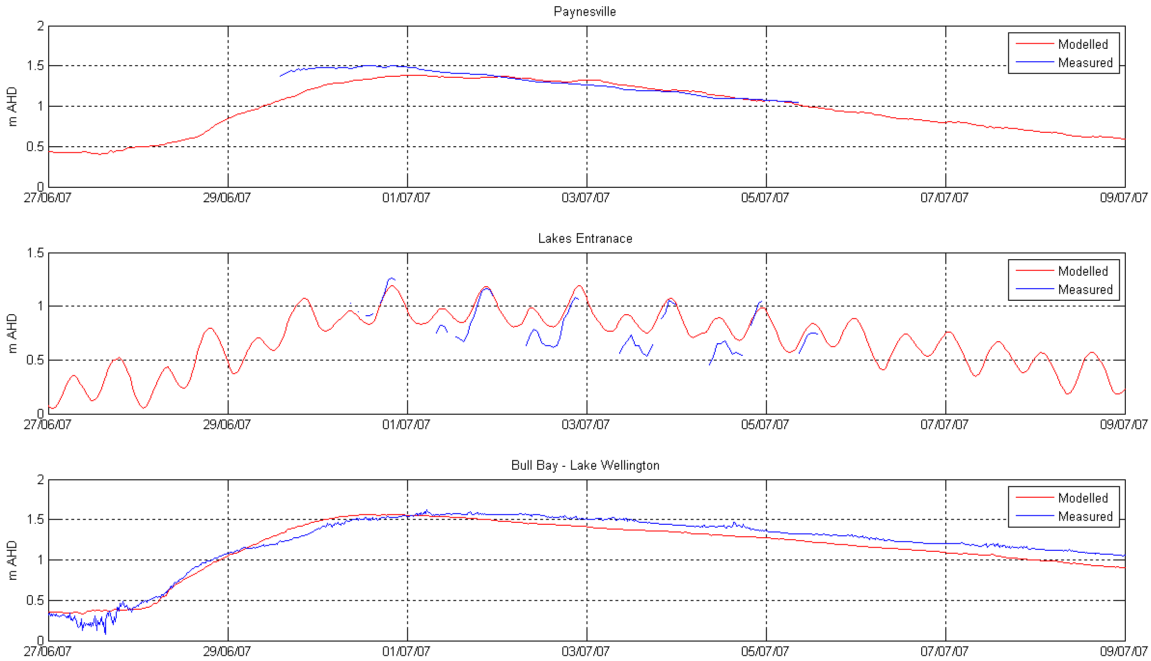


Figure 4-13 **Comparison of Modelled and Available Measured Water Levels at Three Sites During the June 2007 Flood Event**

Table 4-1 **Comparison of Modelled and Measured Peak Water Levels at the Three Available Calibration Sites for the June 2007 Flood Event**

Location	Measured Peak Water Level (m)	Modelled Peak Water Level (m)
Paynesville	1.50	1.39
Lakes Entrance	1.24	1.21
Bull Bay	1.62	1.56

4.2.4 August 2011 Inflow Event

The hydrodynamic model was also calibrated to the August 2011 inflow event. This event did not cause any notable flooding or inundation, but still represented a period of significant freshwater inflow, and resulting elevated lake water levels. During this event peak water levels rose to approximately 0.65 and 0.76 m at Paynesville and Bull Bay respectively. The boundary conditions used to force the hydrodynamic model for this simulation included routed catchment inflows, wind data, and tidal and coastal water levels, as displayed in Figure 4-14.

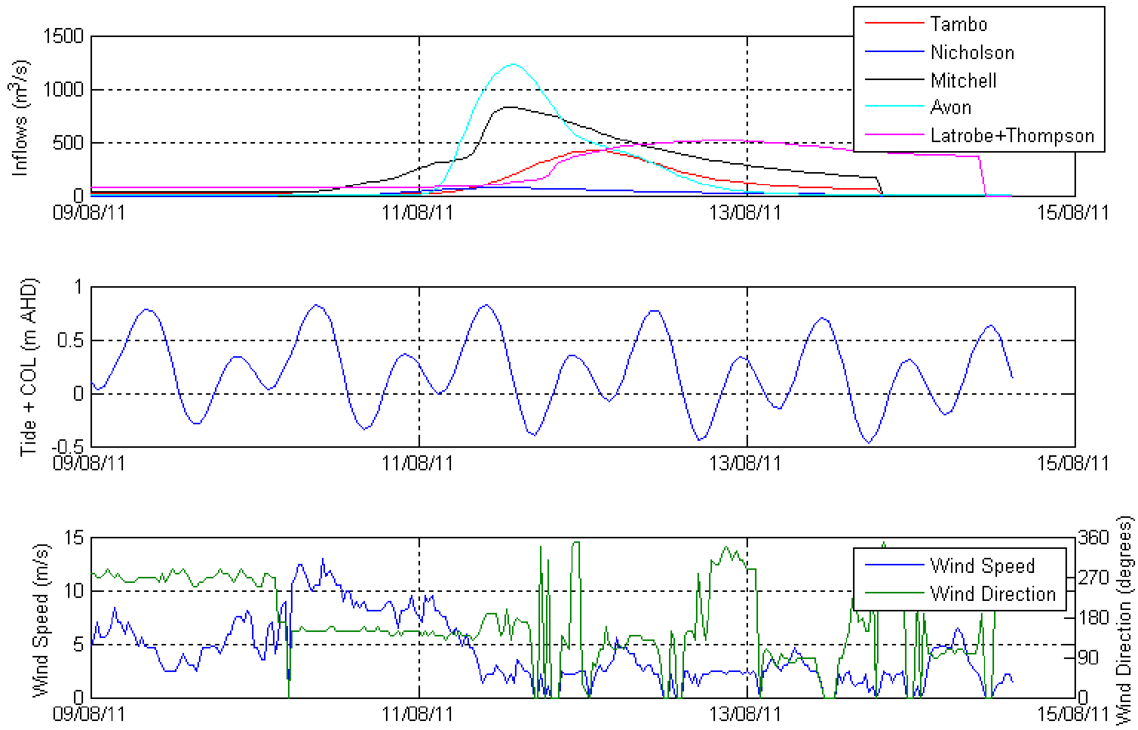


Figure 4-14 Data used to Force the Hydrodynamic Model for the August 2011 Inflow Event

Comparisons of measured and modelled water levels during the August 2011 inflow event are displayed below in Figure 4-15. Modelled water levels were shown to closely match peak levels at Paynesville and slightly over predict water levels by a root mean square error (RMSE) of 0.03 m and 0.08 m at Paynesville and Lakes Entrance respectively. These errors are considered to be within reasonable limits for the model calibration.

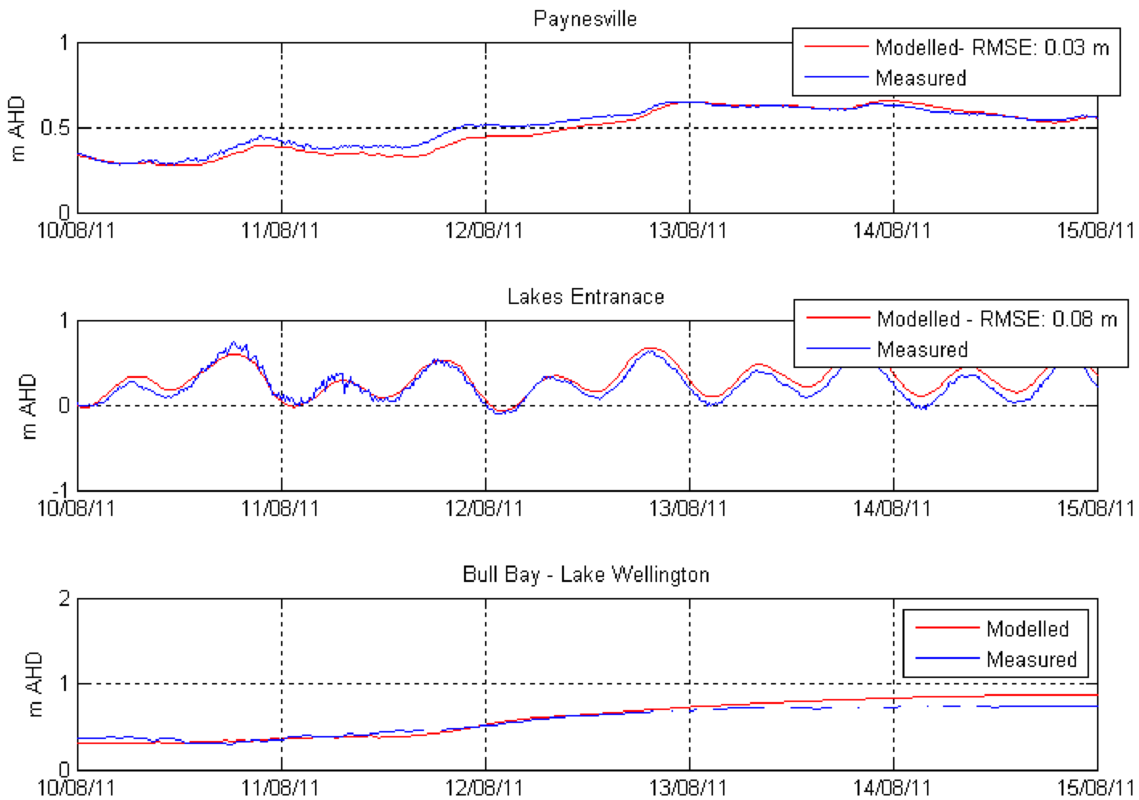


Figure 4-15 Comparison of Modelled and Measured Water Levels at three sites during the June 2011 Inflow Event

4.2.5 June 2012 Flood Event

The hydrodynamic model was also calibrated to the June 2012 flood, a significant but not severe flood event in the Gippsland Lakes. The tidal plus coastal ocean level, catchment inflows and wind forcing boundary conditions used to simulate this event are given below in Figure 4-16. The catchment inflows were set using predicted discharges provided by the BOM.

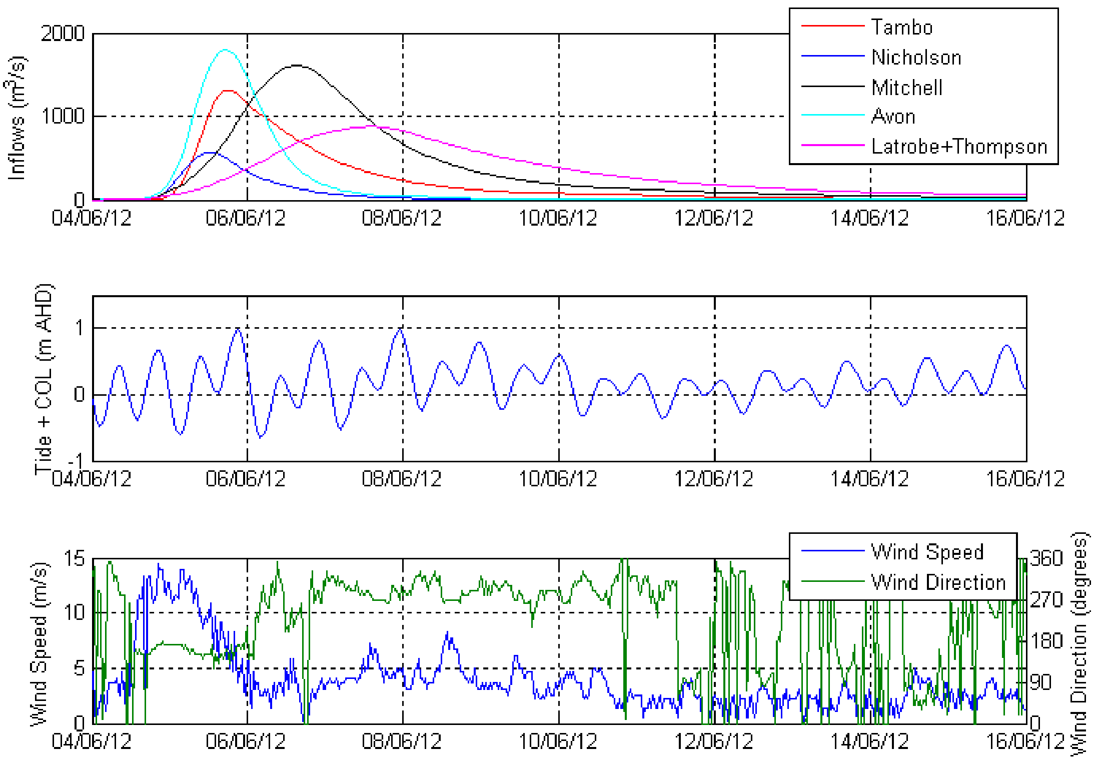


Figure 4-16 Catchment Inflow, Tidal + COL and Wind Forcing Boundary Conditions Used to Simulate the June 2012 Flood Event

Comparisons of measured and modelled water levels for the June 2012 flood event are presented below in Figure 4-17. The model was found to over predict water levels with increasing error from the western to eastern comparison sites. It is suspected the likely cause of these errors was an over-prediction of catchment inflows from the eastern catchments river boundaries. However, given the above, the accurate predictions of the other calibration events provides confidence in the models ability to successfully predict extreme water levels in the Gippsland Lakes, in response to catchment inflows, wind and coastal ocean level forcings.

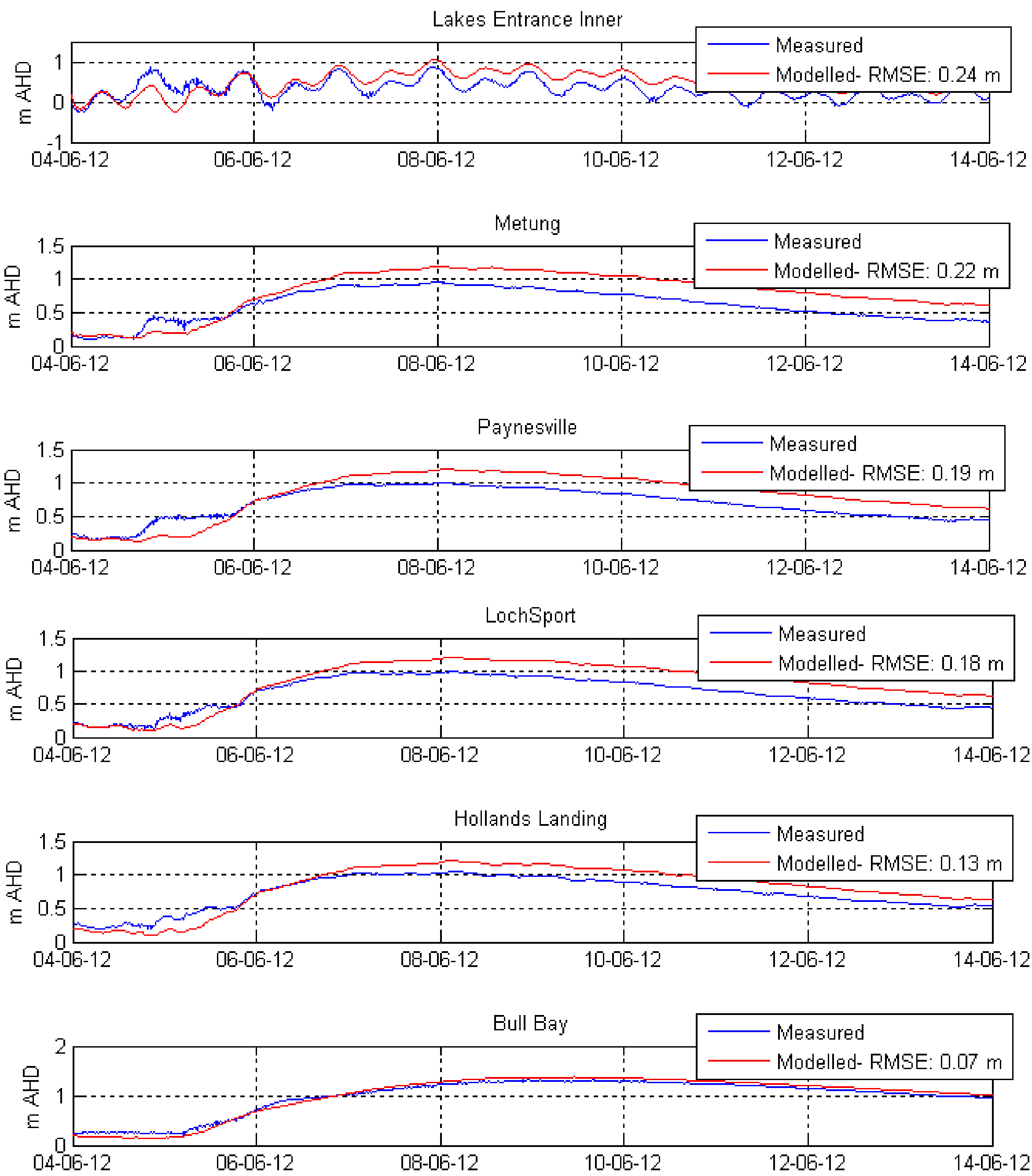


Figure 4-17 Comparisons of Modelled and Measured Water Levels for the June 2012 Flood Event Calibration

4.3 Discussion

The results from the four calibration scenarios are considered to demonstrate that the hydrodynamic model is suitable for the purpose of assessing the relative changes to the extent of inundation hazards due to large floods and sea level rise in the Gippsland Lakes.

