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TRUENERGY

Tallawarra Lands

Coastal Processes and Hazard Study

301020-02476 – 1

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PROJECT 301020-02476 - TALLAWARRA LANDS

REV	DESCRIPTION	ORIG	REVIEW	WORLEY-PARSONS APPROVAL	DATE	CLIENT APPROVAL	DATE
A	Issued for internal review	K Newton	D Messiter	N/A		N/A	
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D	Revision 1	J Burston	E Watterson	E Watterson	20-DEC-2010		

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1 INTRODUCTION

1.1 Background

TRUenergy is seeking concept plan approval from the Minister for Planning under Part 3A (major projects) of the *Environmental Planning & Assessment Act* (EP&A Act) *1979* to rejuvenate the Tallawarra Lands site with a balanced mix-use development including land for business, residential communities and over 200 ha of protected environmental and recreational reserves (**Figure 1.1**). The proposed development of Tallawarra Lands will release the potential of this under-utilised site for the benefit of the local Illawarra community.

Tallawarra Lands covers an area of 535 hectares (ha) of private land adjacent to the existing (Stage A) and proposed (Stage B) Tallawarra Gas Power Station site. Tallawarra Lands comprises the majority of the Yallah locality and is situated on the western foreshore of Lake Illawarra. The site includes a number of wetlands and watercourses that flow to Lake Illawarra, including Duck Creek. There is a boat launching ramp at the Yallah Bay breakwater and a tide gauge at Koonawarra Bay, just to the north.

The area identified for development includes approximately 6 km of Lake Illawarra foreshore land comprising the Yallah Bay breakwater and cleared foreshore to the north of Duck Creek (proposed for public recreation under the site Landscape Masterplan) and wetlands to the south of Duck Creek. The southern portion of foreshore land is owned by TRUenergy, with the northern portion having been dedicated to the Lake Illawarra Authority (LIA) in 2003. Sections of the LIA foreshore land range from 30 to 70 m in width.

The Director-General's (DG's) requirements for the Environmental Assessment (EA) of the proposed development, in relation to coastal processes and hazards, required the Coastline Management Manual and NSW Coastal policy to be addressed and the preparation of a Coastal Hazards Study. In particular, impacts associated with wind and wave action, coastal erosion, sea level rise and more frequent and intense storms are to be considered.

The DG's requirements also included preparation of a site analysis plan showing (amongst other information) all hazards and constraints.

Figure 1.1 Masterplan Concept for Tarrawarra Lands. (Masterplan I: 7 Dec 2010).

1.2 Scope of this Report

This report summarises the current knowledge, to provide an understanding of the coastal processes that operate within the study area. The report also examines the coastal hazards that impact the study area and assesses these hazards to determine the immediate, 2050 and 2100 hazard lines.

The hazards examined in this report are those set out in the NSW Government's Coastline Management Manual (1990), as listed below:

- foreshore erosion;
- shoreline recession;
- sand drift;
- coastal inundation;
- stormwater erosion;
- slope instability; and
- climate change.

This Coastal Hazard Study for the Tallawarra Lands site includes an examination of:

- bathymetry and bottom sediments;
- tides;
- elevated still water levels;
- wave climate (wind generated);
- potential sediment transport mechanisms and rates, and foreshore stability; and
- climate change issues related to coastal hazards.

Sea level rise, as a consequence of climate change, has the potential to increase the average lake levels, leading to shoreline recession and inundation. Depending on the magnitude of the increase in average lake levels, there may be implications for the Yallah Bay breakwater.

The foreshore may also by susceptible to erosion from wind waves, due to the fetch across Lake Illawarra (particularly from the northeast). Erosion from boat wake may also be a consideration along the relatively cleared foreshore areas north of Duck Creek. Information included in each section of this report is as follows:

Section 2 outlines the geographical setting;

Section 3 outlines the data used in the preparation of this report;

Section 4 examines the coastal processes operating in the study area;

Section 5 discusses the coastline hazards affecting the study area, quantifying these hazards where possible; and

Section 6 provides a summary of the findings of the report.

2 STUDY AREA

2.1 Geographical Setting

The Tallawarra Lands site is situated on the western foreshore of Lake Illawarra (**Figure 2.1**). Lake Illawarra is a coastal barrier estuary located between the Illawarra escarpment and the Pacific Ocean, approximately 90 km south of Sydney and 10 km south of Wollongong on the South Coast of NSW (**Figure 2.2**). The lake is connected to the ocean through a narrow entrance channel which is located approximately midway along the lake's extent.

Lake Illawarra is located at latitude 34°30'S and longitude 150°50'E and is within the Wollongong and Shellharbour Local Government Areas (LGA). The lake has a foreshore area of 38 km and a total catchment area of 270 km^2, 35 km^2 of which is comprised of the waterway itself (i.e. a land catchment area of 235 km^2). The catchment extends from sea level to 700 m, over a distance of about 20 km from the coast (WBM 2003).

In 2003, land use in the catchment was approximately 23 % urban, 40 % rural and 37 % forested (CSIRO Land & Water 2000). Considerable development means that these percentages have likely changed since this time. Two thirds of the catchment has been cleared for development over the past 150 years.

Lake Illawarra is a typical barrier estuary system that formed during the post glacial marine transgression associated with the last sea level rise, some 20,000 – 7,000 years ago (PWD 1988). This system is characterised by a coastal sand barrier (dunes) and a shallow flat-bottomed bed that is connected to the ocean by a long and narrow shoaled entrance channel that intermittently closes.

The channel linking Lake Illawarra to the sea is approximately 3.6 km long. It winds through the lake opening which is approximately 1.8 km long and 600 m wide. The channel is shallow and sea water normally runs in on the northern side of Windang Island but occasionally entered from the southern side prior to entrance training. At other times, access to the channel may be cut off altogether by sand build up. Lake Illawarra has been recorded to have closed off at least ten times over the past 50 to 100 years. The Lake Illawarra Authority has a policy to open the lake mechanically when the lake reaches a level of 0.8 m AHD in order to alleviate the risk of flooding. The beach to the north of the lake entrance is Perkins Beach and that to the south is Warilla Beach.

Lake Illawarra is in an advanced state of infilling. Despite its large size, the lake is relatively shallow with a maximum depth of 3.5 m relative to Port Kembla Harbour Datum (PKHD) (refer to Section 3.4). The average lake depth is now only 1.9 m PKHD and is infilling at a rate of 2-3 mm / year. A large proportion of the lake has a depth of less than 1 m PKHD. NSW Maritime's Boating Map for Lake Illawarra notes water depths of less than 2 m PKHD around the foreshore of the site. The average depth to bed rock in the lake is 10-20 m.

In 2001, the Lake Illawarra Authority (LIA) completed construction of the southern breakwater, extending 700 m to Windang Island, accompanied by dredging of the channel. This breakwater forces the entrance of Lake Illawarra to the north of Windang Island, where previously it could open on either side of the island. This southern breakwater was constructed with the aim of maintaining an open entrance of the lake for extended periods of time to improve flushing of the lake and reducing the potential for flooding. However, drought conditions in 2002 led to closure of the lake due to the lack of freshwater outflow and the migration of sand southwards from Perkins Beach (Lawson & Treolar 2004). A northern breakwater was constructed in 2005, accompanied by further dredging of the channel (**Figure 2.3**). The channel width is 90 m. The twin breakwaters will maintain the opening of the lake most of the time, but it is expected that the lake will still occasionally close.

Patterns of rainfall in the catchment are influenced by topography. Average rainfall in the catchment is approximately 1 100 mm (western side of the Lake and lowlands around Dapto) to 1 600 mm (higher ground of the western escarpment) per annum, and 40 % of this falls between the months of January and April (WBM 2003). Rainfall runoff from the steeper western parts of the catchment flows eastward (down slope) to quickly reach the much flatter coastal floodplain. Macquarie Rivulet and Mullet Creek catchments contribute 70 % of the total catchment area (Lawson & Treloar 2002).