5. INUNDATION HAZARD ANALYSIS

5.1 Background

The scope of the inundation hazard analysis for the Gippsland Lakes has focused principally on the assessment of the impact of sea level rise and climate change on major flood events. Section 5.2 documents the analysis and results of the flood scenario modelling of impact of sea level rise on extreme catchment generated floods in the Gippsland Lakes.

Changes to mean depths within the Gippsland Lakes due to sea level rise could also potentially impact the water level components associated with astronomical tide, storm surge and wind setup under prevailing conditions. To identify the sensitivity of these water level components to increases in mean sea level, additional hydrodynamic model scenarios have been undertaken to document the expected magnitude of any changes identified from the hydrodynamic modelling in Section 5.3.

5.2 Impact of Sea Level Rise on Extreme Water Levels

5.2.1 Gippsland Lakes Overall

The fundamental geometry of the Gippsland Lakes basin in terms of the relationship between the storage volume and elevation of the basin provides a first order control on the characteristics of extreme flood levels in the Gippsland Lakes. The slope (rate of change) of the storage-elevation relationship for the Gippsland Lakes basin will significantly influence the relative increase in flood levels that is observed from an equal flood volume input into the basin under different mean sea level scenarios.

The storage-elevation volume of the Gippsland Lakes basin was calculated for surface elevation increments of 0.2 m from 0.0 m to 3.0 m AHD from the digital elevation model (DEM). Figure 5-1 displays the relationship between storage volume and elevation determined from this analysis. The storage-elevation relationship of the Gippsland Lakes basin can be approximated closely by a 2nd order polynomial. The rate of change of the storage volume with elevation therefore increases linearly such that between the relevant elevations of interest of approximately 1.0 to 3.0 m AHD, the storage volume within the Gippsland Lakes basin increases by a factor of approximately 5.

Assuming that the rate at which flood flows can exit the Gippsland Lakes through the entrance remains approximately constant with sea level rise, each increment of mean sea level rise could be therefore expected to result in a relative flood level increase factor of approximately 0.6 of the increase in mean sea level between 1.0 to 3.0 m AHD.

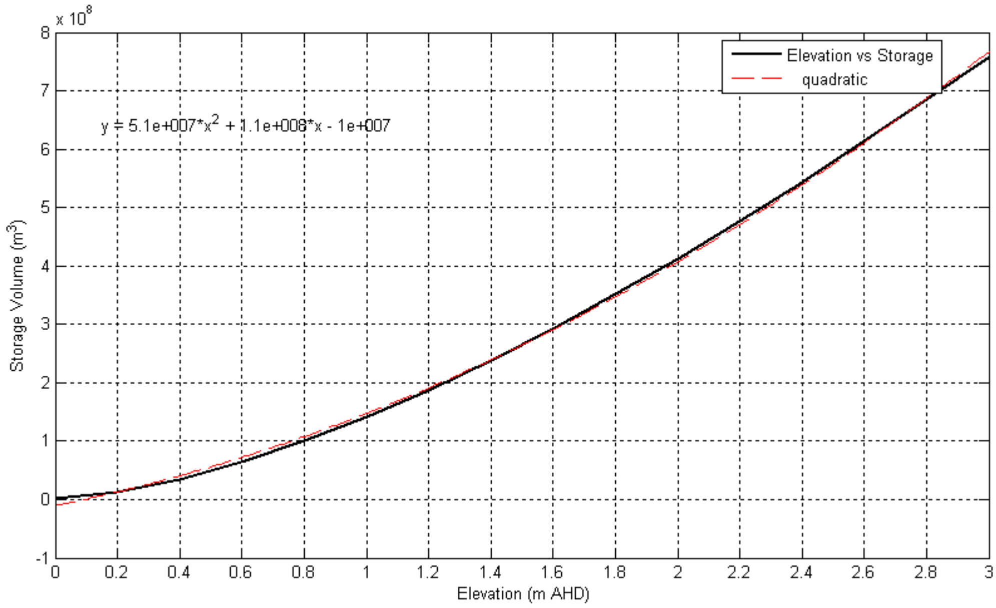


Figure 5-1 Relationship between Storage Volume and Elevation for the Gippsland Lakes Basin

In reality, the unequal distribution of storage within the Gippsland Lakes basin and influence of hydrodynamic processes would be expected to result in variations from this first order approximation. The hydrodynamic model has therefore been simulated under the representative 10% AEP flood scenario cases described in Section 3 under present mean sea level, and 0.2, 0.4 and 0.8 m sea level rise scenarios. The modelling scenarios have assumed the geometry of the Gippsland Lakes basin and location and configuration of the entrance remain static under these conditions. The potential impact of changes to entrance configurations and other geometric properties of the Gippsland Lakes Basin on extreme water levels are considered separately through sensitivity testing described in Section 6.

The maximum predicted inundation extents from the estimated 10% AEP flood case for each sea level rise scenario are displayed for the entire Gippsland Lakes in Figure 5-2, with the result for the 1% AEP flood incorporating 0.2 m SLR shown in Figure 5-3. These figures also show the relevant average SLR Response Factor (the relative increase in peak flood level relative to the increase in mean sea level) for different locations within the lakes. Figure 5-4 shows the change in peak flood depths for the same set of scenarios. This shows that the maximum changes to flood levels (due to SLR) are at Lakes Entrance and in the western end of Lake Reeve, towards Seaspray.

The following sections describe the modelling results in more detail for relevant representative locations within the Gippsland Lakes.

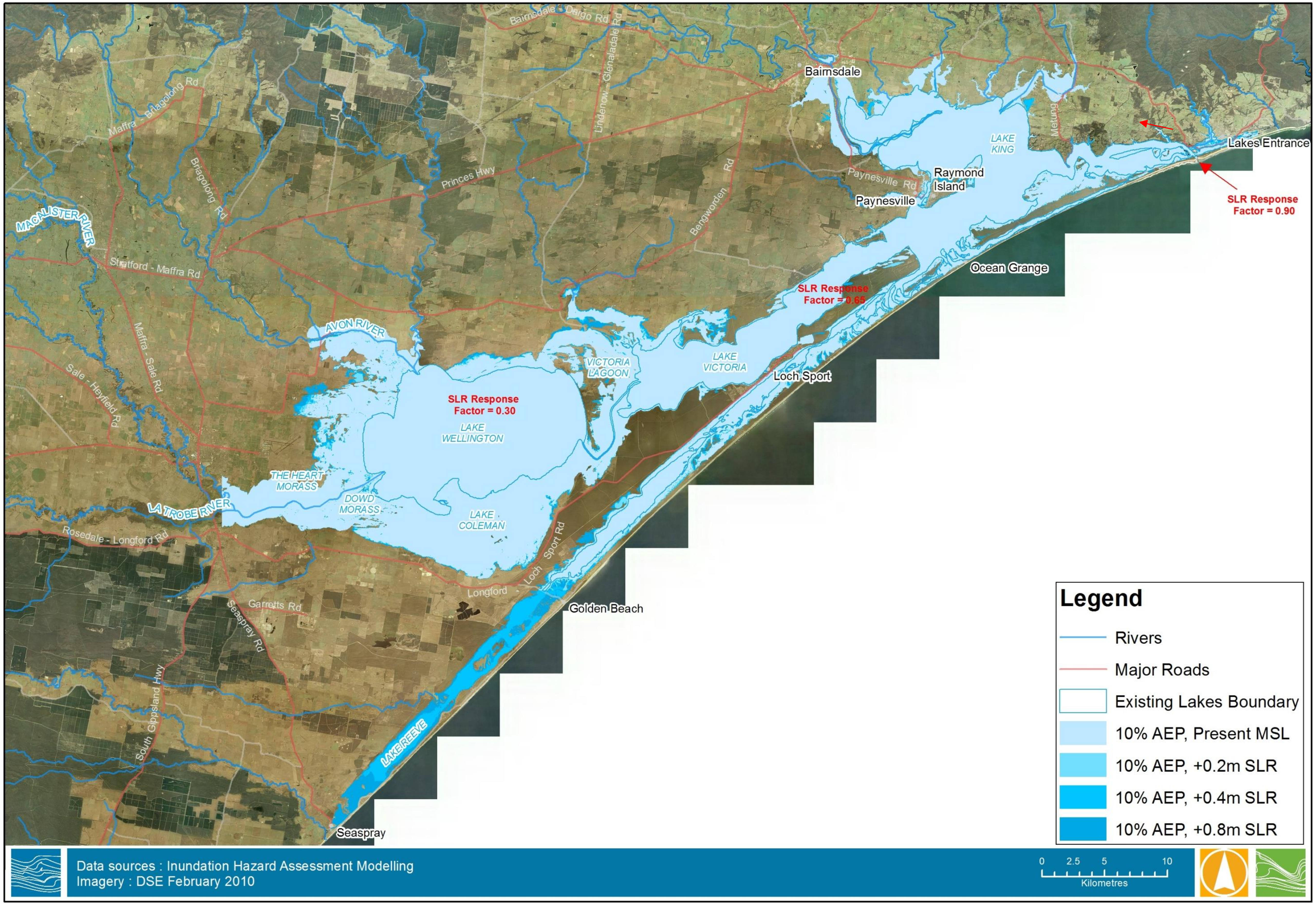


Figure 5-2 **Maximum Predicted Inundation Extent of the Representative 10% AEP Flood Case and Sea Level Rise Scenarios**

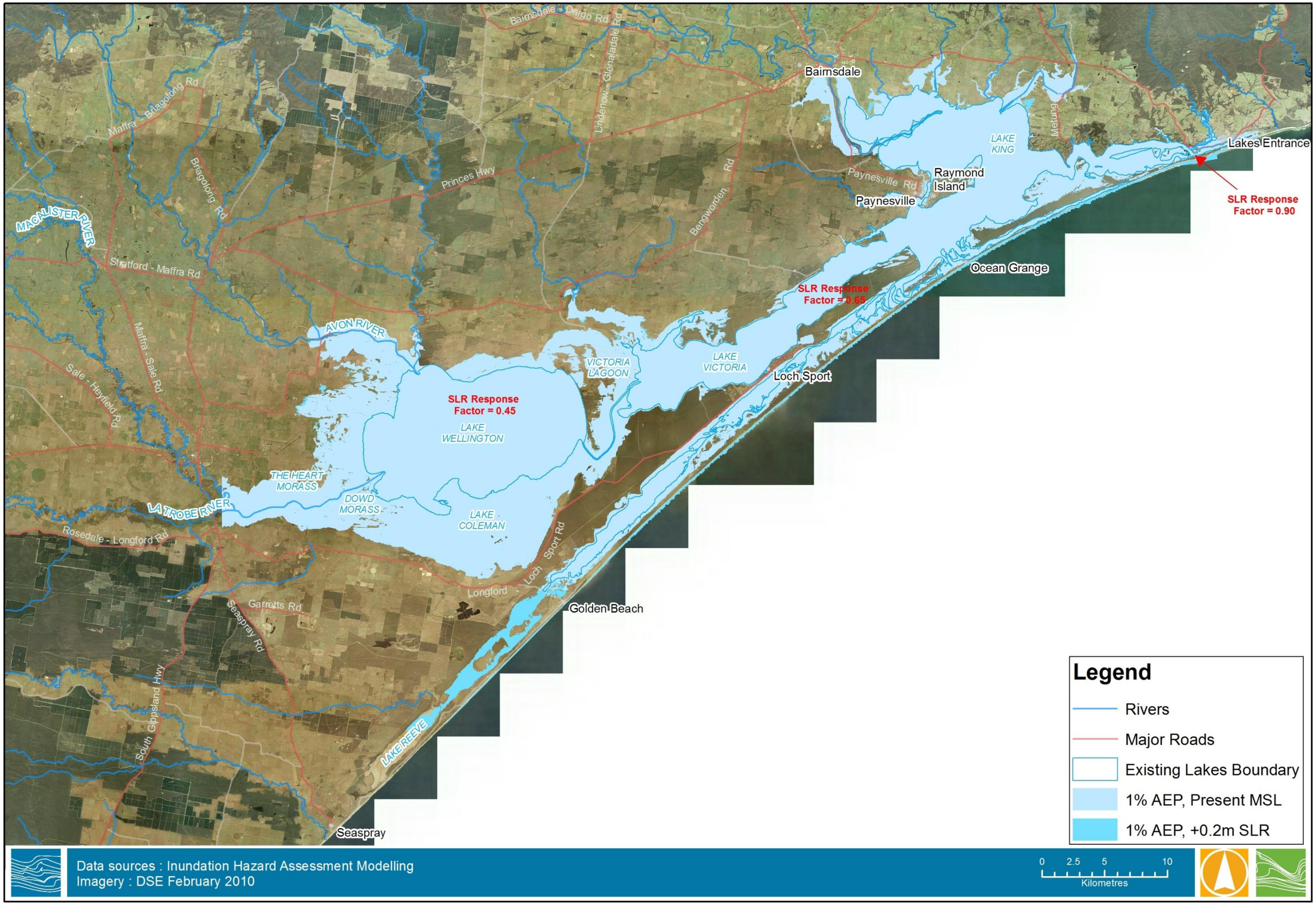


Figure 5-3 **Maximum Predicted Inundation Extent of the Representative 1% AEP Flood Case and Sea Level Rise Scenarios**

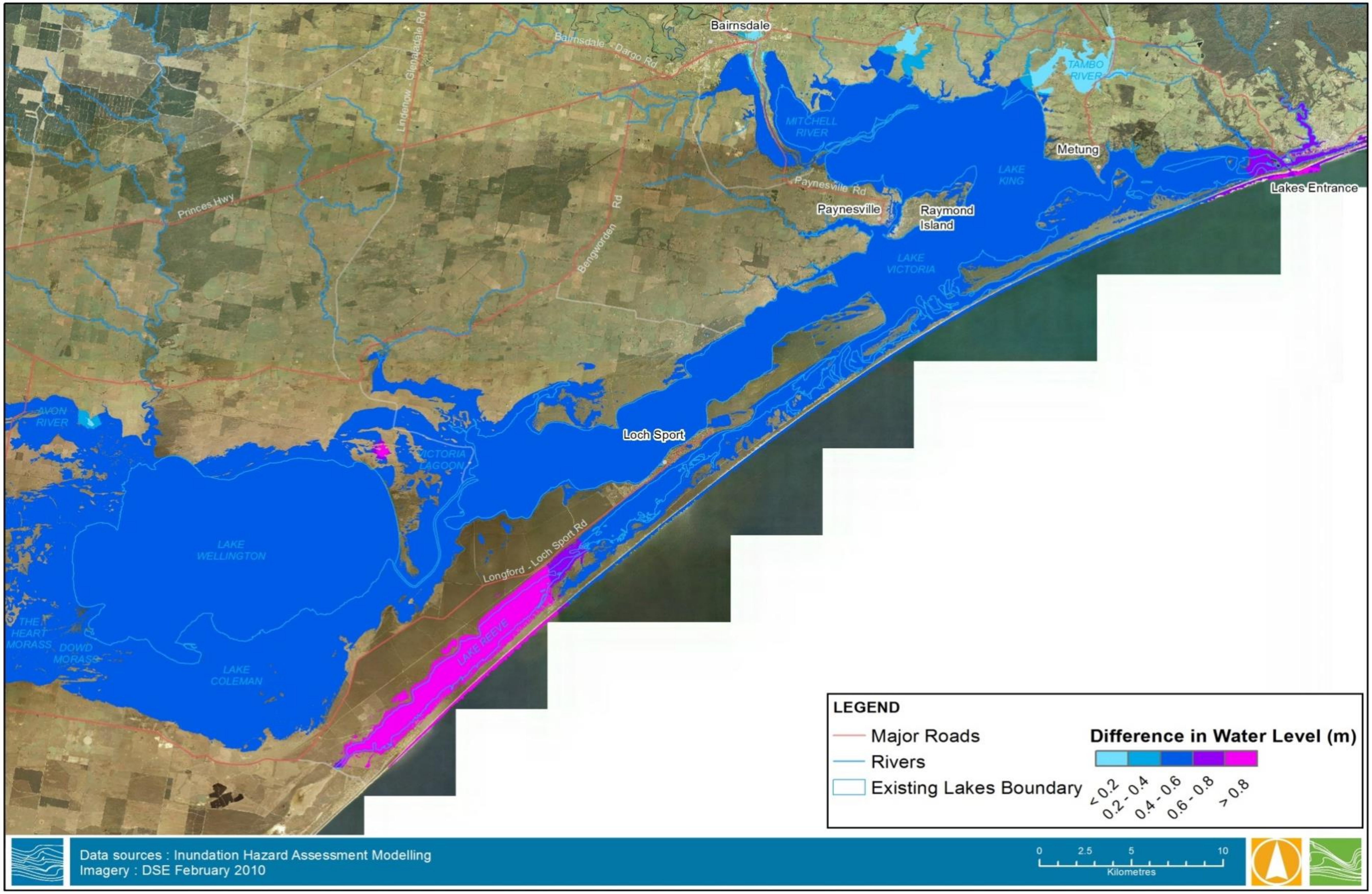


Figure 5-4 **10% AEP Inundation Hazard Assessment Broad Scale Overview, Flood Depth**

5.2.2 Lakes Entrance

Hydrodynamic modelling was undertaken for the estimated 10% AEP (10 year ARI) flood under present, 0.2, 0.4 and 0.8 m sea level rise conditions and 1% AEP (100 year ARI) flood under present and a 0.2 m sea-level rise condition.

Representative results at the location shown by the red dot in Figure 5-5 are provided in Table 5-1 below for each scenario. This shows the relative change in inundation impact between the open ocean and at Lakes Entrance.

It should be noted that the modelled 1% and 10% AEP levels at Paynesville do not exactly match the declared levels produced by the Gippsland Lakes Flood Level Modelling Project (Grayson R, 2004). This is due to the complex combination of boundary conditions that produce flood levels in the lakes and that a single combination does not match the peak levels for a given ARI at all locations throughout the lakes. The purpose of this analysis is to identify the change to inundation hazard attributable to sea level rise within the lakes. Hence the change in levels between the scenarios is of primary interest rather than the absolute level. This is the case for levels at each of the representative locations.

An important finding of the modelling analysis was that the relative increase in peak flood levels at Lakes Entrance for each scenario was approximately 0.9 times the magnitude (90%) of the associated sea level rise. This ratio has been termed the sea level rise response factor (SLR Response Factor). The results suggest that for greater sea level rise scenarios, the SLR Response factor increases slightly.

Table 5-1 Relative Change in Peak Flood Levels to Sea level Rise at Lakes Entrance

Sea Level Rise Scenario	0.0 m	+ 0.2 m	+ 0.4 m	+ 0.8 m
10% AEP Flood				
Peak Level (m AHD)	1.16[1]	1.34	1.53	1.91
Level Change (m)	0.0	0.17	0.37	0.75
SLR Response Factor	-	0.86	0.92	0.93
1% AEP Flood				
Peak Level (m AHD)	1.76[1]	1.93	Not modelled	Not modelled
Level Change (m)	0.0	0.17		
SLR Response Factor	-	0.86		

[1] Note that the modelled 1% and 10% AEP levels for existing conditions are approximate and do not match the declared flood levels at Lakes Entrance.

The sea level rise response factors were larger at Lakes Entrance than the other representative locations due to the presence of the artificial entrance close to Lakes Entrance and the confined nature of the lakes in the area. This resulted in water levels being more directly influenced by tidal and ocean levels in comparison to other representative locations, where flood storage has a greater impact on flood heights.

Figure 5-5 shows the change in inundation extents for the four sea level rise scenarios during a representative 10% AEP flood event at Lakes Entrance. The inundation extent was observed to progressively increase over the Lakes Entrance township under each sea level rise scenario. The 0.2 m SLR case in conjunction with a 1% AEP flood is shown in comparison to mean sea level conditions in Figure 5-6. This shows a relatively modest change in flood extents for this scenario although the depths would be expected to increase by approximately 0.18 m.

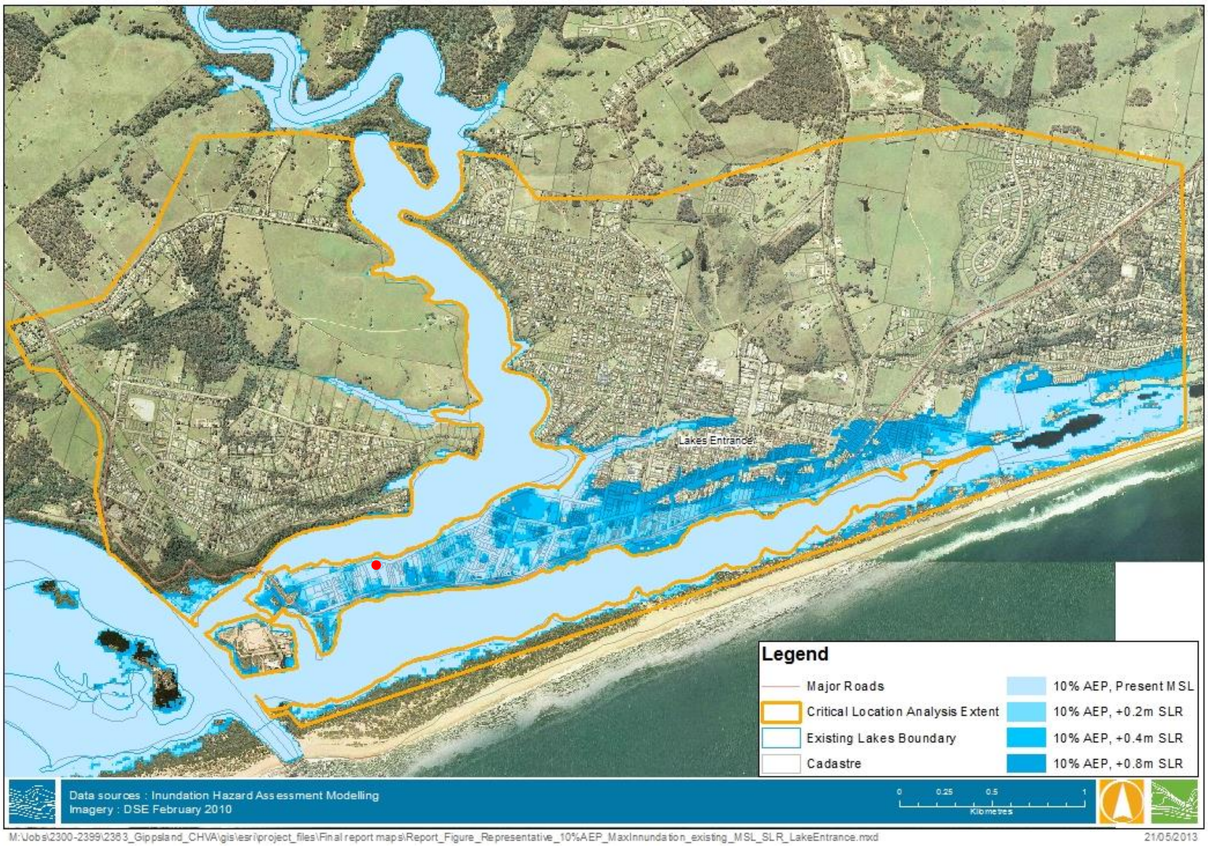


Figure 5-5 **Representative 10% AEP Flood Scenario Maximum Inundation Extent under Existing MSL and SLR Scenarios at Lakes Entrance. The red marker indicates the location of the depth and duration time series displayed in Figure 5-7.**

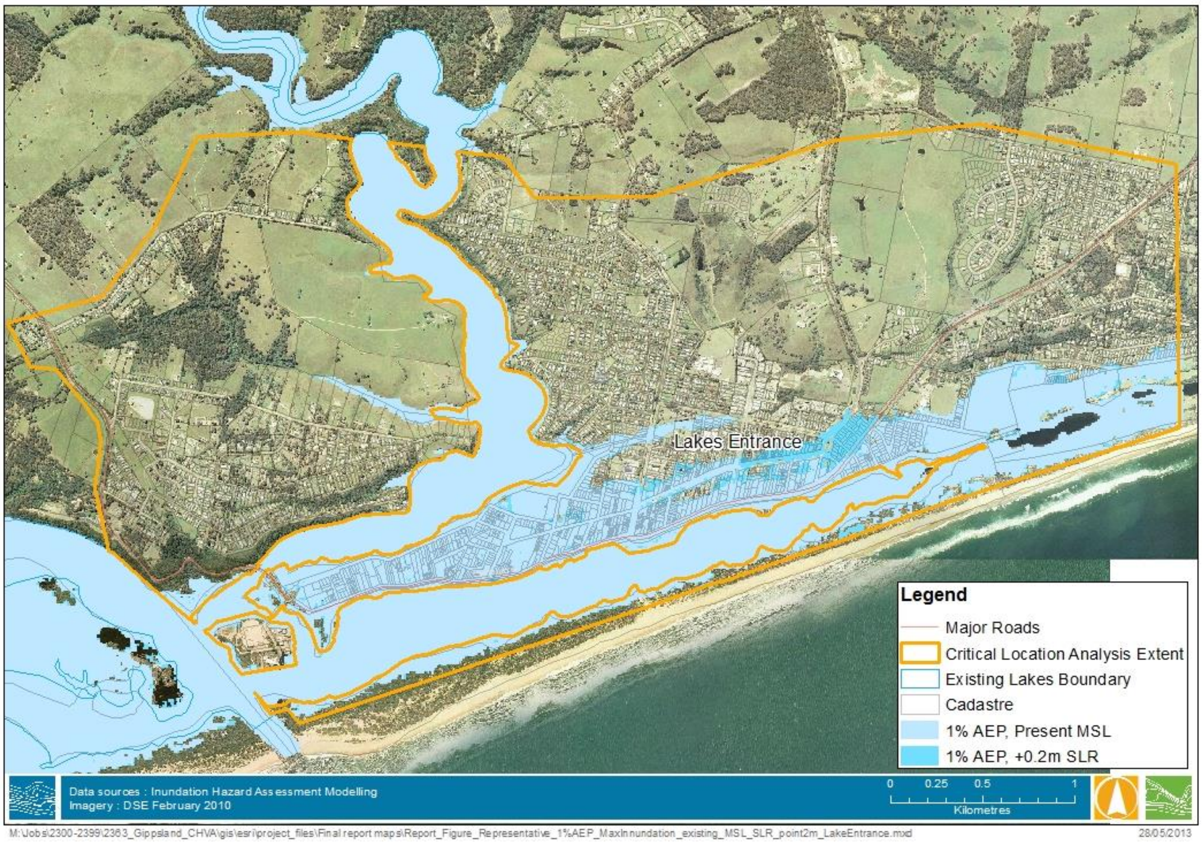


Figure 5-6 Representative 1% AEP Flood Scenario Maximum Inundation Extent under Existing MSL and 0.2 m SLR Scenario at Lakes Entrance

Table 5-2 provides four metrics that highlight the impacts associated with flood events for higher mean sea level scenarios at Lakes Entrance. The extent inside which these metrics were calculated for Lakes Entrance is indicated in Figure 5-5 by the solid orange line. It is noted from Table 5-2 that the inundated area within each metric approximately more than doubles under +0.8 m SLR compared to existing conditions.

Table 5-2 Inundation Metrics for the Representative 10% and 1% AEP Inundation Events Lakes Entrance under Various SLR Scenarios

Sea Level Rise Scenario	*10% AEP Flood*			
	Length of Road Inundated (km)	*Public Land Inundated (ha)*	*Number of Private Land Parcels Inundated (count)*	*Total Area of Township Inundated (ha)*
0.0 m	6	67	640	94
+ 0.2 m	10	82	830	127
+ 0.4 m	14	98	1,020	161
+ 0.8 m	20	114	1,420	211

Figure 5-7 displays a time series of inundation depths for a point extracted from the hydrodynamic model along Marine Parade, Lakes Entrance (Figure 5-5, red marker). Figure 5-7 demonstrates that inundation duration and depths increase significantly within Lakes Entrance for the 10% AEP flood case including the sea level rise scenarios. This highlights that frequency and timing/duration of inundation is just as important as the maximum level in terms of impact to the community.

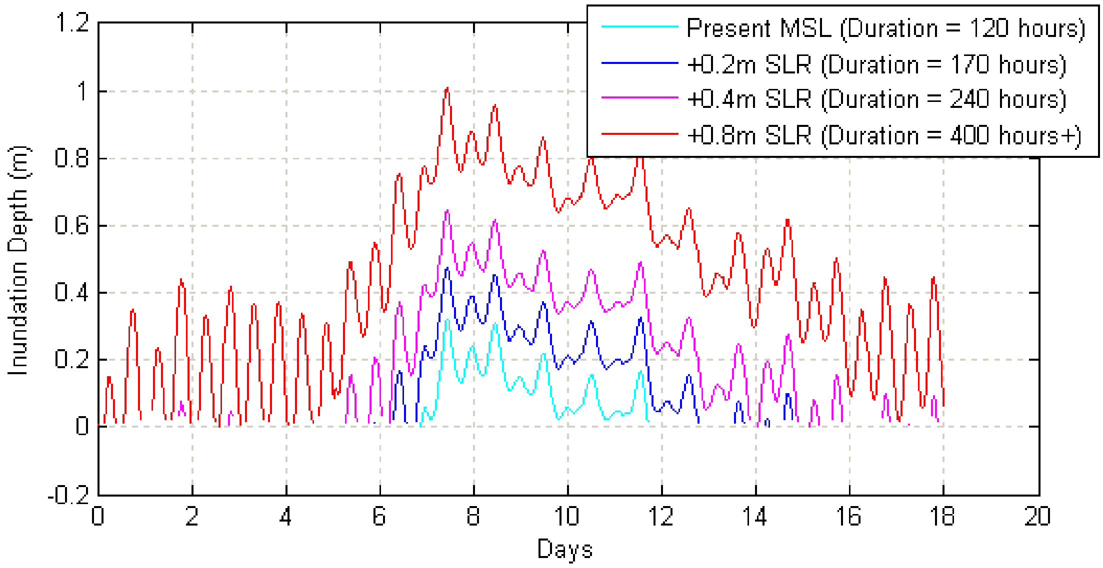


Figure 5-7 Inundation Depths and Times for the Representative 10% AEP Flood Case and Sea Level Rise Scenarios at Lakes Entrance

5.2.3 Paynesville

Hydrodynamic modelling was undertaken for the estimated 10% AEP (10 year ARI) flood under present, 0.2, 0.4 and 0.8 m sea level rise conditions and 1% AEP (100 year ARI) flood under present and a 0.2 m sea-level rise condition.

Representative results at the location shown by the red dot in Figure 5-8 are provided in Table 5-3 below which shows the change in peak water level and corresponding SLR response factor for each scenario at Paynesville.

A key result of this analysis was that the SLR factor at Paynesville for each scenario was found to be approximately 0.65 times the magnitude (65%) of the associated mean sea level rise.

Figure 5-8 displays the change in inundation extents for the sea level rise scenarios resulting from the representative 10% AEP flood case. The largest changes in inundation extent occurred over the south-western and northern shorelines of Raymond Island and the south-eastern corner of Paynesville, near the Esplanade. The 0.2 m SLR case in conjunction with a 1% AEP flood is shown in comparison to mean sea level conditions in Figure 5-9. This shows a relatively modest change in flood extents for this scenario with the depths expected to increase by approximately 0.13 m.