With regard to the Tallawarra Lands site, the original coal-powered Tallawarra Power Station owned by Pacific Power was opened in 1954 and operated until 1989. Ash dams on the Tallawarra site were built with coal wash walls to contain the fly ash by-product of the power station. These ash dams are shown in **Figure 2.4**. A breakwater along the cooling water outlet was constructed prior to 1955. Construction began on a new gas-powered power station owned by TRUenergy in 2006.

Figure 2.1 Locality plan.

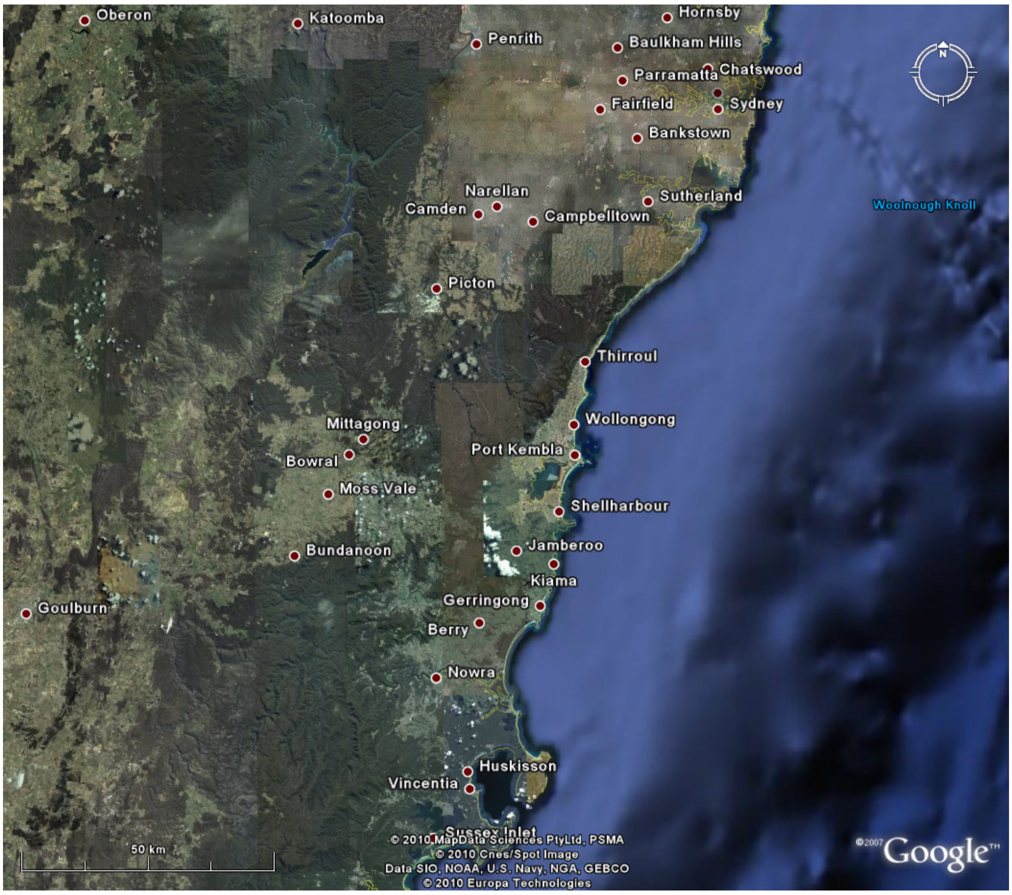


Figure 2.2 Regional locality.

Lake Illawarra entrance looking west

Lake Illawarra entrance channel looking south-east

Figure 2.3 Aerial images of Lake Illawarra entrance (Source: MHL 2009).

Figure 2.4 Tallawarra Power Station ash dams (1984 photo).

3 DATA ACQUISITION

As part of this study a comprehensive search and review of previous literature was undertaken. The reports most relevant to the current study are outlined below:

- Wollongong Coastal Hazards Study, Cardno Lawson Treloar 2010
- Lake Illawarra Estuary Management Study and Strategic Plan, WBM Oceanics 2006
- Lake Illawarra Floodplain Risk Management Study and Plan, Lawson and Treloar 2005
- Lake Illawarra Entrance Works Project (Stage 2) – Environmental Impact Statement, Patterson Britton and Partners 2005 *(now incorporated in WorleyParsons)*
- Lake Illawarra Entrance Improvements-Proposed Northern Training Wall off Perkins (Windang) Beach, Lawson and Treloar 2003
- Lake Illawarra Estuary Processes Study, WBM 2003
- Lake Illawarra Flood Study, Lawson and Treloar 2001
- Lake Illawarra Data Compilation and Assessment Report, CSIRO and University of Wollongong 2000

3.1 General

3.2 Wind data

Wind data was sourced from the Bureau of Meteorology (BoM) for three sites surrounding Lake Illawarra. These sites were Kiama (Bombo Headland), located approximately 16.5 km to the southwest of the Tallawarra site on the coast, Albion Park 3.7 km to the southwest, and Bellambi 20 km to the northwest on the coast (**Table 3.1**). The wind data consisted of hourly average wind speeds and directions.

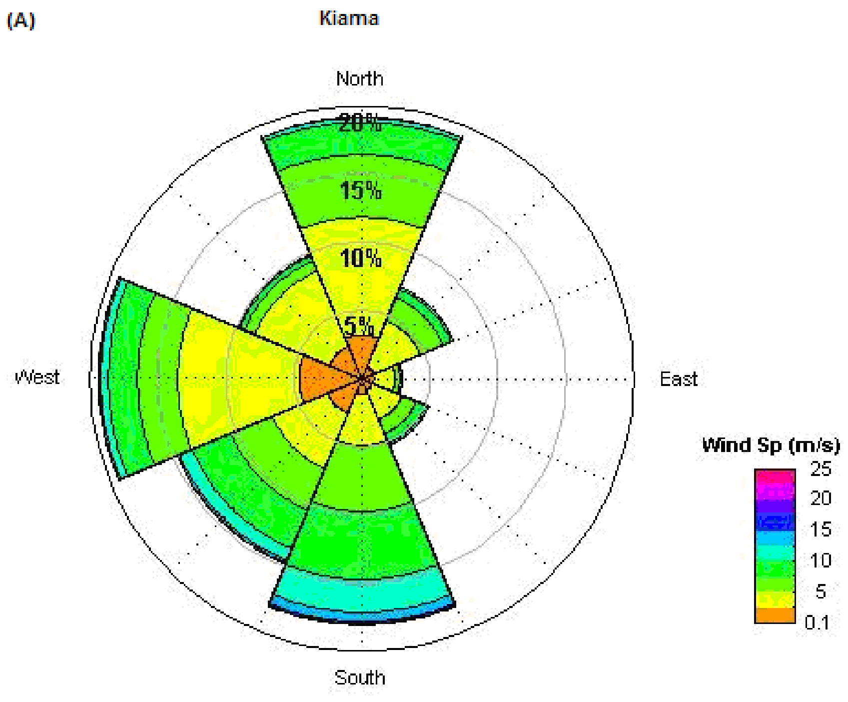
Table 3.1 Summary of regional wind data sites (BoM).