Table 5-3 Relative Change in Peak Flood Levels to Sea level Rise at Paynesville

Sea Level Rise Scenario	0.0 m	+ 0.2 m	+ 0.4 m	+ 0.8 m
10% AEP Flood				
Peak Level (m AHD)	1.59[1]	1.71	1.85	2.13
Level Change (m)	0.0	0.12	0.26	0.54
SLR Response Factor	-	0.58	0.65	0.67
1% AEP Flood				
Peak Level (m AHD))	1.70[1]	1.83	Not modelled	Not modelled
Level Change (m)	0.0	0.13		
SLR Response Factor	-	0.65		

[1] Note that the modelled 1% and 10% AEP levels for existing conditions are approximate and do not match the declared flood levels at Paynesville.

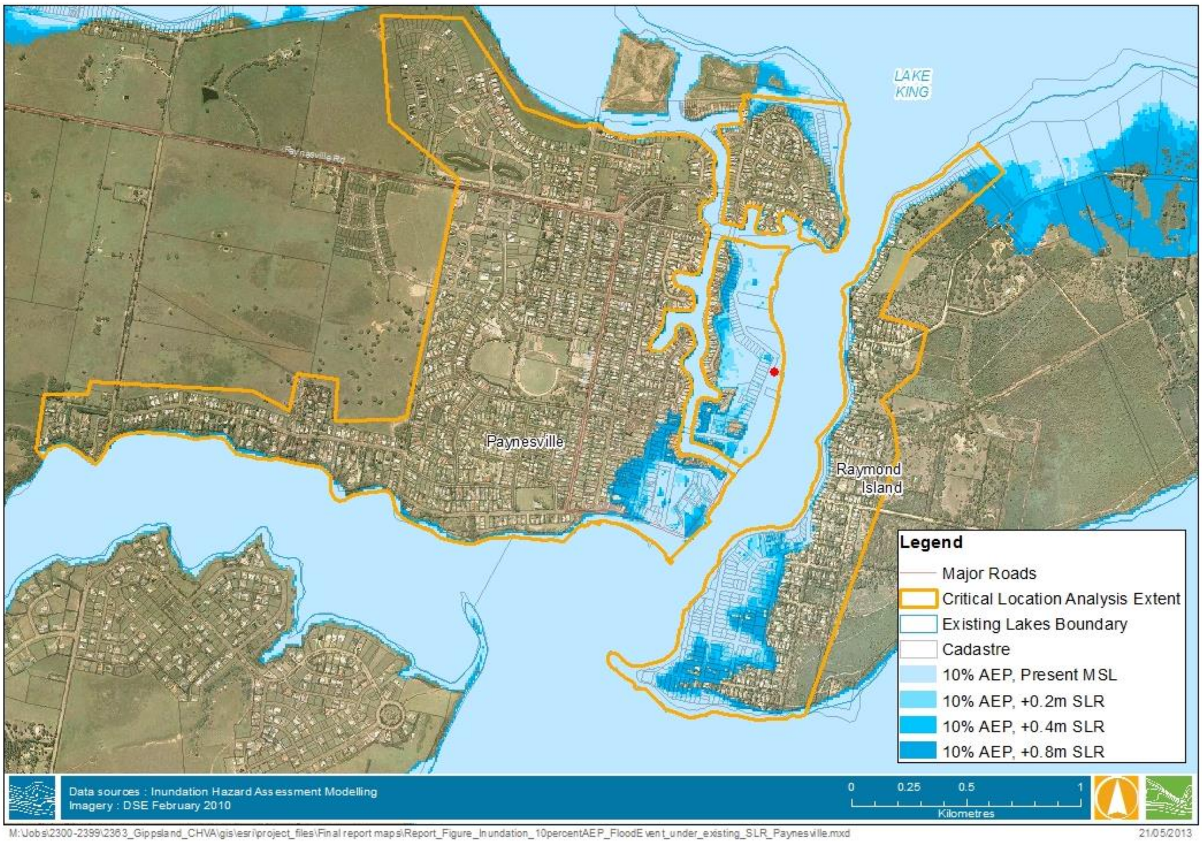


Figure 5-8 Representative 10% AEP Flood Scenario Maximum Inundation Extent under Existing MSL and SLR Scenarios at Paynesville. The red marker indicates the location of the depth and duration time series displayed in Figure 5-10.

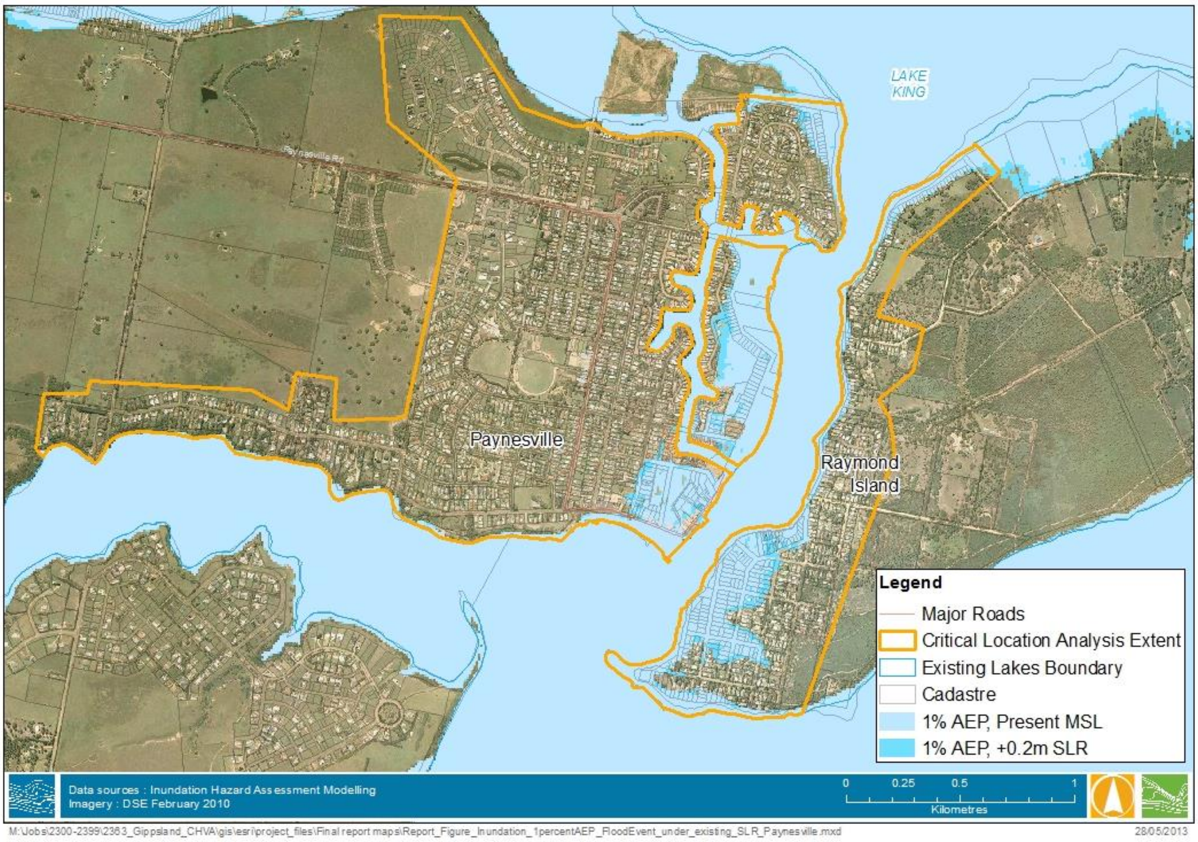


Figure 5-9 Representative 1% AEP Flood Scenario Maximum Inundation Extent under Existing MSL and 0.2 m SLR Scenario at Paynesville

Table 5-4 provides four metrics that highlight the increasing impacts associated with flood events for higher mean sea level rise scenarios at Paynesville / Raymond Island. The extent of the area inside which these metrics were calculated is illustrated in Figure 5-8 by the solid orange line.

Table 5-4 Inundation Metrics for the representative 10% and 1% AEP Inundation Events at Paynesville/Raymond Island under Various SLR Scenarios

Sea Level Rise Scenario	***10% AEP Flood***			
	Length of Road Inundated (km)	***Public Land Inundated (ha)***	***Number of Private Land Parcels Inundated (count)***	***Total Area of Township Inundated (ha)***
0.0 m	6	32	750	59
+ 0.2 m	7	34	780	69
+ 0.4 m	8	35	890	78
+ 0.8 m	11	36	1070	98

Figure 5-10 displays a time series plot of inundation depths for a point extracted from the hydrodynamic model at Slip Road, Paynesville (Figure 5-8, red marker). Figure 5-10 highlights the extent to which duration and depth of inundation may increase during major floods due to sea level rise.

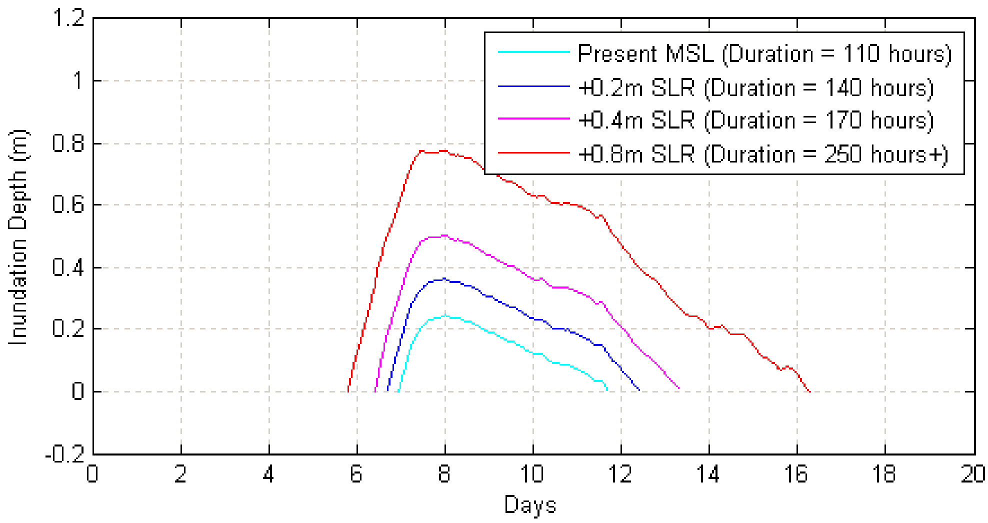


Figure 5-10 Inundation Depths and Times for the Representative 10% AEP Flood Event and Sea Level Rise Scenarios at Paynesville

5.2.4 Loch Sport

Hydrodynamic modelling was undertaken for the estimated 10% AEP (10 year ARI) flood under present, 0.2, 0.4 and 0.8 m sea level rise conditions and 1% AEP (100 year ARI) flood under present and a 0.2 m sea-level rise condition.

Table 5-5 below shows the change in peak flood level and SLR response factor for each of the three sea level rise scenarios. A key result of this analysis was that the relative increase in peak flood levels at Loch Sport for each scenario was approximately 0.65 times the magnitude (65%) of the associated sea level rise.

Table 5-5 Relative Change in Peak Flood Levels to Sea level Rise at Loch Sport

Sea Level Rise Scenario	0.0 m	+ 0.2 m	+ 0.4 m	+ 0.8 m
10% AEP Flood				
Peak Level (m AHD)	1.59[1]	1.71	1.85	2.12
Level Change (m)	0.0	0.12	0.26	0.54
SLR Response Factor	-	0.58	0.64	0.67
1% AEP Flood				
Peak Level (m AHD)	1.71[1]	1.84	Not modelled	Not modelled
Level Change (m)	0.0	0.13		
SLR Response Factor	-	0.65		

[1] Note that the modelled 1% and 10% AEP levels for existing conditions are approximate and do not match the declared flood levels at Loch Sport.

Figure 5-11 shows the change in inundation extents for the sea level rise scenarios during a 10% AEP flood event at Loch Sport. Minimal change in inundation extent was observed between all four sea level rise scenarios. The 0.2 m SLR case in conjunction with a 1% AEP flood is shown in comparison to mean sea level conditions in Figure 5-12. This shows a negligible change in flood extents for this scenario with the depths expected to increase by around 0.13 m.

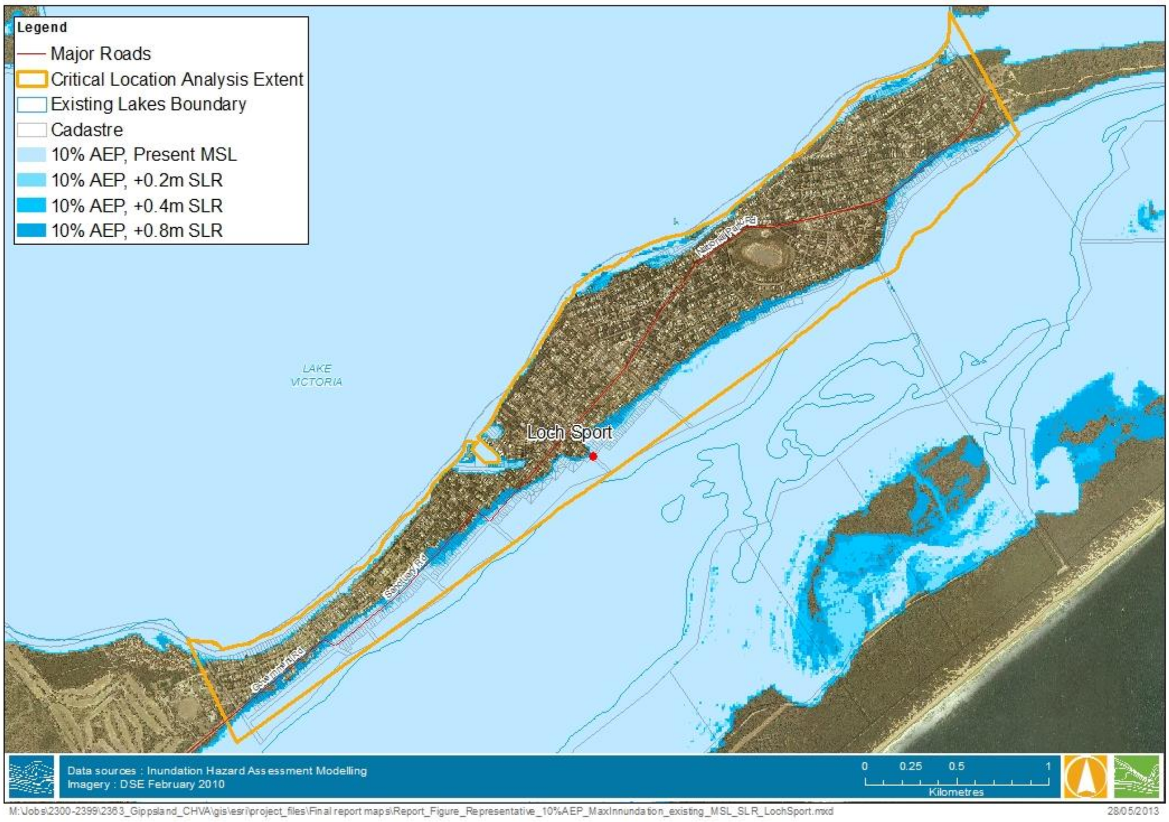


Figure 5-11 Representative 10% AEP Flood Scenario Maximum Inundation Extent under Existing MSL and SLR Scenarios at Loch Sport. The red marker indicates the location of the depth and duration time series displayed in Figure 5-13.

Figure 5-12 Representative 1% AEP Flood Scenario Maximum Inundation Extent under Existing MSL and 0.2 m SLR Scenario at Loch Sport

Table 5-6 provides four metrics which highlight the increasing impacts associated with flood events during higher mean sea levels at Loch Sport. The extent of the area inside which these metrics were calculated is indicated in Figure 5-11 by the solid orange line. As a result of the small change in inundation extent (relative to the other representative locations), there was also a relatively small increase in each of the four metrics between sea level rise scenarios.

Table 5-6 Inundation Metrics for the Representative 10% and 1% AEP Inundation Events at Loch Sport under Various SLR Scenarios

Sea Level Rise Scenario	*10% AEP Flood*			
	Length of Road Inundated (km)	*Public Land Inundated (ha)*	*Number of Private Land Parcels Inundated (count)*	*Total Area of Township Inundated (ha)*
0.0m	5	44	540	116
+ 0.2 m	6	45	590	123
+ 0.4 m	6	46	650	130
+ 0.8 m	8	47	790	143

Figure 5-13 displays a time series plot of inundation depths for a point extracted from the hydrodynamic model near Davies Street, Loch Sport (Figure 5-11, red marker). These results highlight that while inundation extents are not impacted significantly due to sea level rise, the duration and depth of inundation is predicted to significantly increase.

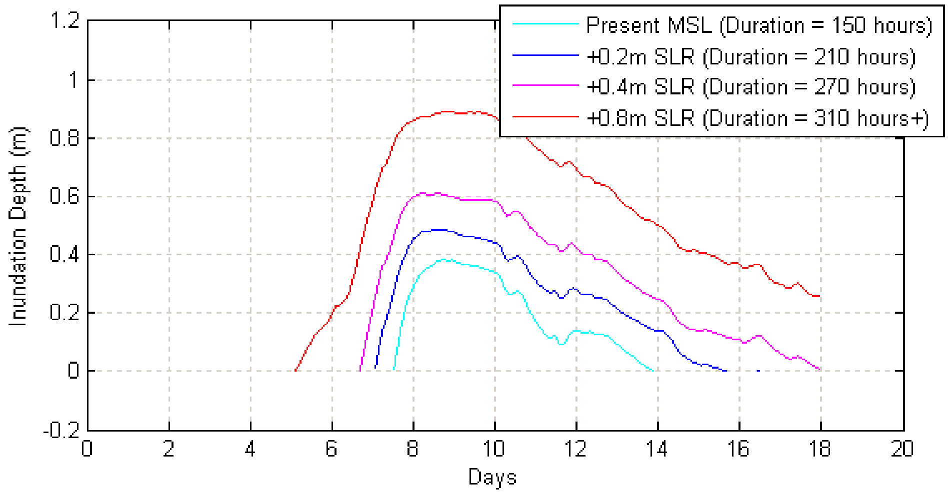


Figure 5-13 **Inundation Depths and Times for the representative 10% AEP Flood Event and Sea Level Rise Scenarios at Loch Sport**

5.2.5 Bunga Arm

Hydrodynamic modelling was undertaken for the estimated 10% AEP (10 year ARI) flood under present, 0.2, 0.4 and 0.8 m sea level rise conditions and 1% AEP (100 year ARI) flood under present and a 0.2 m sea-level rise condition.

Table 5-7 below shows the change and SLR factor in peak water levels relative to the increase in mean sea level for each of the three sea level rise scenarios. Similar to Paynesville and Loch Sport, the relative increase in peak flood levels at Bunga Arm for each scenario was approximately 0.65 times the magnitude (65%) of the associated sea level rise.

Table 5-7 **Peak Water Levels Relative to Sea level Rise Bunga Arm**

Sea Level Rise Scenario	0.0 m	+ 0.2 m	+ 0.4 m	+ 0.8 m
		10% AEP Flood		
Peak Level (m AHD)	1.60[1]	1.72	1.86	2.13
Level Change (m)	0.0	0.12	0.26	0.53
SLR Response Factor	-	0.58	0.64	0.66
		1% AEP Flood		
Peak Level (m AHD)	1.73[1]	1.86	Not modelled	Not modelled
Level Change (m)	0.0	0.13		
SLR Response Factor	-	0.65		

[1] Note that the modelled 1% and 10% AEP levels for existing conditions are approximate and do not match the declared flood levels at Bunga Arm.

Figure 5-14 shows the change in inundation extents for the four sea level rise scenarios during the representative 10% AEP flood event at Bunga Arm. There was minimal change in inundation extent along the length of Bunga Arm due to the relatively steeply sloped shorelines at this location. The 0.2 m SLR case in conjunction with a 1% AEP flood is shown in comparison to mean sea level conditions in Figure 5-12. This shows minimal change in flood extents for this scenario with the depths expected to increase by around 0.13 m.

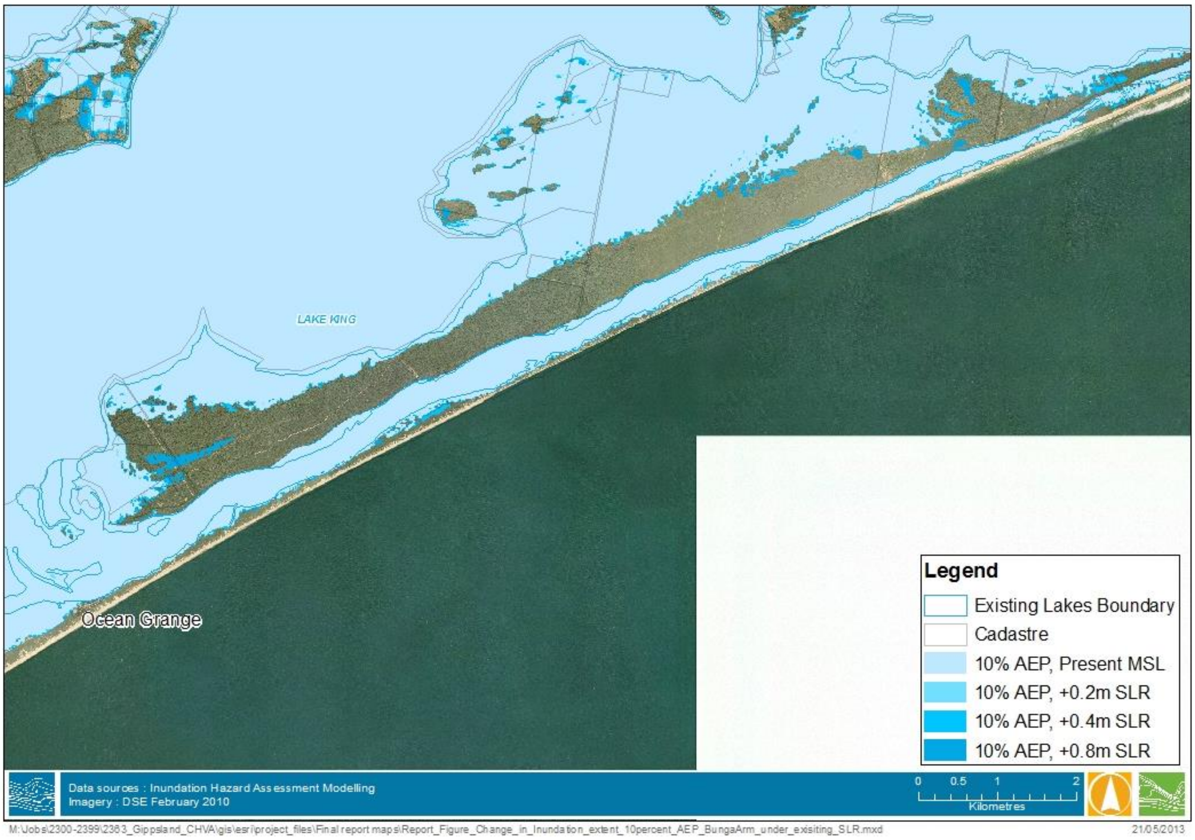


Figure 5-14 Representative 10% AEP Flood Scenario Maximum Inundation Extent under Present MSL and SLR Scenarios at Bunga Arm

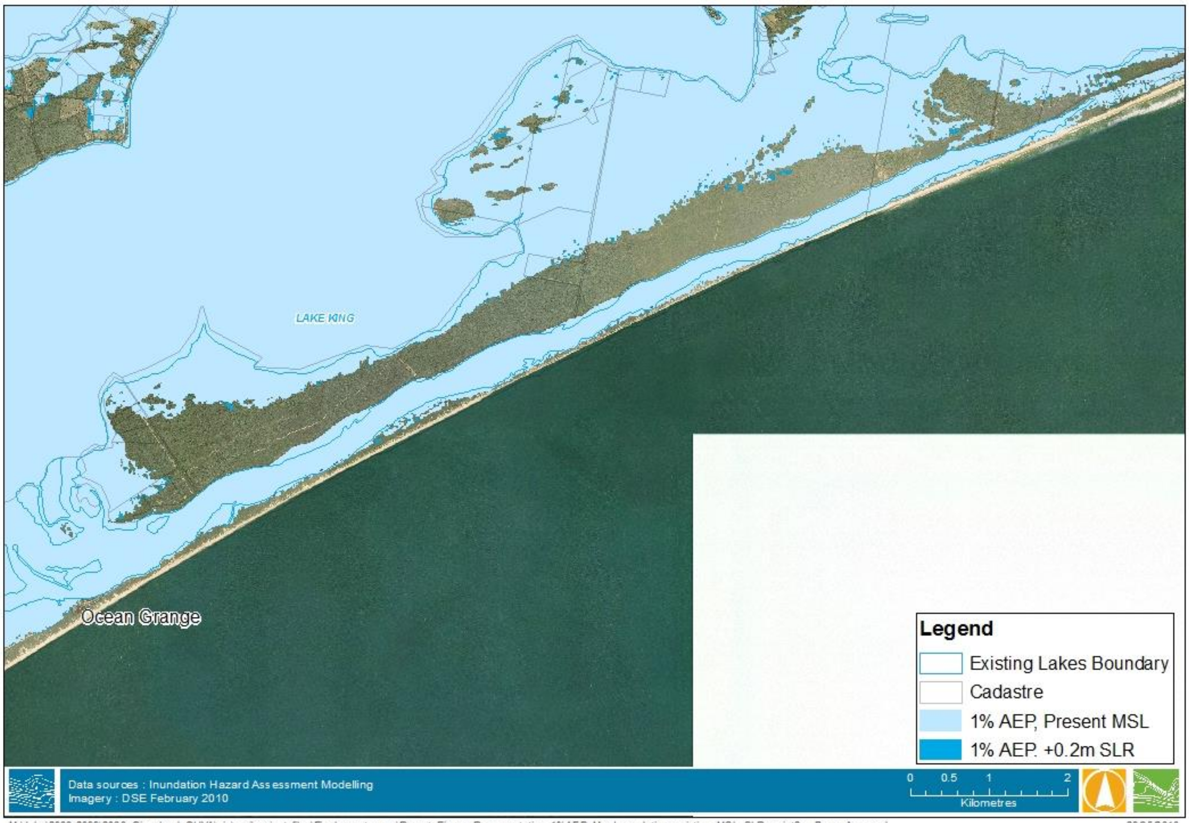


Figure 5-15 Representative 1% AEP Flood Scenario Maximum Inundation Extent under Present MSL and 0.2 m SLR Scenario at Bunga Arm

5.2.6 Seaspray

Hydrodynamic modelling was undertaken for the estimated 10% AEP (10 year ARI) flood under present, 0.2, 0.4 and 0.8 m sea level rise conditions and 1% AEP (100 year ARI) flood under present and a 0.2 m sea-level rise condition.

A key result of this analysis was that the floodplains around Seaspray only became inundated during the 10% AEP flood event under the +0.8 m sea level rise scenario. However, the flood levels did not reach a height sufficient to overtop the levees surrounding Seaspray

It should be noted that the simulations presented here only considered potential inundation from the Gippsland Lakes and not from Merriman Creek or the open coast, as coincident flooding of the Gippsland Lakes and Merriman Creek is considered unlikely. This is primarily because of the significant difference in size between the two catchments. The Merriman Creek catchment is much smaller (around 500 km^2 in area) than the Gippsland Lakes catchment (around 20,000 km^2 in area), hence it would be expected to respond to rainfall much faster than the Lakes catchment and hence the Lakes itself. Subsequently a major flood in Merriman Creek is likely to have receded well before a flood peak occurs in the Gippsland Lakes.

The impacts of flooding in Merriman Creek at Seaspray has previously been assessed by (Cardno Lawson Treloar, 2010), and therefore was not considered in this study.

Coastally driven inundation due to overwash of the outer barrier is separately assessed in Section 6.1.1 this report.

Figure 5-16 **Representative 10% AEP Flood Scenario Maximum Inundation Extent under Present MSL and SLR Scenarios at Seaspray.**

5.3 Impact of Sea Level Rise on Hydrodynamics

Sensitivity of the potential impact of sea level rise on the tidal, storm surge and wind setup hydrodynamics of the Gippsland Lakes has been assessed. The hydrodynamic model was simulated over a three month period of typical ambient forcing conditions incorporating 0.4 and 0.8 m sea level rise scenarios. The same ambient forcing conditions of June – August 2011, used as part of the hydrodynamic model calibration (Section 4.2), were utilised for the analysis. This three month period contains a relatively dynamic sequence of storm surges, moderate streamflow inputs and wind conditions from which to test the sensitivity of sea level rise on the different water level components within the Gippsland Lakes.

5.3.1 Sensitivity of Tide

Changes to the astronomical tide were assessed by tidal decomposition of the modelled water levels for the present sea level condition and the sea level rise scenarios. The differences in the main tidal constituent amplitudes and phases were compared. Table 5-8 provides a summary of the changes in amplitude and phase of the 4 main tidal constituents under 0.4 and 0.8 m of sea level rise scenarios compared to present sea levels at Paynesville and Lakes Entrance.

Compared to the increases in mean sea level (+ 0.4 and 0.8 m) the predicted increases in amplitude of the 4 main constituents were , in the order of 0.001 – 0.003 m at Paynesville, and -0.005 – -0.024 m at Lakes Entrance, with the greatest changes to the main semi-diurnal (twice daily), M_2 (lunar) constituent. These increases are generally around 5 to 15% and considered moderate. Moderate changes in phase of between -3° and -11° at Paynesville were also predicted.

Table 5-8 Impact of Sea level Rise on Astronomical Tide at Paynesville & Lakes Entrance

Tidal Constituent	Paynesville			Lakes Entrance		
	Amplitude (m)					
	Present MSL	+ 0.4 m SLR	+ 0.8 m SLR	Present MSL	+ 0.4 m SLR	+ 0.8 m SLR
O1	0.011	0.012 *(+0.001)*	0.013 *(+0.002)*	0.061	0.0515 *(-0.0095)*	0.052 *(-0.009)*
K1	0.016	0.017 *(+0.001)*	0.018 *(+0.002)*	0.105	0.095 *(-0.01)*	0.089 *(-0.016)*
M2	0.013	0.015 *(+0.002)*	0.016 *(+0.003)*	0.167	0.152 *(0.015)*	0.143 *(-0.024)*
S2	0.003	0.004 *(+0.001)*	0.004 *(+0.001)*	0.052	0.047 *(-0.005)*	0.044 *(-0.008)*

5.3.2 Sensitivity of Storm Surge and Wind Set-up

The sensitivity of sea level rise and subsequent changes to mean depths within the Gippsland Lakes on the dynamics of storm surge propagation and wind setup has been assessed. This was done through comparisons of the water level residuals following tidal decomposition of the three-month period at Paynesville and Lakes Entrance. Figure 5-17 and Figure 5-18 display comparisons of the normalised total, tidal and residual water levels for Paynesville and Lakes Entrance respectively, for existing sea level and the 0.8 m sea level rise scenario.

The results in Figure 5-17 and Figure 5-18 show that only small changes (<0.05 m) in residual water levels associated with storm surges and wind setup are expected due to sea level rise increments of up to 0.8 m in the Gippsland Lakes.

Figure 5-17 shows a more significant relative reduction in residual water levels of approximately 0.1 m is predicted at Paynesville between the 10/08 and 20/08. Water levels in the Gippsland Lakes during this period were influenced by a minor streamflow flood event, and as detailed in Section 5.2.

The results of the sensitivity analysis of tidal, storm surge and wind setup water level components to increases in mean sea level demonstrate that only minor changes could be expected to the relative magnitudes of these water level components due to sea level rise within the Gippsland Lakes.