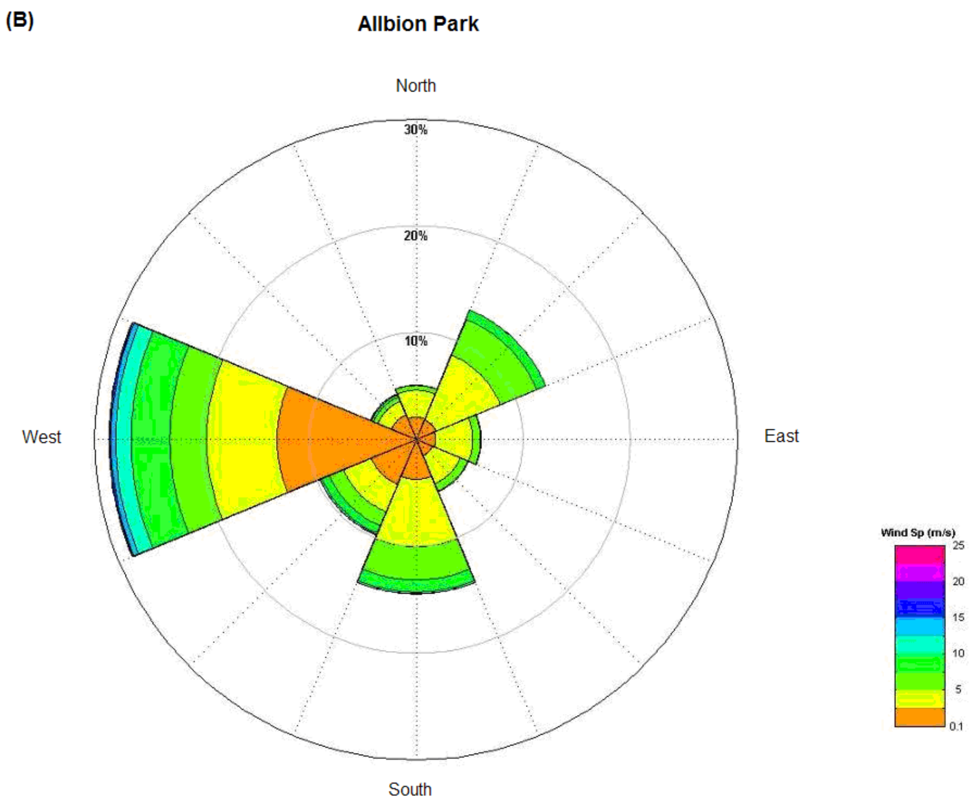
Location	BoM Station No.	Altitude (m AHD)	Start Date	End Date
Kiama	068242	15.5	11/12/2001	8/4/2010
Albion Park	068241	8	4/6/1999	8/4/2010
Bellambi	068228	10	1/1/1989	8/4/2010

A statistical analysis of these wind time series was undertaken in order to determine the appropriate wind forcing for the spectral wave modeling undertaken. Summary statistics of wind speed and direction for each site are given in **Table 3.2**. The mean wind speed was higher for Kiama (5.2 m/s) and Bellambi (4.5 m/s) on the coast than for Albion Park (3.7 m/s), which is 7 km inland. Wind roses for each site are shown in **Figure 3.1**. Wind speed events exceeding 20 m/s were more common at Bellambi. The wind direction is more westerly at Albion Park than the coastal locations. The Bellambi wind data set was selected for use as input for the spectral wave modelling. It provides the longest time series, would give conservative wave statistics, and the highest waves generated at the Tallawarra Lands site are likely from the NE to SE sector driven by coastal winds.

Table 3.2 Summary of statistics for regional wind data sites (BoM).

	Wind Speed (m/s)			Wind Direction (deg N)	
Location	**Mean**	**Std Dev**	**Max**	**Mean**	**Std Dev**
Kiama	5.2	2.9	22.2	198	108
Albion Park	3.7	2.8	22.5	169	108
Bellambi	4.5	3.2	27.8	167	115


(A)
Kiama
North
20%
15%
10%
5%
West
East
South
Wind Sp (m/s)
25
20
15
10
5
0.1


(B)
Allbion Park
North
30%
20%
10%
West
East
South
Wind Sp (m/s)
25
20
15
10
5
0.1

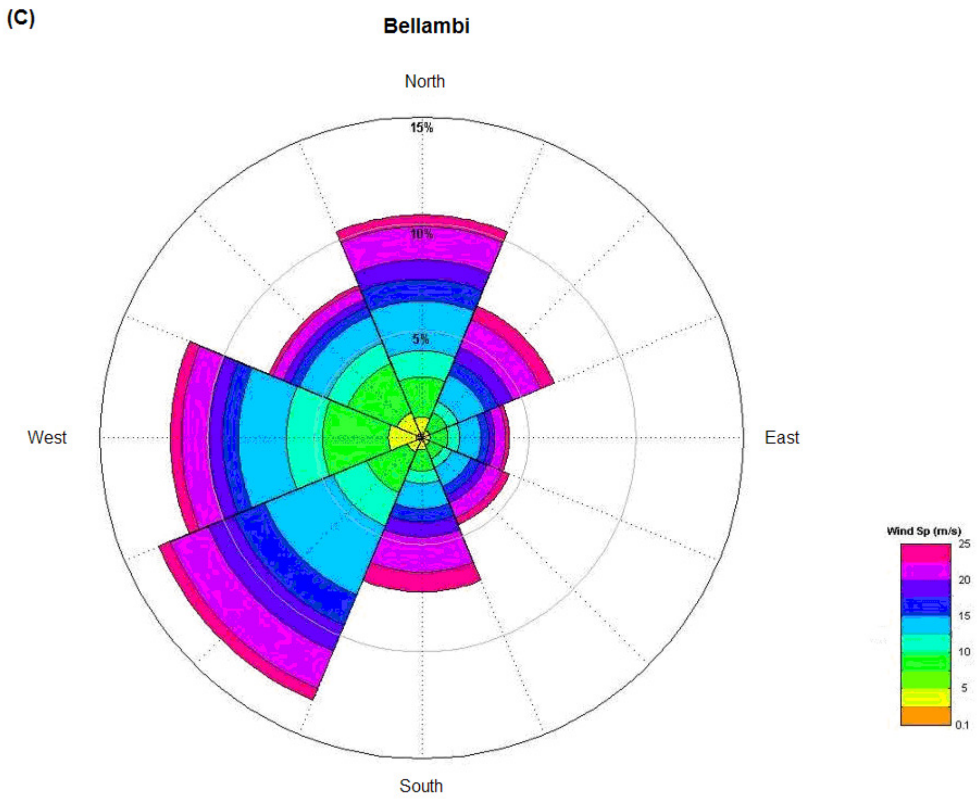


Figure 3.1 Wind roses for (a) Kiama (Bombo Headland), (b) Albion Park and (c) Bellambi (data source: BoM).

3.3 Water Level Data

Two sets of water level data were sourced for this study. Water level data was made available for the permanent tide gauge at the Koonawarra Bay site (**Figure 3.2**) from Manly Hydraulics Laboratory (MHL). This site is just north of the Tallawarra Lands site in Lake Illawarra and data were available for the period from 1/1/1995 to 1/6/2010. Additionally, an intensive data collection campaign also took place from February 2008 to February 2009 (MHL 2009). Water level data was collected at eleven sites around Lake Illawarra and made available for this study by the NSW Department of Environment, Climate Change and Water (DECCW). The most appropriate open ocean tidal gauge is Jervis Bay, 65 km to the south. This water level data will be discussed further in **Section 4.2**.