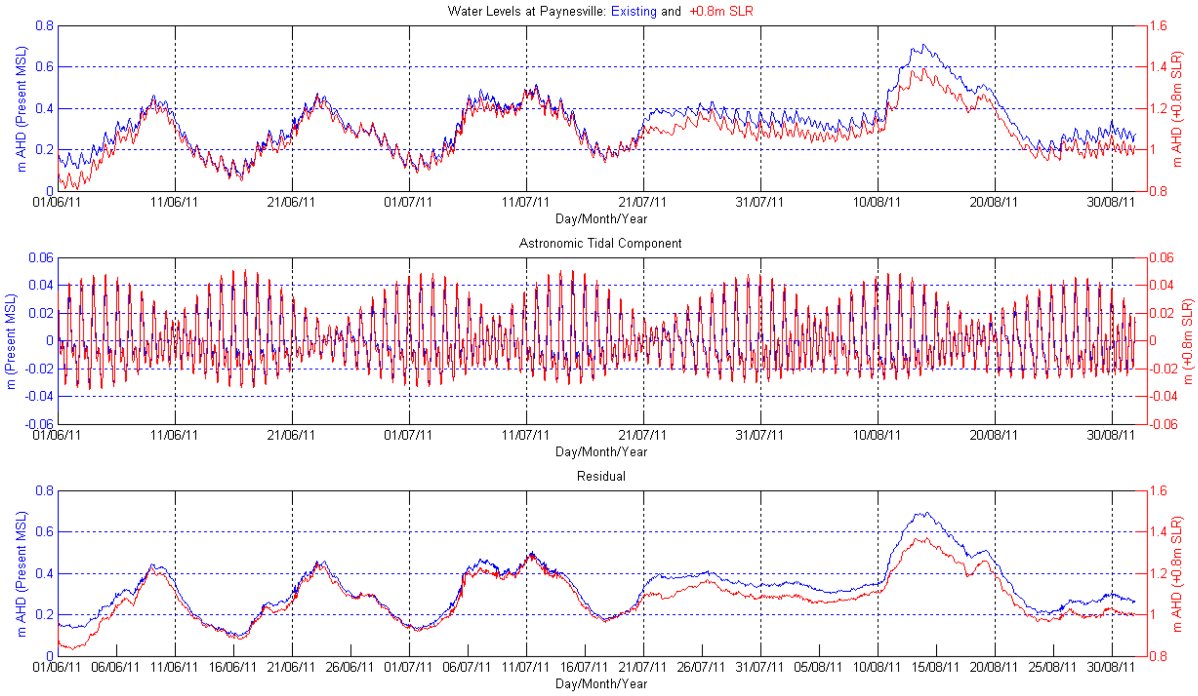


Figure 5-17 **Effect of 0.8 m of Sea Level Rise on the Astronomical Tide and Water Level Residuals at Paynesville.**

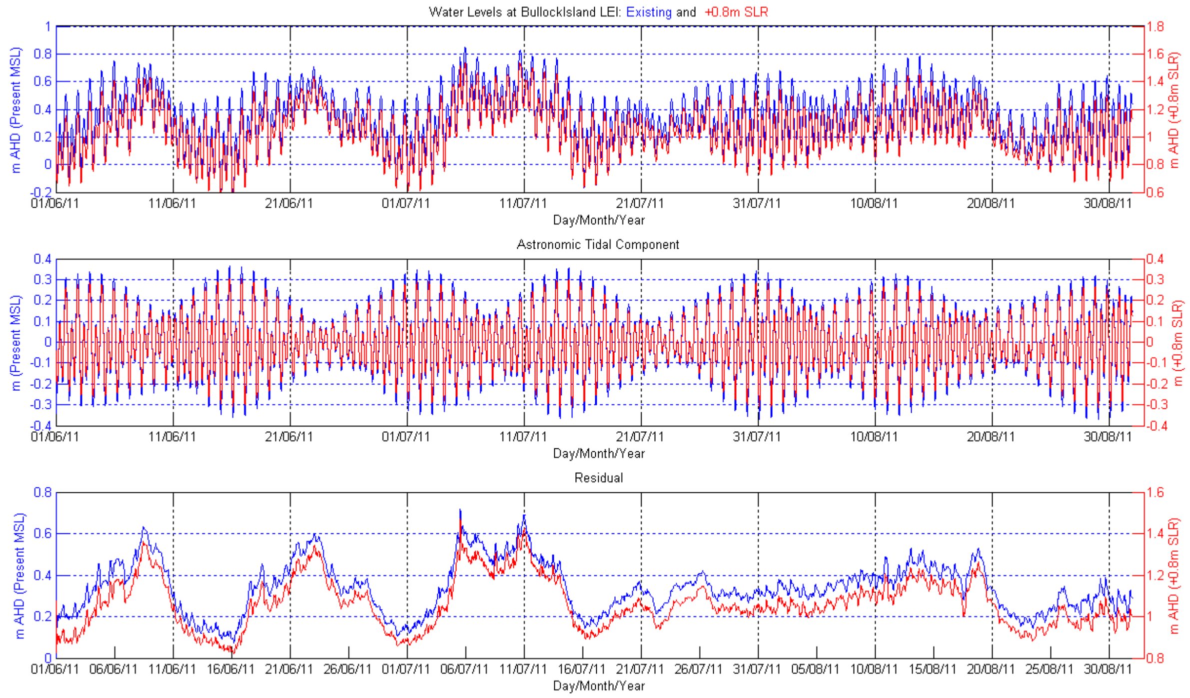


Figure 5-18 **Effect of 0.8 m Sea Level Rise on the Astronomical Tide and Water Level Residual at Lakes Entrance.**

5.3.3 Sensitivity Modelling Assumptions

Entrance Geometry

Under higher mean sea levels it is likely there would be some adjustment to the entrance geometry, which would in turn have some effect on tidal amplitudes within the lakes. At the same time it is considered unlikely that such a change in geometry would significantly influence residual water levels in the Lakes, as these operate over longer periods of influence (days) without the same degree of attenuation that occurs for the shorter tidal signal.

No changes in the geometry of the Entrance at Lakes Entrance were included for the sensitivity assessment above. Such changes to the model would potentially make it more difficult to isolate any changed hydrodynamic behaviour due to sea level rise from the impact of changed geometry. In addition, the effort and complexity involved in adding geometry response to the assessment was beyond the scope of this project (which is focussed on the assessment extreme event hazards).

Lakes Bathymetry

As with all the SLR scenarios in the report, the existing bathymetry was used with no alterations that may occur due to inundation of the shoreline over time. Clearly there would be some response in terms of shore and bed erosion as mean sea levels increase. However, the morphologic prediction of these changes is a complex and uncertain process that would require a separate study in order to adequately determine and was not included in the scope of this project. Further it is considered unlikely that such morphological change would have significant influence over the broader hydrodynamic behaviour of the Gippsland Lakes.

6. EVALUATION OF SOURCES OF UNCERTAINTY

The analysis and modelling of the impact of sea level rise and climate change on extreme water levels within the Gippsland Lakes has a number of potential sources of uncertainty. These sources of uncertainty require evaluation to determine the sensitivity they may have on the findings of the inundation hazards assessment.

From the literature review and the parallel assessments of the coastal hazard and lake shoreline erosion hazards, the assessment of the inundation hazards due to sea level rise and climate change is considered potentially sensitive to the following sources of uncertainty:

- Coincidence of flooding and storm surge events at Seaspray (the joint occurrence of flood and storm has been implicitly incorporated into the general Gippsland Lakes analysis through the combination of forcings from the Gippsland Lakes Flood Level Modelling Project, (Grayson, et al., 2004));
- A potential overwash(s) of the outer barrier creating an additional permanent or ephemeral entrance(s) to the Gippsland Lakes;
- Significant changes to catchment flood hydrology due to climate change and associated increases in rainfall intensity; and
- Land subsidence associated with aquifer deflation

The following sections evaluate the sensitivity of the uncertainty scenarios on the extent of inundation hazards in the study area due to sea level rise and climate change.

6.1.1 Coincidence of Flooding and Storm Surge Events at Seaspray

There is insufficient data to accurately determine the exact probability of coincidence between floods in Merriman Creek and storm surge in Bass Strait. Anecdotal evidence suggests they are not strongly correlated, as the timing of surge events occurs after days of sustained winds whereas the catchment response is on a shorter timeframe. The likelihood of these peaks occurring at the same time is minimal. This is consistent with the approach adopted in the Seaspray Caravan Park – CHVA and Flood Study (Cardno Lawson Treloar, 2010), where a 10 year ARI storm surge condition was used in conjunction with design floods in Merriman Creek.

6.1.2 Outer Barrier Overwash

Two different scenarios were identified and have been assessed as potentially having an influence on inundation in the project study area. The first scenario was an overwash of the outer barrier at Bunga Arm, resulting in a temporary second entrance to the open coast. Following this, the influence of coastally driven inundation through a storm tide overtopping the outer barrier at Seaspray has been assessed.

Bunga Arm Barrier Overwash

A number of washover events of the outer barrier have occurred historically. These events are documented in Report 3: Outer barrier Coastal Hazards. One of the most likely locations of further overwash events in the future due to sea level rise was determined to be along the Outer Barrier at Bunga Arm, due to the low barrier volume and dune crest elevation as detailed in Report 3.

In order to investigate the effects of an outer barrier overwash on extreme elevated water levels in the Gippsland Lakes, an artificial overwash was introduced into the model by lowering the bathymetry along part of the dune. The 10% AEP flood scenario event under 0.8 m sea level rise was then re-simulated. Figure 6-1 shows a subset of the modified hydrodynamic model mesh, with the overwash occurring along a narrow barrier section of Bunga Arm. The overwash bathymetry was assumed to be approximately 100 m wide with a depth of approximately 0.7 m below the peak storm tide water level.

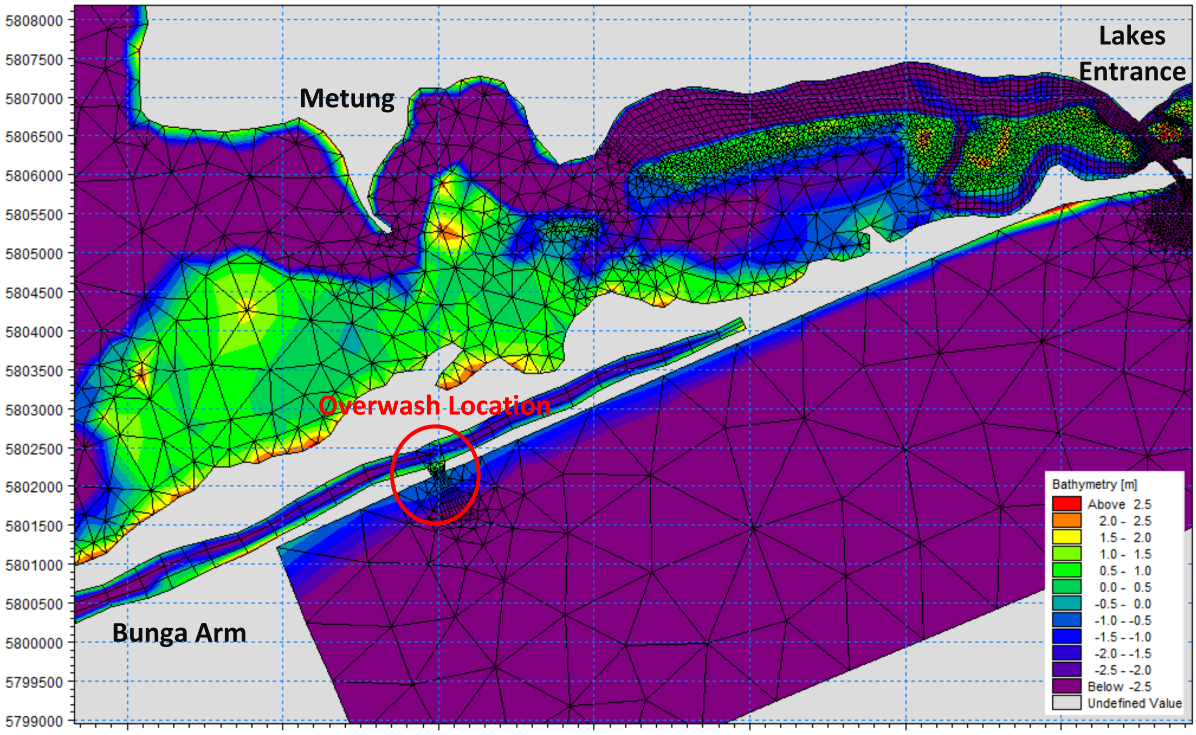


Figure 6-1 Modified Hydrodynamic Model Mesh used to Simulate the Barrier Overwash Scenario

A summary of the peak water level results from this overwash scenario is provided in Table 6-1. Time series of water levels at Lakes Entrance, Paynesville, Loch Sport and Lake Wellington are shown in Figure 6-2. This shows that modelled peak water levels are slightly lower with the inclusion of the overwash scenario. The sensitivity factors in the table ($WL_{Overwash}/WL_{Existing}$) show only a 1 to 3% decrease in water levels.

Overwash of the barrier and the formation of a second entrance in Bunga Arm resulted in similar response factors at all four of the above sites. As seen in Figure 6-2, the presence of a second entrance accelerated the post-flood recession in water levels at all sites, although Bull Bay (Lake Wellington) is constrained by flow capacity through McLennan's Strait and hence showed less change (sensitivity) than the other locations. These results suggest that overall flood levels within the Lakes are not highly sensitive to an overwash event along Bunga Arm.

It should be noted that a key limitation of the overwashing and formation of a second entrance simulation is that the model was run with a fixed bathymetry. Whereas, during a flood event the barrier cut would likely increase in size due to increased scour as the flood waters are released through the overwash location. This would potentially result in further lowering of the peak flood levels within the lakes system, and increase the rate of the post-flood recession in water levels.

The influence of a secondary entrance, near Bunga Arm, between the Gippsland Lakes and the sea on tidal water level variations within the lakes was previously assessed as part of the Gippsland Lakes Changing Hydrodynamic Conditions Assessment (Water Technology, 2005), and therefore was not considered in detail as part of this project. Gippsland Lakes Changing Hydrodynamic Conditions Assessment concluded that there was a significant increase in the tidal range through Bunga Arm (up to +0.8m addition range); however, changes to water level variations within Lakes Wellington, Victoria and King were minimal.

Table 6-1 Peak Water Levels and the Sensitivity Factor at Various Locations for the Existing and Barrier Overwash, 10% AEP Flood Scenario with 0.8 m SLR

Location	Peak Water Level (m AHD)		Sensitivity Factor
	Existing	Barrier Overwash	
Paynesville	2.13	2.09	0.98
Lakes Entrance	1.91	1.87	0.99
Loch Sport	2.12	2.09	0.98
Lake Wellington	2.18	2.14	0.97

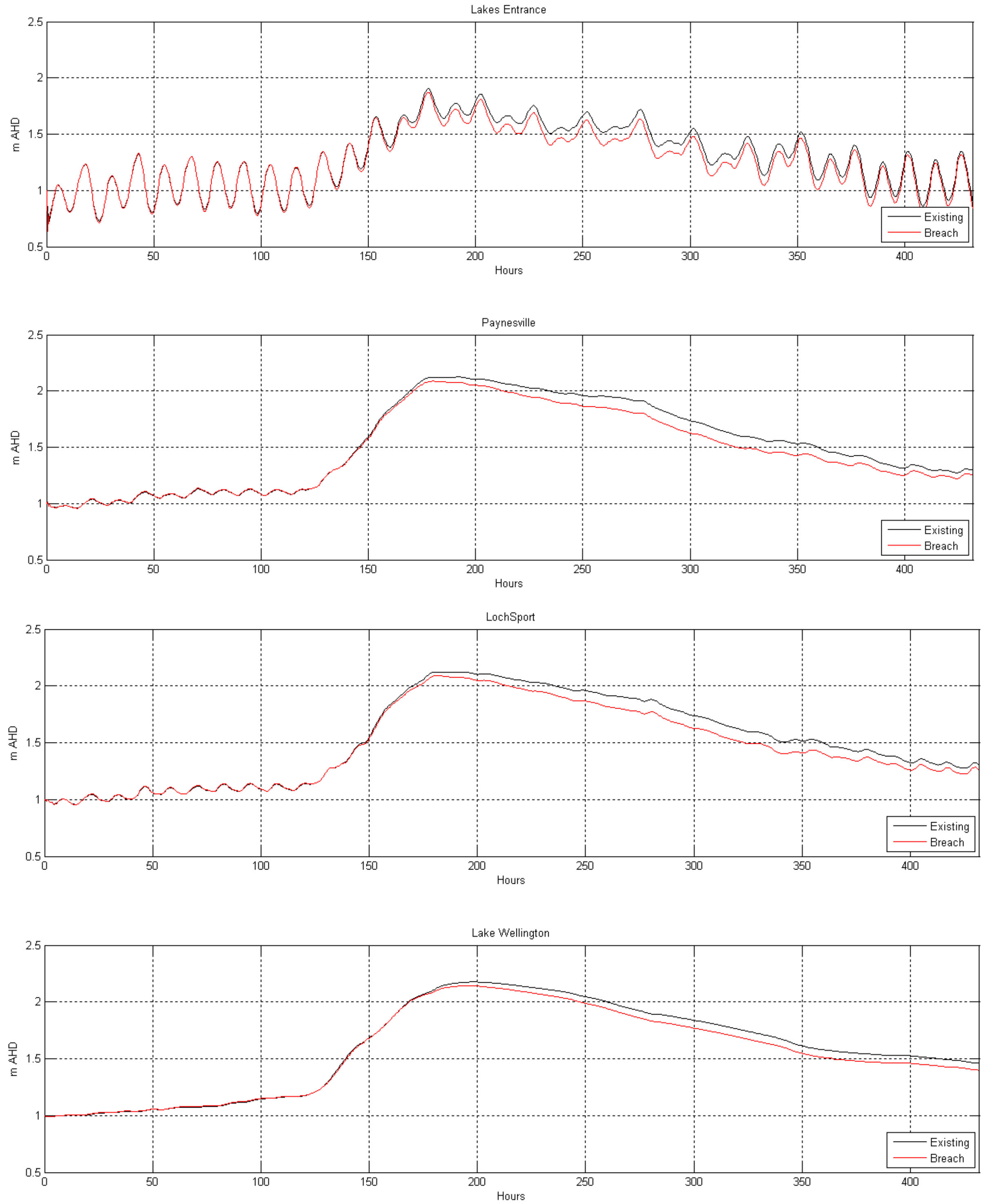


Figure 6-2 **Time Series of Modelled Water Levels at Various Key Locations within the Gippsland Lakes for the 10% AEP Flood Scenario with 0.8 m SLR for Existing Conditions and with an Overwash of the Outer Barrier**

Coastally Driven Inundation at Seaspray

The potential for translation of the Outer Barrier due to sea level rise and associated overwash and washover processes was identified as likely for sea level rise scenarios greater than approximately 0.4 m for the Seaspray-Honeysuckle geomorphic unit as discussed further Report 3: Outer Barrier Coastal Hazards.

The impact of an overwash of the outer barrier at Seaspray was assessed through the development of a coupled hydrodynamic and sediment transport model of the region from Merriman Creek to the eastern extent of the Honeysuckles. The model extended from approximately 15 m water depth offshore, to the marginal bluff on the landward side of the barrier, and included the settlements of Seaspray and the Honeysuckles.

To create a condition that would initiate overwash of the Outer Barrier, the model topography was edited initially to include a lowered section of barrier to the east of Seaspray. The section was approximately 85 m wide, with a maximum dune crest that was 0.5 m below the peak water elevation of a 1% AEP storm tide sequence incorporating 0.8 m of mean sea level rise.

The model was simulated with the 1% AEP storm tide water level sequence, initiating an overwash event through the barrier. The process and influence of washover sediment deposition over the back barrier region at Seaspray are further described in Section 7.3.1 of the accompanying report, Report 3: Outer Barrier Coastal Hazards.

Figure 6-3 shows the inundation resulting from simulation of a 1% storm tide incorporating +0.8 m SLR. Localised inundation occurs surrounding the overwash site and spreads westward and eastward, however, it is predominantly confined in the north/northwest directions by the levee banks, with the exception of slight overtopping directly in front of the overwash location. Significant inundation of the low-lying plains surrounding the Seaspray Township also occurs due to overtopping of the channel connected to Merriman Creek. It should be noted that although Figure 6-3 provides an indication of the potential inundation from an overwash event, the amount of inundation and location ultimately depends on the size/location of the low section in the barrier through which the overwash occurs.

Inundation due to catchment flood conditions and coincident storm tide flooding via Merriman Creek has previously been assessed in detail by (Cardno Lawson Treloar, 2010), and thus was not considered for this assessment.

Figure 6-3 Seaspray 1% Storm Tide Overwash Inundation, with +0.8 m SLR

6.1.3 Catchment Flood Hydrology

Theoretical, model and observational studies all suggest that precipitation extremes will increase in a warmed climate but that the period between rainfall events will also increase. This manifests as an increase in heavy rainfall, a decrease in light and moderate rainfall and an increase in the number of rain-free days. However, despite the general consensus on the trajectory of change, there is significant uncertainty about the magnitude of change in precipitation extremes that may occur at any particular location, such as the Gippsland Lakes.

Consistent with this research, an increase in rainfall intensity and in the number of rain-free days has been projected for Lakes Entrance by the Victorian Department of Sustainability and Environment (DSE, 2008a) (DSE, 2008b). For example, rainfall intensity is projected to increase by 15.3% in summer with a 13% decrease in the number of rain days. More specific information may be obtained from work by Abbs and Rafter (2008) who investigated likely climate impacts in the Westernport region, the closest such study to the Gippsland Lakes. They found that by 2070, all catchments were projected to experience increases in extreme rainfall intensity. Increases were 60% for short duration events (2-hour) and 30-40% for the 24-hour and 72-hour events.

These trends have not been observed, as yet, in measured data in the Gippsland Lakes area. A study of rainfall data 1910 to 2005 for southeast Australia, including Gippsland, did not find any significant trends in rainfall intensity or the number of rain days (Gallant, Hennessy, & Risbey, 2007).

Catchment wetness also influences the rate and total volume of runoff. Usually catchments need to be relatively wet before intense rainfall will lead to runoff that causes a flood. Both short term and long term effects are important in regards to catchment wetness. Rain a few days before a large storm can increase runoff but there is also a seasonal effect where catchments wet-up over months (Pathiraja, Westra, & Sharma, 2012). There is little research on the influence of climate change on catchment wetness. Total rainfall for the Gippsland Lakes catchment is expected to decrease under climate change and a drier climate could lead to increased losses i.e. less rainfall being converted to streamflow.

The potential impact of climate change on the flood hydrology of the Gippsland Lakes is considered to be highly uncertain, to the extent that it is difficult to identify a particular climate change scenario that is most appropriate for the uncertainty analysis. It has however been determined that it is prudent to consider an increase in rainfall intensity of approximately 20%, with losses remaining unchanged such that the streamflow flood volumes are also increased by 20%. Therefore, a 'typical' 10% AEP flood event in 2100 would be expected to have 20% more volume than under current climate conditions.

To test the uncertainty associated with the potential change in flood hydrology the representative 10% AEP flood scenario under 0.8 m of sea level rise was re-simulated with all freshwater inflows scaled up by 20%. The changes in peak water levels at various key locations are presented below. The sensitivity factors in Table 6-2 ($WL_{CC}/WL_{Existing}$) and flood hydrographs in Figure 6-4 show an increase of approximately 10% in water levels due to a 20% increase in flood flows.

These results suggest that flood levels in the Gippsland Lakes are moderately sensitive to uncertainty of inflows. It should be noted that with increased catchment inflows and higher mean sea levels it is likely the entrance to the Gippsland Lakes would increase in size, resulting in lower peak water levels than presented here. However, an assessment of potential changes to the entrance geometry were beyond the scope of this project, and therefore the results presented in Table 6-2 are likely to be at the upper bounds of expected response.

Table 6-2 Peak Water Levels and the Sensitivity Factor at Various Locations for the Existing and 20% Increased flows, Representative 10% AEP Flood Scenario with 0.8 m SLR

Location	Peak Water Level (m AHD)		Sensitivity Factor
	Existing	Increased Inflows	
Paynesville	2.13	2.36	1.11
Lakes Entrance	1.91	2.08	1.09
Loch Sport	2.12	2.35	1.11
Lake Wellington	2.18	2.40	1.10

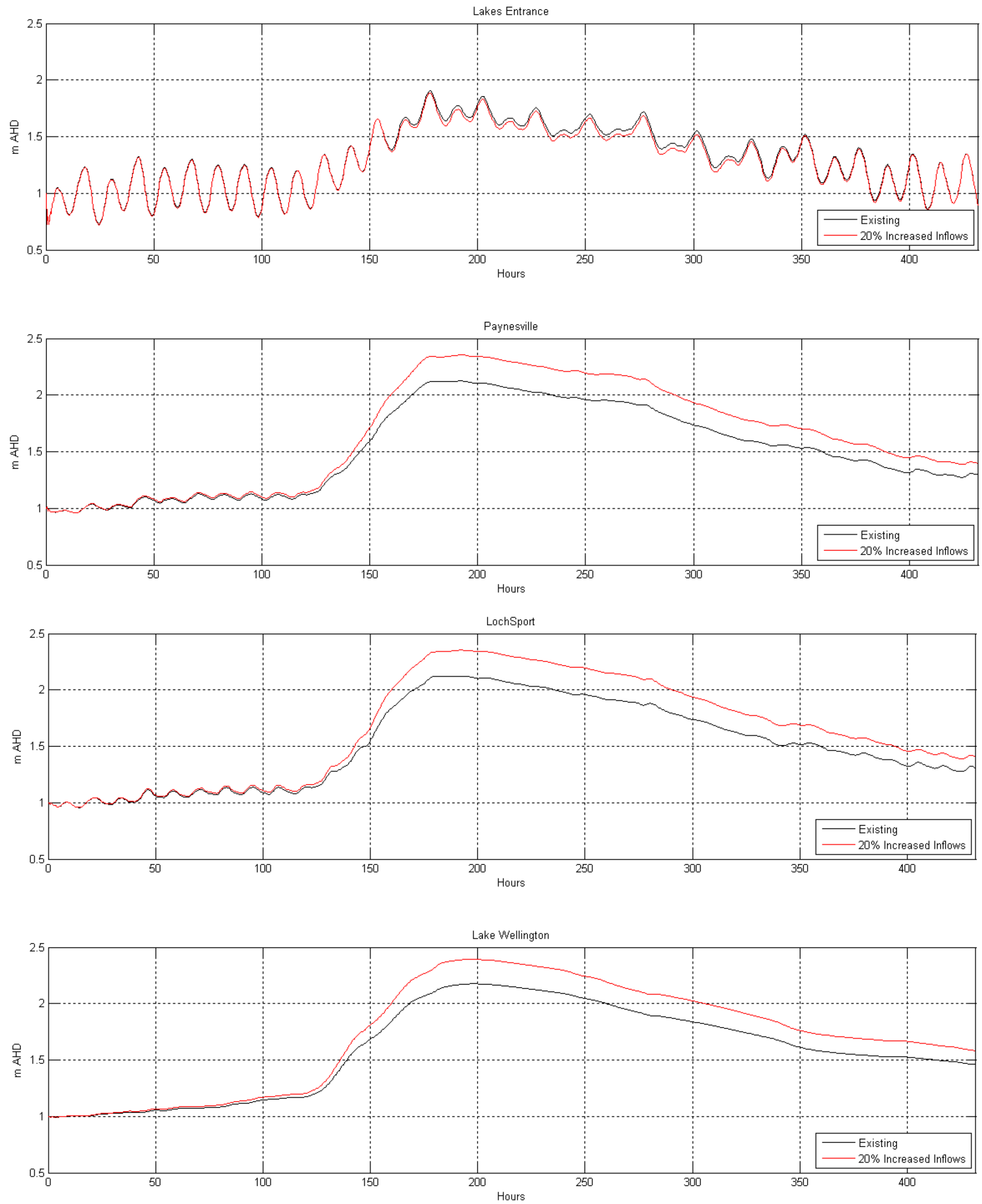


Figure 6-4 Time Series of Modelled Water Levels at Various Key Locations within the Gippsland Lakes for the representative 10% AEP Flood Scenario with 0.8 m SLR for Existing Conditions and with Increased Catchment Inflows Associated with a Warming Climate

6.1.4 Land Subsidence

Extraction of oil and gas, dewatering of open pit coal mines and groundwater extraction for irrigation have been identified as lowering pressures within the Latrobe Aquifer (Freij-Ayoub, et al., 2007). Reduction of pore water pressure within the aquifer has the potential to result in consolidation/compression of the aquifer sediments causing a lowering of the land surface above the aquifer. On the coastline and within the Gippsland Lakes, the relative fall in the land surface would cause isostatic sea level rise. The isostatic sea level rise due to land subsidence would need to be added to the eustatic, climate change induced sea level rise projections to enable the total extent of potential inundation and erosion hazards to be assessed for the study area.

Freij-Ayoub et al. (2007) undertook a modelling analysis of the potential extent and rate of subsidence of the Latrobe Aquifer. The modelling analysis incorporated what was deemed to be realistic and pessimistic subsidence scenarios for the period up to 2056. Figure 6-5 displays the predicted pessimistic subsidence contours up to 2056 for the study area. As can be seen from Figure 6-5, subsidence of up to 1.0 m is predicted in the south-west of the study area, for the 2056 pessimistic scenario. The magnitude of the potential isostatic sea level rise in the south west of the study area is therefore similar to that associated with projected eustatic sea level rise and would result in a very rapid relative sea level rise scenario for the south west of the study area.

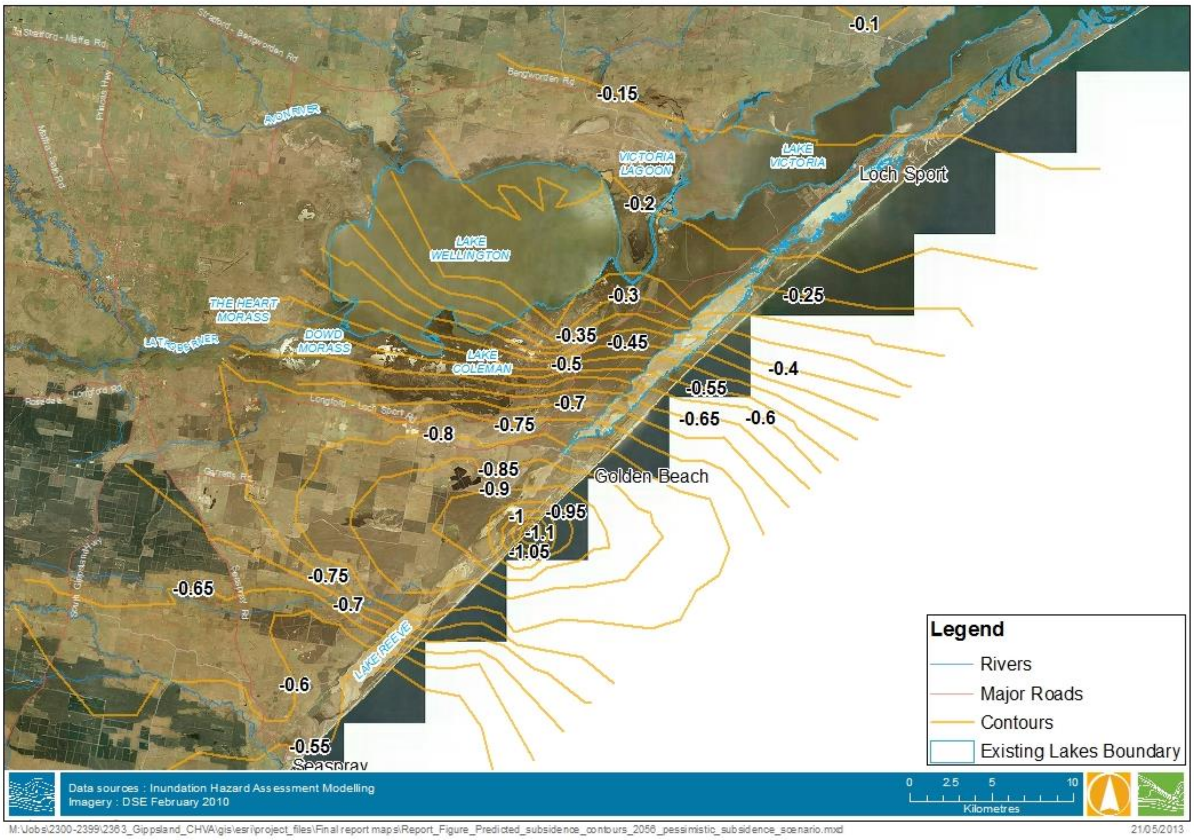


Figure 6-5 Predicted Subsidence Contours for the Year 2056 Pessimistic Subsidence Scenario

It is noted that the modelled subsidence predictions are based on a number of assumptions, uncertainties and limitations and thus there is a large degree of uncertainty surrounding the likely rate of subsidence into the future. To provide an indication on the range of predicted subsidence levels in the Gippsland region the 2056 Realistic subsidence scenario contours are shown in Figure 6-6, however, this scenario was not modelled as part of this project.