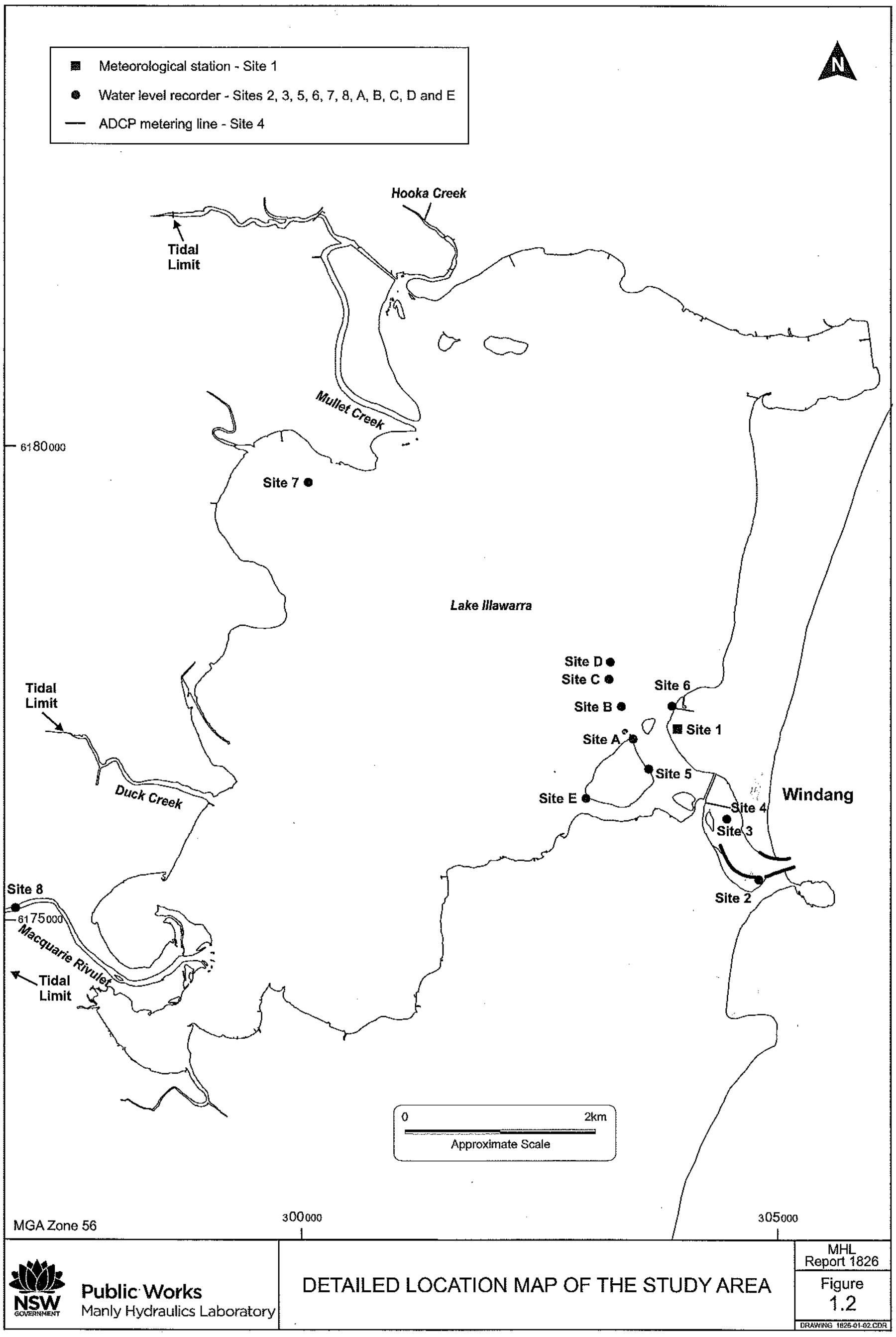


Figure 3.2 Locations of water level data collected (MHL, 2009).

3.4 Bathymetric data

Bathymetric data from a hydrographic surey undertaken in 2008/09 for Lake Illawarra was sourced from the NSW DECCW (**Figure 3.3**). This bathymetry dataset covers the whole of the lake, including the channel and entrance and creeks feeding into the lake. The bathymetry was incorporated in the spectral wave model used for this study (**Section 4.4**). Additionally, offshore bathymetry to a depth of 100 m was digitized from the Hydrographic Chart AUS818: Jervis Bay to Port Hacking and incorporated into the hydrodynamic model used for this study (**Section 4.5**).

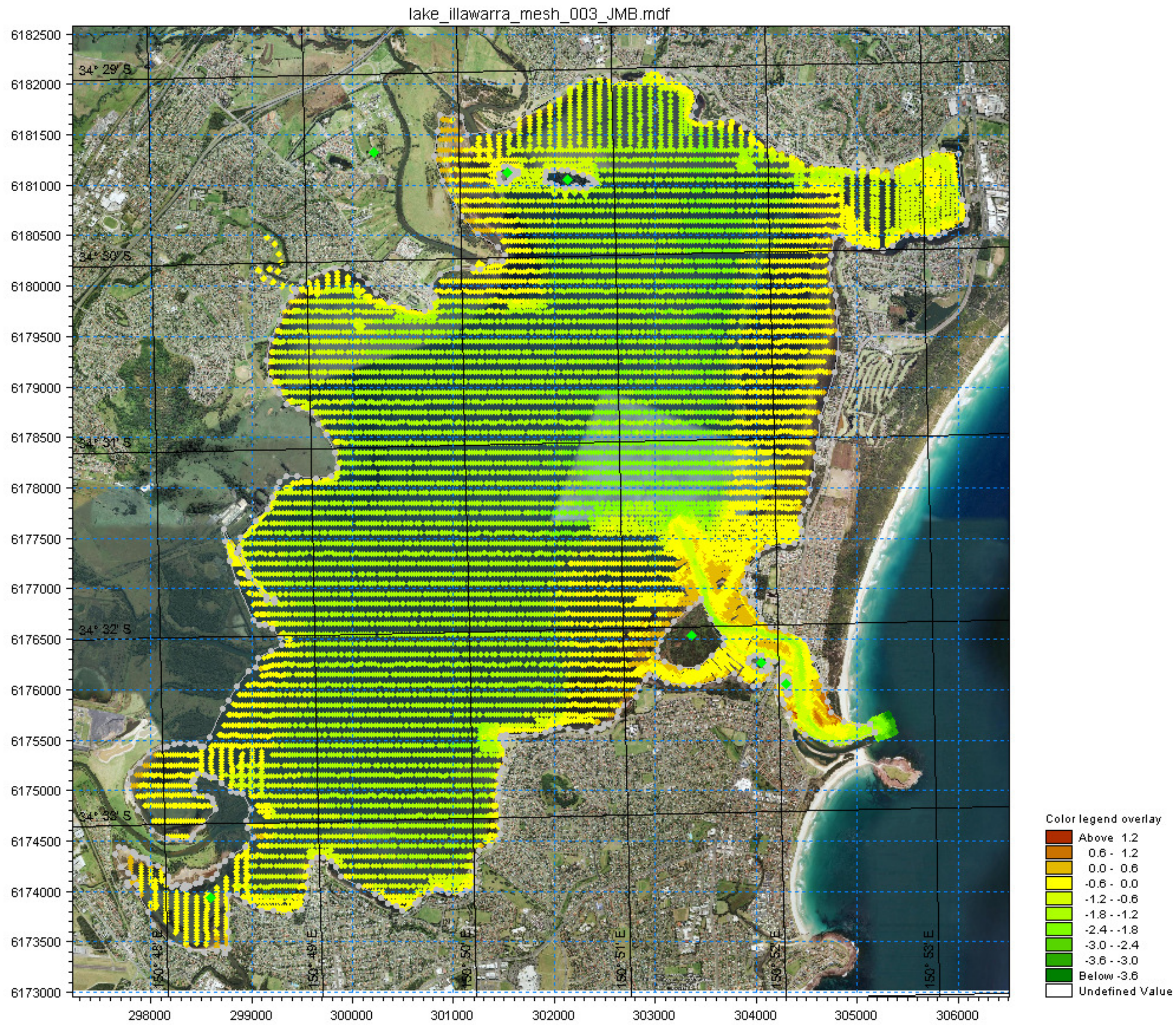


Figure 3.3 Lake Illawarra bathymetry (data source: DECCW 2008/2009).

Sediment infilling of Lake Illawarra has occurred for thousands of years. However, sedimentation rates appear to have accelerated in recent years. This is indicated by the rapid growth of deltas at the mouth of streams, broadening mudflats around the foreshore and shallowing of the bays. Sources of infilling includes material from eroding creeks and tributaries, clearing of vegetation for farming, urbanisation and industrial development (WBM 2003).

The average depth of Lake Illawarra is approximately 1.9 m PKHD (Deepers *et al.* 1994). More than 50 % of Lake Illawarra has a water depth of less than 2 m PKHD. Areas which are especially heavily shoaled include Mullet Creek, Koona Bay, Haywards Bay, Mullet Creek, Griffins Bay and the area around the lake’s entrance.

The Public Works Department (PWD) has conducted several bathymetric surveys of Lake Illawarra (1885, 1923, 1949, 1955 and 1988). Using data from these surveys, WBM (2003) assessed the changes in lake bed levels across a number of transects in Lake Illawarra (refer **Figure 3.4** taken from PWD 2003). Depth soundings (levels) were correlated to zero of the tide gauge at Port Kembla. The Port Kembla Authority has indicated that the zero of the tide gauge is equivalent to Low Water Ordinary Spring Tides (LWOST) which has since become known as the Port Kembla Harbour Datum (PKHD). The PKHD is 0.872 m below Australian Height Datum (AHD). Most transects showed a general shallowing of the lake over the last century (WBM 2003).

Figure 3.4 Bathymetric transect lines (reproduced from PWD 2003).

Summary of bathymetry results across transects (PWD 2003):

Transect 1: Shows dynamic nature of entrance with a 1.5 m difference seen at locations along transect. Difference in depths considered to be due to natural cyclic variation in entrance shoaling rather than sedimentation.

Transect 2: Lake depths decreased by 10 cm from 1923 – 1988 providing sedimentation rates of 1.5 and 3.8 mm/year respectively. Average sedimentation rate of 1.5 mm/year for Transect 2.

Transect 3: Transect crosses outlet for Duck Creek. Lake depths indicate that fluvial delta has extended 150m further into the lake since 1923 - 1945 and 1955 - 1988. The large change suggests massive deposition from storm events between 1945 and 1955. Shallowing near Gerongar Pt.

Transect 4: Largest changes near Yangar Pt. Lake depths decreased by 6 to 36cm from 1923 to 1988 providing sedimentation rates of 0.9 and 5.5 mm/year respectively. Average sedimentation rate of 2.5 mm/year for Transect 4.

Transect 5: Transect near outlet for Mullet Creek. Lake depths here shallowed by >1 m indicating movement of fluvial delta by approximately 400 m towards Burry Point between 1923 and 1988. Average sedimentation rate of 1.8 mm/year for Transect 5.

Transect 6: Lake depths decreased by 6 to 22 cm from 1923 to 1988 providing sedimentation rates of 0.9 and 3.4 mm/year respectively. Average sedimentation rate of 2.1 mm/year for Transect 6.

Transect 7: Lake depths appear to have remained constant or decreased by up to 45 cm from 1923 to 1988 providing a sedimentation rate of 6.9 mm/year. Average sedimentation rate of 2.8 mm/year for Transect 7.

3.5 Review of Historical Aerial Photographs

Aerial photographs of the Tallawarra Lands site and the surrounding lake and suburbs were made available for this study. The photographs used in the review of changes in the shoreline position in **Section 4.6** were from 1948, 1955, 1966, 1977, 1987, 1993, 1998, 2004 and 2008. These photographs were registered to the geo-referenced 2008 image. The historical change of the lake as a whole, including the dynamics of the entrance channel, has previously been assessed by PBP (2005) amongst others.

Figure 3.5 presents a photographic timeline of the western Lake Illawarra shoreline. Visual analysis of these images indicate that, other than anthropogenic changes as a result of the power station construction, there has been little discernable change of the shoreline configuration of the western side of the lake since 1948.

The Tallawarra Power Station started operation in 1954 and the inlet channel and the breakwater for the outlet channel are evident in the 1955 photographs onward. Land was reclaimed and protected by a rock revetment lakeward of the cooling water channel. The adjacent shorelines have not significantly altered from the 1948 position by the construction of the breakwater. The outline of rocky

Tallawarra, Wollingurry and Pentarong Points (from north to south) has remained stable. The configuration of the bays between these points has also remained stable. No evidence of progradation or recession (updrift and downdrift of the constructed breakwater, respectively) indicates there is no significant alongshore sediment transport processes at this location.

The main discernable change over time is in the continued deposition and distribution of the delta shoals at the mouths of Duck Creek and Macquarie Rivulet and on the northern shoreline of Haywards Bay.

The general stability of the western shoreline of Lake Illawarra indicates that the shoreline is in equilibrium with the prevailing tidal and wave hydrodynamic regimes and this area is generally a low energy environment experiencing few extreme events or seasonal fluctuations. There is a net influx of sediment from fluvial sources, as opposed to sediment loss, on this side of the lake.

1948

1955

1966

1977

1987

1993

2004

2008

Figure 3.5 Samples of historical aerial photographs at the Tallawarra site

3.6 Survey Data

Survey data of the topography of the Tallawarra Lands site and surrounds were made available by TRUenergy for this study. The survey data comprised of 0.5 m contours generated from an aerial laser survey of the area made in 2005 by AAM (**Figure 3.6**). The land south of Duck Creek has low elevations and gradient, with elevations generally lower than 2.0 m relative to Australia Height Datum (AHD), rising to 2.5 m AHD around the edge of the ash dams, before rising further towards the western side of the site. The foreshore north of Duck Creek is steeper in gradient, with the 2.5 m AHD contour generally lying close to the shoreline. Elevations at the northern side of the site rise to 105 m AHD on the summit of Mt Brown.

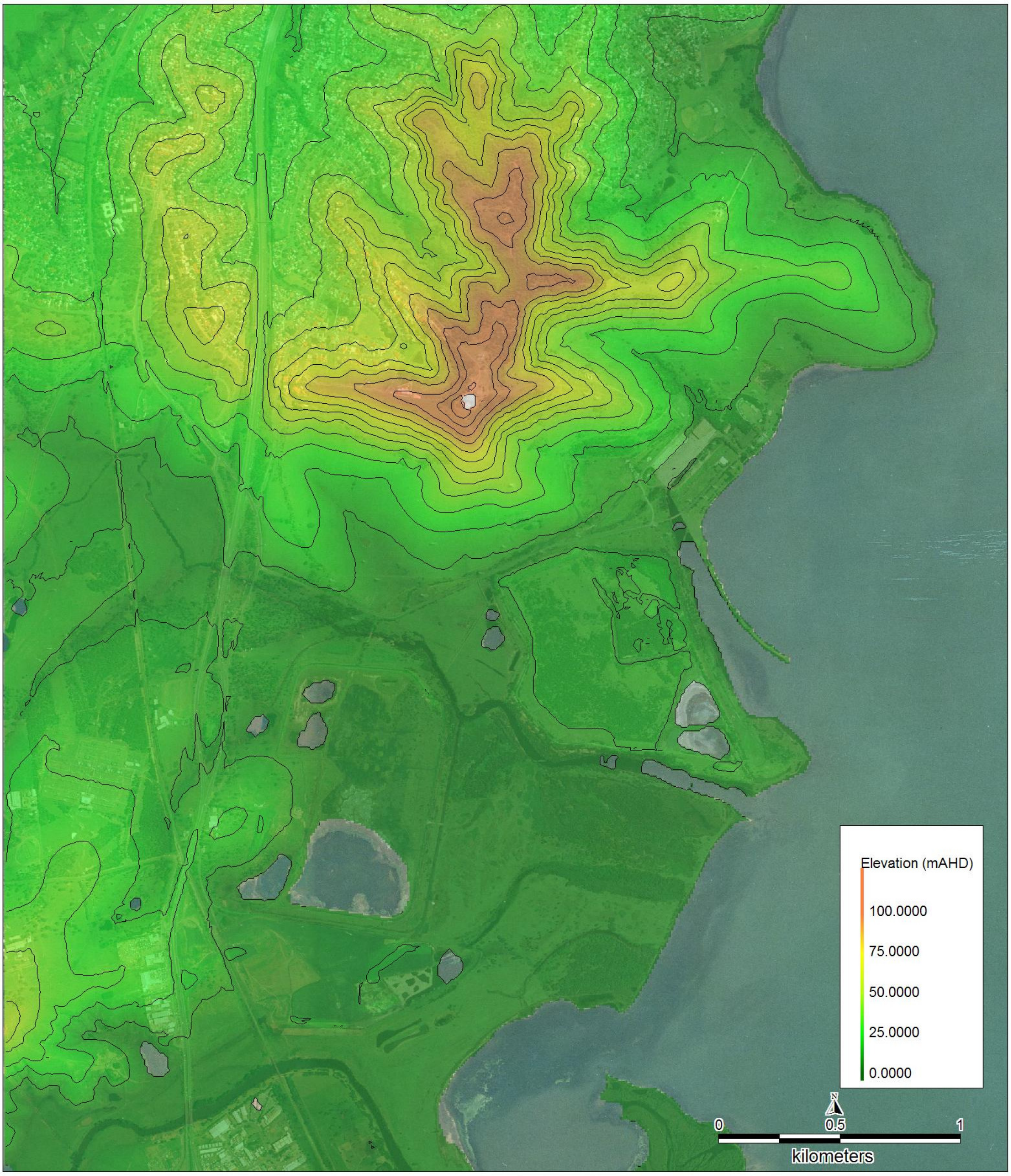


Figure 3.6 DTM and 10 m contour lines across the Tallawarra Lands site.