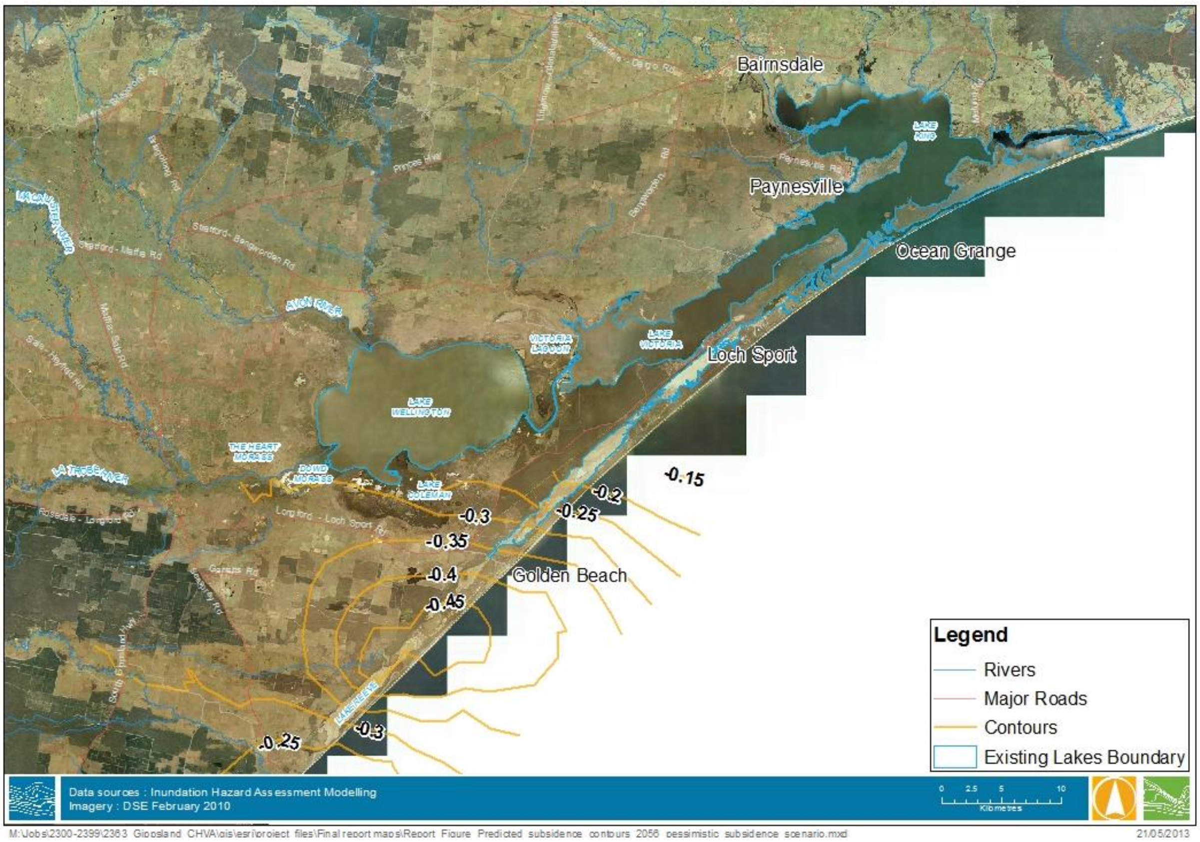


Figure 6-6 Predicted Subsidence Contours for the Year 2056 Realistic Subsidence Scenario

To evaluate the sensitivity of subsidence within the study area on inundation hazards extents, the hydrodynamic model topography elevations were lowered, based on the spatial variation in subsidence displayed in Figure 6-5. The hydrodynamic model was then simulated with the representative 10% AEP flood case including 0.8 m eustatic sea level rise. The relative impacts on inundation extents and water levels within the study area have been compared to the base case eustatic sea level rise scenario and are presented below. Table 6-3 shows the peak modelled water levels and sensitivity factors ($WL_{Sub}/WL_{Existing}$) and Figure 6-8 displays flood hydrographs at locations across the Lakes.

The response of peak water levels to land subsidence is essentially the same as increased mean sea levels, with storage volume increasing with subsidence. The decrease in peak water levels (response factors < 1) under the land subsidence scenario at Paynesville, Lakes Entrance and Loch Sport were in the order of 3-4 cm. This corresponds to the maximum subsidence predicted to occur around Lake Reeve, south-south-west of Lake Wellington, decreasing in the north-east direction to zero towards Paynesville and Lakes Entrance. The largest change in peak water levels from the above four sites was observed in Lake Wellington, as Lake Wellington is predicted to experience a larger degree of subsidence.

Whilst peak water levels have been demonstrated to be relatively insensitive to subsidence, the main impact of subsidence is in relation to flood extents and depths, which would increase for the same absolute peak water level, compared to existing conditions. The change in inundation extent at Seaspray resulting from land subsidence and +0.8m SLR for the representative 10% AEP flood event is displayed in Figure 6-7, and highlights the large increase in inundation extent. However, as predicted land subsidence decreases spatially in the north-west direction, the change in inundation extent at the other representative locations was minimal (Figure 6-8).

Figure 6-7 Representative 10% AEP Flood Scenario Maximum Inundation Extent under the +0.8m SLR Scenario, and the +0.8m SLR Scenario Incorporating Land Subsidence at Seaspray

Table 6-3 Peak Water Levels and Sensitivity Factor at Various Locations for the 10% AEP Flood Scenario with 0.8 m SLR for Existing Conditions and with Land Subsidence

Location	Peak Water Level (m AHD)		Sensitivity Factor
	Existing	Land Subsidence	
Paynesville	2.13	2.09	0.98
Lakes Entrance	1.91	1.89	0.99
Loch Sport	2.12	2.08	0.98
Lake Wellington	2.18	2.12	0.97

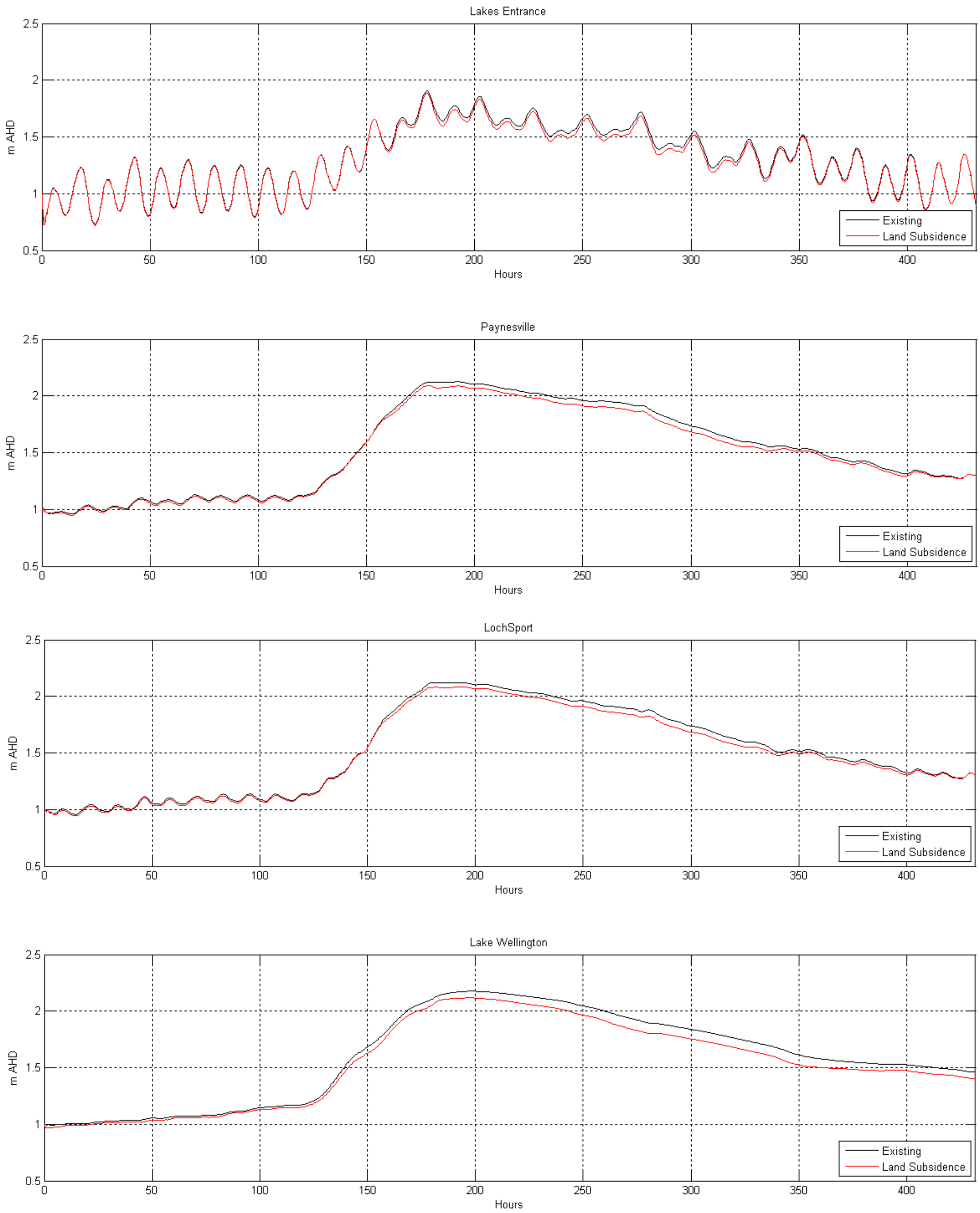


Figure 6-8 Time Series of Modelled Water Levels at Various Key Locations within the Gippsland Lakes for the 10% AEP Flood Scenario with 0.8 m SLR for Existing Conditions and with Land Subsidence

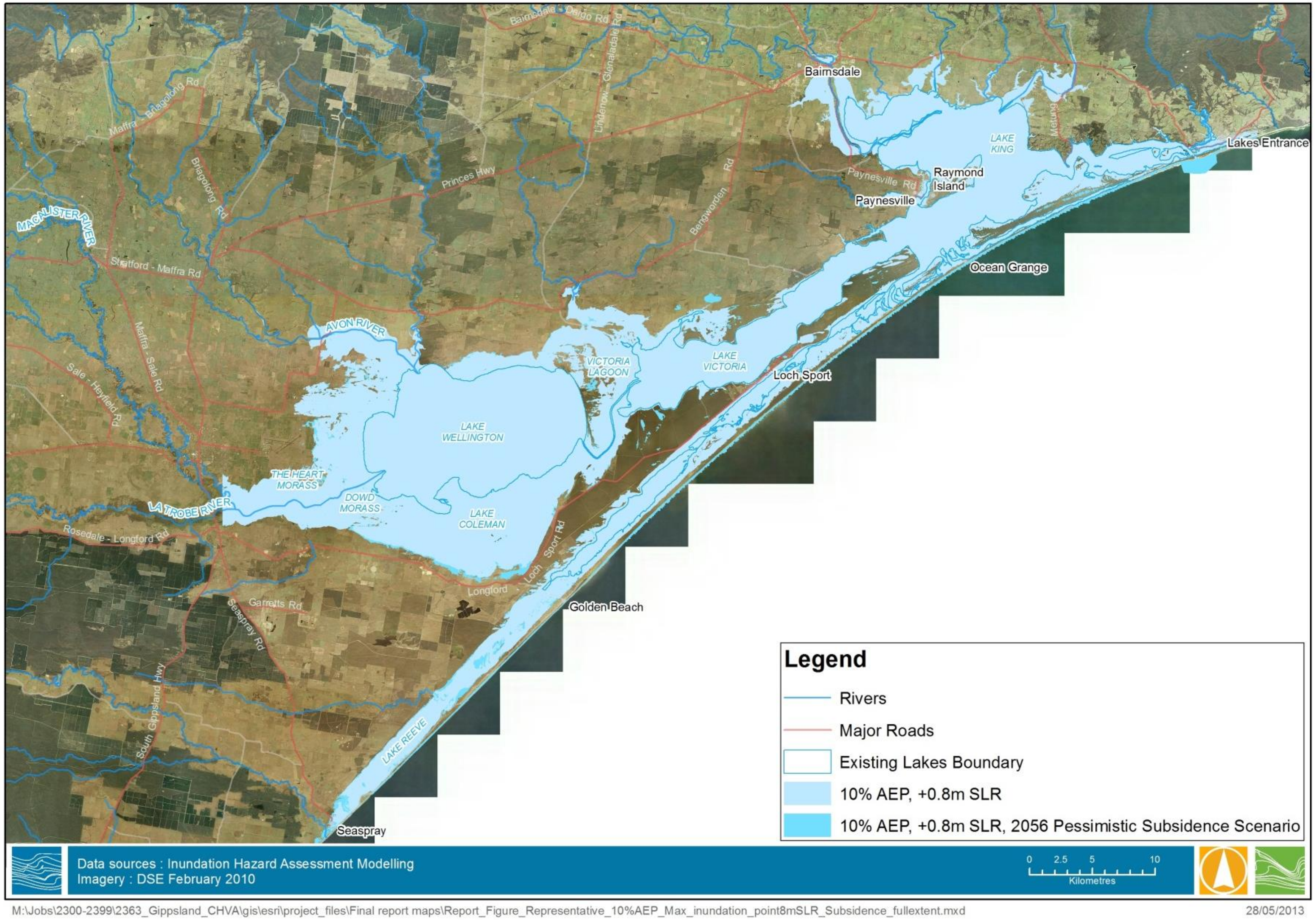


Figure 6-9 Representative 10% AEP Flood Scenario Maximum Inundation Extent under the +0.8m SLR Scenario, and the +0.8m SLR Scenario Incorporating Land Subsidence

7. CONCLUSION AND RECOMMENDATIONS

A detailed two-dimensional model of the Gippsland Lakes has been developed for the analysis of inundation hazards under a range of future climate change scenarios. The model has been calibrated to a level sufficient to demonstrate it is fit for the purposes of the study.

The results of the modelling show that relative increases in inundation hazard (compared to increments of sea level rise) decrease from east to west through the Gippsland Lakes. This difference has been characterised by a SLR Response Factor which varies from 0.9 at Lakes Entrance to 0.45 at Lake Wellington.

A number of sensitivity analyses have been undertaken that show flood levels in the lakes are moderately sensitive to a change in catchment hydrology and slightly sensitive to aspects such as washover events and changes in tides/wind.

It is important to note that the predicted flood levels under the climate change scenarios are sufficient to define the likely coastal hazards under different climate change scenarios but are not appropriate for, nor intended to provide levels suitable for planning purposes. Further refinement of the design flood cases and additional calibration would be required to meet the requirements of a full flood study.

As a result of these investigations, the following recommendations are made:

- A Water Level Frequency Analysis should be undertaken for the main townships of the Gippsland Lakes to aid understanding of the full range of SLR impacts on these communities. This project has assessed the impact of SLR on flood levels due to large floods within the Gippsland Lakes. However, it has also been highlighted that there is a need to further understand the potential changes to the frequency of inundation associated with smaller flood and coastal water level events with sea level rise in the Gippsland Lakes.
- The flood modelling in this study has been undertaken to provide a reliable indication of the impact of sea level rise and climate change on flood levels within the Gippsland Lakes. It does not however constitute a full flood study. Further work in the refinement of calibration parameters and boundary conditions could be undertaken to allow for the modelling to provide outputs that meet the requirements of a full flood study such that the results could be applied to set levels for future land-use planning.
- The impact of climate change on salinity within the Gippsland Lakes is of major ecological importance. Changes to the salinity regime could influence the biota within the lakes including fringing vegetation and related aspects such as algae and the entire food web. The existing hydrodynamic model can be utilised to investigate salinity impacts in the future.
- The sensitivity of entrance dynamics was not able to be investigated by this study. The interaction of SLR with tides, floods and dredging of the entrance and surrounds potentially has significance and could be investigated through further modelling and data collection.
- As discussed in the Hazard Scenarios, modelling of the 1% AEP flood scenario with +0.8 m sea level rise was not undertaken due to uncertainties and potential to confuse model outputs with current declared flood levels. It is recognised that some agencies would benefit from this analysis. As noted above, further refinement of the design flood cases and additional calibration would be necessary to meet the requirements of a full flood study.

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