3.7 Bottom Sediments

3.7.1 Sediment Characterisation

Depers *et al.* (1994) investigated the sediment characteristics of the Lake (refer to **Figure 3.7**). Much of the sediment in Lake Illawarra is mud, with only small areas of sand occurring. Soft black muds constitute 54 % of the lake bed, lithic sand sediments cover 26 % and quartzone sediments 20 %. Those areas which are sandy tend to be less than 1 m deep, with wind induced wave currents likely to be responsible for preventing the settlement of finer particles in these locations. Such sandy areas include the entrance, the Windang Peninsula area and the deltas of the major creeks (i.e. Macquarie Rivulet, Mullet Creek and Ducks Creek). The deeper areas of the lake are typically mud, and since European settlement black organic 'ooze' has formed in many of the deeper sections of the lake, a result of increased inputs of silts, clays and organics (WBM 2003). Small rocky outcrops / headlands occur at a number of locations including Tallawarra Point and Wollingurry Point near the Tallawarra Lands site.

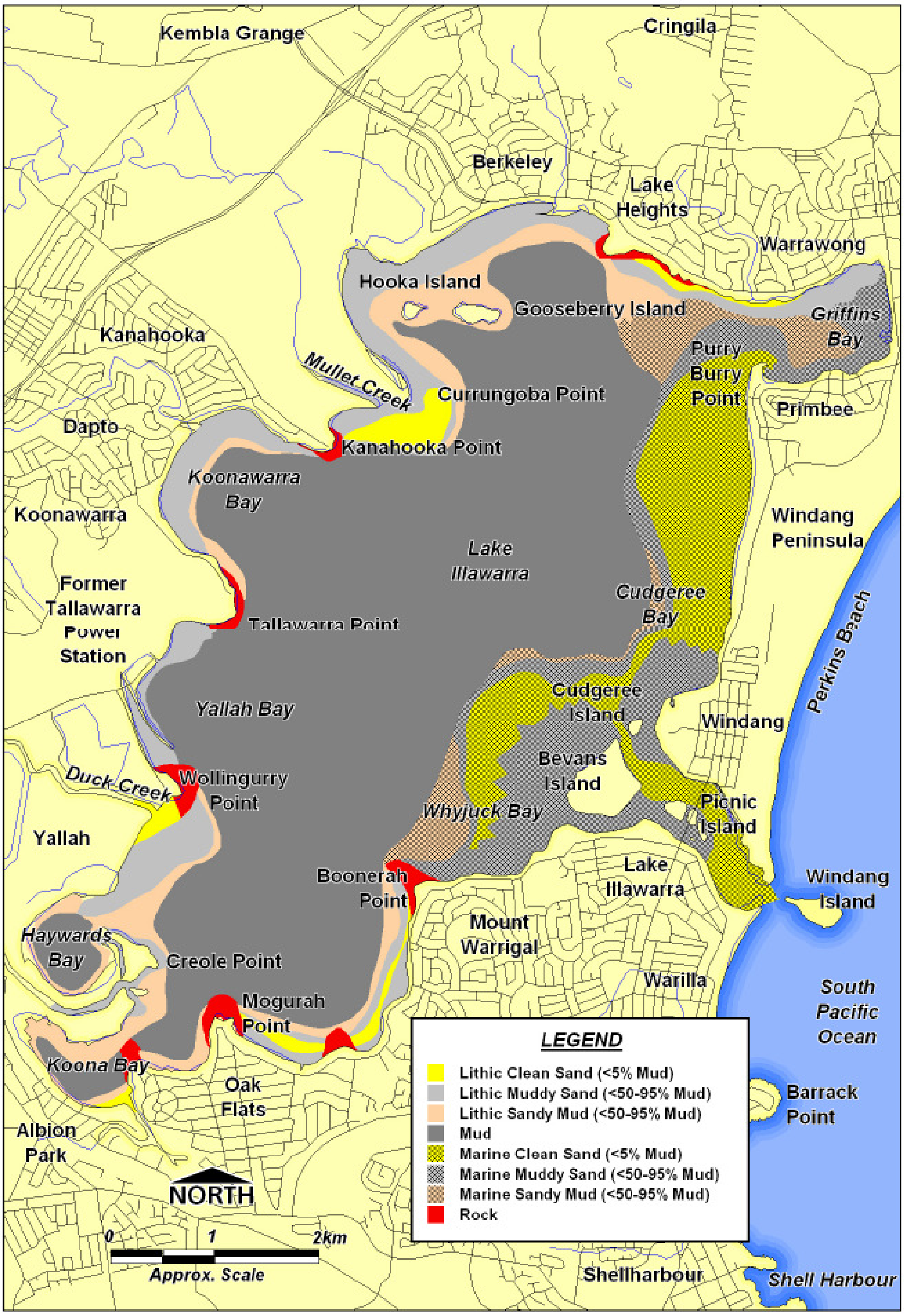


Figure 3.7 Sediments of Lake Illawarra (taken from WBM 2003).

3.7.2 Sedimentation Rates

The formation of deltas at the mouths of streams entering the lake, the broadening of mudflats around the foreshore and shallowing of bays all provide evidence of high sedimentation rates in Lake Illawarra. A number of obvious deltas exist on the western side of the lake including the mouths of Hooka Creek, Mullet Creek, Brooks Creek, Wollingurry Creek and Macquarie Rivulet.

In 1985, Hean and Nanson estimated that approximately 100,000 m^3 /year of material has been deposited into the Lake from its creeks during the 20th century. Pre-European long term rates (i.e. over the last 8000 years) were estimated to be significantly lower, at between 25,000 to 50,000 m^3/year (Hean & Nanson 1985). The recent increase in sedimentation is thought to be a result of clearing in the catchment area. During times of flood the rate of sedimentation increases substantially (WBM 2003). For example, during the February 1984 flood it was estimated that approximately 270,000 m^3 of sediment was transported into the lake via stream runoff (Hean & Nanson 1985).

In 2000, modelling by Forbes Rigby provided annual sediment loads to the lake from various sub-catchments around Lake Illawarra (**Table 3.3**). Coarse sediments contained in stormwater tend to settle within the creeks or at their mouths forming fluvial deltas in the lake. Finer sediments are carried further into the main section of the Lake. Forbes Rigby (2000) estimated an average annual sediment volume of approximately 4,100 m^3/year for the lake, significantly lower than those rates estimated by Hean and Nanson (1985) (100,000 m^3/year). The Forbes Rigby calculations (based on stormwater input) may have overlooked other sources of sediment input e.g. bed loads from tributaries resulting from creek bank erosion, bed erosion and atmospheric deposition). Littoral processes of the sea can also provide sediment input. For example, PWD (1982) estimated that approximately 110,000 m^3 of sand is transported into and out of the entrance annually by tidal currents, only 1,000 m^3/yr of which is carried up the channel and deposited on the tidal delta.

Table 3.3 Annual sediment loads by catchment in Lake Illawarra (kg/year) (Forbes Rigby 2000).

Sub-catchment	Average Year (kg/yr)	Wet Year (kg/yr)	Dry Year (kg/yr)
Lake Illawarra North	900,930	1,293,194	471,280
Mullet Creek	1,305,235	1,827,777	691,864
Duck Creek	1,020,390	1,431,511	540,166
Macquarie Rivulet	1,220,708	1,765,676	642,680
Lake Illawarra South	912,643	1,307,159	476,268
Totals (tonnes / year)	**5,368**	**7,624**	**2,822**

WBM (2003) reports that average infill rates, assuming uniform sediment load deposition across the Lake, as follows:

- Preceding 8000 years 0.7 - 1.4 mm/year
- Last century 2.9 mm/year
- 1984 flood 7.7 mm (in a single event)
- Present rates 2 – 3 mm/year

These rates are consistent with sedimentation rates that have been estimated based on carbon dating and trace element analysis given by Depers *et al.* (1994):

- Pre-European settlement (i.e. 25,000 – 50,000m^3/year) 0.3 – 0.7 mm/year
- Last Century (i.e. 100,000m^3/year) 4.1 – 11 mm/year

The highest sedimentation rates were recorded close to Macquarie Rivulet delta (21 mm/year) and the lowest in Koona Bay (4.1 mm/year).

In addition to fluvial inputs, industrial activities since 1817 have contributed significant minor and major particulate material into Lake Illawarra, thus contribute to the acceleration of sedimentation rates. Quarry spoil, fly ash, heavy metals and other pollutants have all been deposited in and around the Lake (WBM 2003). Depers *et al.* (1994) suggested that 7% of recent sedimentation could be attributed to Port Kembla industry, with approximately equal contribution from other industries to the north east of the lake and the former coal-fired Tallawarra Power Station.

High sediment loads have, and continue to cause sedimentation of creek mouths, smothering of seagrass, high turbidity after rainfall and high pollutant loads entering the lake, thus has a considerable impact on the ecological and amenity value of the lake.

4 COASTAL PROCESSES

4.1 Summary of Coastal Processes

In this section, the coastal processes prevalent along the study area coastline are outlined. In particular, details are provided on:

- tides (**Section 4.2**);
- entrance stability (**Section 4.3**);
- wave climate (wind generated) (**Section 4.4**);
- elevated still water levels (**Section 4.5**);
- flooding (**Section 4.6**);
- potential sediment transport mechanisms and rates, and foreshore stability (**Section 4.7**); and
- impacts of climate change (**Section 4.8**).

4.2 Tides

On the NSW south coast, the average open ocean tidal range (or difference between high and low tides) is around 1.0 m. This difference can be as small as 0.3 m or up to 2.0 m for king tides (Lake Illawarra Authority 2010). However, the behaviour of tides in Lake Illawarra is different to that in the ocean. Lake Illawarra is connected to the Pacific Ocean by a long shallow entrance channel which has limited tidal flow capacity and acts as a friction device that slows or limits tidal exchange. Due to the nature of the channel, very little tidal variation occurs in the lake, and the tidal range is considerably attenuated with distance along the channel to the main body of the lake. The level of attenuation is related to the degree of shoaling at the mouth of the channel.

Tidal exchange is the primary driver of water levels in the Lake (PWD 1982). The constricted nature of the entrance channel causes the mean lake level to be higher than the mean sea level (Lake Illawarra Authority 2010). In the absence of freshwater inflows, typical water levels in the Lake were about 0.20 - 0.25 m higher than in the ocean (median level = 0.21 m AHD) before the training walls were constructed. The lake level has been recorded to reach as high as 1.9 m AHD prior to training wall construction, and as low as -0.225 m AHD when closed. Lake Illawarra also experiences tidal pumping, where the water level varies further over a spring-neap tidal cycle as the ebb tide does not completely exit the lake before the next flood tide occurs.

4.2.1 Water levels prior to training wall construction

Prior to the installation of the southern training entrance wall in 2001, the lake's entrance condition was as follows (PWD 1982):

- Closed – 10% of time
- Very heavily shoaled – 20% of time
- Heavily shoaled – 50% of time
- Moderately shoaled – 15% of time
- Scoured – 5% of time

PWD (1982) found the mean tidal range in the lake to be 0.02 m. Tidal variations change with the degree of shoaling at the entrance of the lake. Between 1993 and 2000, Manly Hydraulics Laboratory (MHL) recorded tidal ranges of between 0.0 m and 0.1 m, corresponding to periods of entrance closure and scour, respectively. Tidal ranges of >0.05 m occurred less than 10 % of the time, as did a zero tidal range (i.e. closed entrance). Water levels in the lake were higher than 0.1m AHD for 90 % of the time, whilst levels in excess of 0.5 m AHD occurred less than 2 % of the time.

Based on MHL data, the tidal ranges for different entrance conditions (prior to entrance training) were as follows (WBM 2003):

- Closed entrance 0.00 m
- Very heavily shoaled 0.01 m
- Heavily shoaled 0.02 m
- Moderately shoaled 0.04 m
- Scoured 0.07 m

4.2.2 Water levels following training wall construction

Following the training wall construction at the lake entrance, the tidal range within Lake Illawarra has increased and the average lake level has decreased to +0.11 m AHD in the main body of the lake. MHL (2009) found that the estuary experiences maximum tidal flows very close to the time of the high and low tide, and the minimum tidal flows occur close to mid-tide, using data described in **Section 3.1**. The tidal limits are located in the creeks feeding the lake: Duck Creek, Mullet Creek and Macquarie Rivulet. From data measured in 2008 and 2009 (refer **Figure 3.2** for locations), MHL (2009) found a decline in tidal range along the estuary, with the tidal range (higher high water (HHW) – Indian Spring Low Water (ISLW)) varying from:

- 1.82 m at Jervis Bay;
- 1.56 m (phase lag 5 min) just inside the channel entrance at Site 2;

- 0.97 m (phase lag 16 min) at the permanent tide gauge at Site 3;
- 0.50 m (phase lag 42 min) at Site 5;
- 0.20 m (phase lag 123 min) at Site 6 in Cudgeree Bay;
- 0.16 m (phase lag 196 min) at the permanent tide gauge at Site 7 in Koonawarra Bay; to
- 0.15 m at the permanent tide gauge at Site 8 in Macquarie Rivulet.

Koonawarra Bay (Site 7) is closest to the Tallawarra Lands site. Current velocities were also measured as part of the MHL campaign on 10/3/2008, and at Site 4 in the channel, the peak tidal velocity on the flood tide was 0.72 m/s and on the ebb tide was 0.84 m/s (MHL 2009).

Tidal planes and ranges were calculated by MHL (2009) using the Foreman method of tidal analysis (Foreman 1979) and are presented in **Tables 4.1 and 4.2**, respectively. These tidal planes do not account for shallow water effects or tidal pumping (a fortnightly cycle increasing water levels on the spring tides and decreasing water levels at neap tides), and MHL (2009) acknowledge that these planes should not be used for high water boundary definition. **Figure 4.1** demonstrates why these tidal predictions for Site 7 (Koonawarra Bay) should not be used to define the high water boundary, due to mean tide level fluctuations.

Table 4.1 Lake Illawarra tidal planes (Source: MHL 2009).

Tidal Planes	Ocean	Entrance Channel			Lake Illawarra		Macquarie Rivulet
	Site 0 (m AHD)	Site 2 (m AHD)	Site 3 (m AHD)	Site 5 (m AHD)	Site 6 (m AHD)	Site 7 (m AHD)	Site 8 (m AHD)
HHW (SS)	1.01	0.91	0.61	0.43	0.24	0.21	0.24
MHWS	0.65	0.59	0.41	0.32	0.17	0.16	0.19
MHW	0.53	0.49	0.35	0.29	0.17	0.15	0.19
MHWN	0.42	0.40	0.30	0.26	0.16	0.15	0.18
MTL	0.05	0.08	0.10	0.16	0.13	0.13	0.16
MLWN	-0.32	-0.23	-0.10	0.07	0.10	0.10	0.14
MLW	-0.44	-0.33	-0.16	0.04	0.09	0.10	0.14
MLWS	-0.55	-0.42	-0.21	0.01	0.08	0.09	0.13
ISLW	-0.81	-0.65	-0.36	-0.07	0.04	0.05	0.10

HHW(SS) – Higher High Water (Spring Solstices)
MHWS – Mean High Water Springs
MHW – Mean High Water
MHWN – Mean High Water Neaps
MTL – Mean Tide Level
MLWN – Mean Low Water Neaps
MLW – Mean Low Water
MLWS – Mean Low Water Springs
ISLW – Indian Spring Low Water

Table 4.2 Lake Illawarra tidal ranges (Source: MHL 2009).

Tidal Ranges	Ocean	Entrance Channel			Lake Illawarra		Macquarie Rivulet
	Site 0 (m AHD)	Site 2 (m AHD)	Site 3 (m AHD)	Site 5 (m AHD)	Site 6 (m AHD)	Site 7 (m AHD)	Site 8 (m AHD)
HHW (SS) to ISLW	1.82	1.56	0.97	0.50	0.20	0.16	0.15
Mean Spring	1.20	1.01	0.62	0.30	0.09	0.07	0.06
Mean	0.97	0.82	0.51	0.25	0.08	0.06	0.05
Mean Neap	0.74	0.62	0.40	0.20	0.06	0.05	0.04

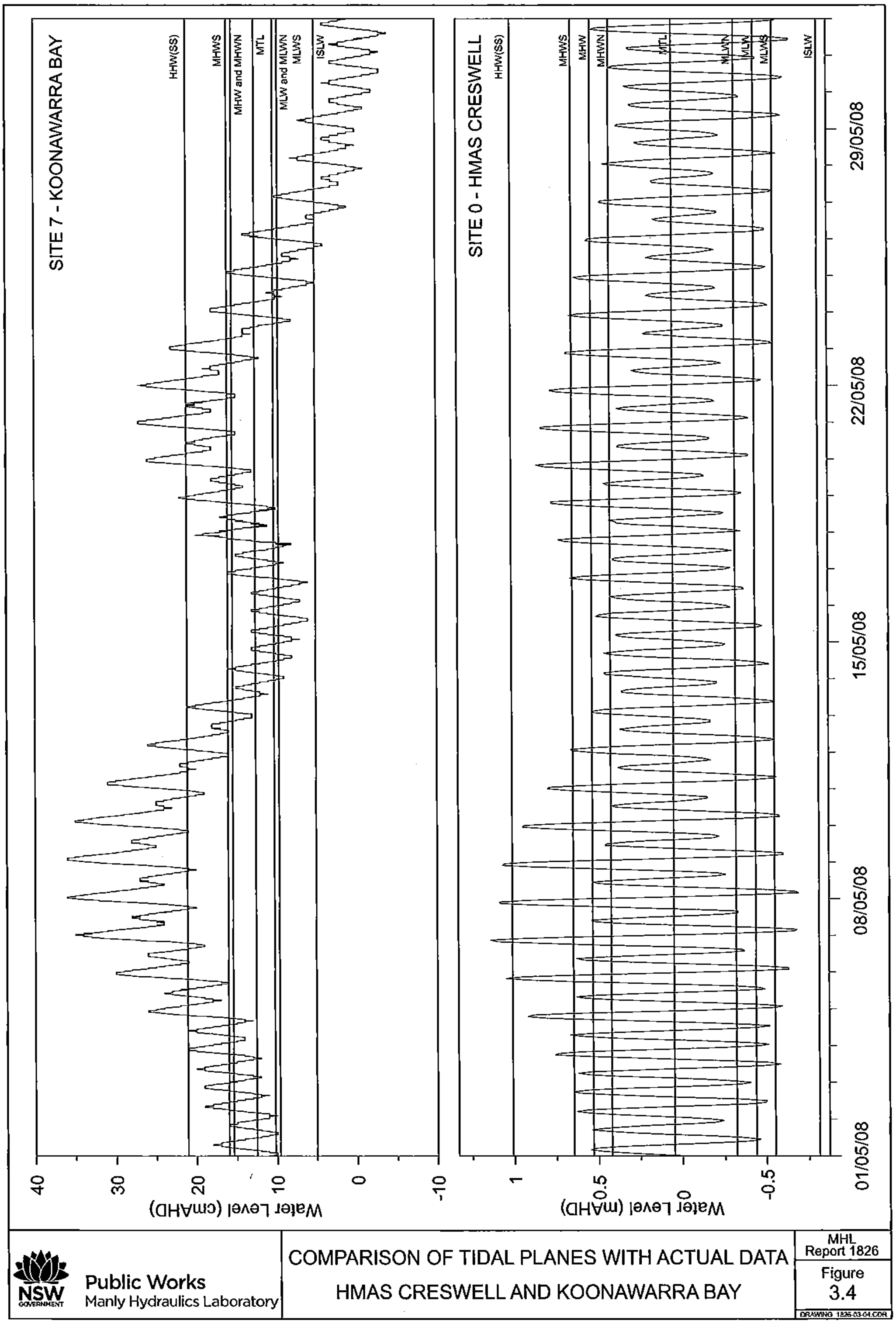
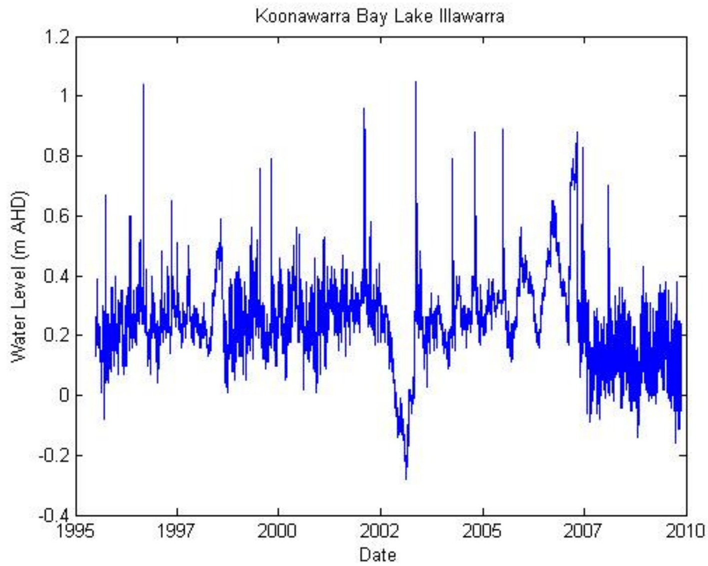

SITE 7 - KOONAWARRA BAY
SITE 0 - HMAS CRESWELL
HHW(SS)
MHWS
MHW and MHWN
MTL
MLW and MLWN
MLWS
ISLW
MHW
MHWN
MLWN
MLW
Water Level (cmAHD)
Water Level (mAHD)
01/05/08
08/05/08
15/05/08
22/05/08
29/05/08
Public Works
Manly Hydraulics Laboratory
NSW GOVERNMENT
COMPARISON OF TIDAL PLANES WITH ACTUAL DATA
HMAS CRESWELL AND KOONAWARRA BAY
MHL Report 1826
Figure 3.4

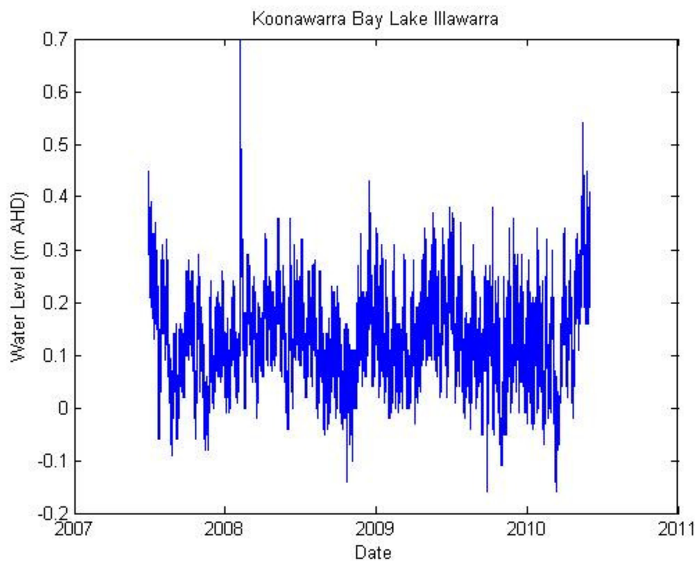
Figure 4.1 Comparison of tidal planes with actual tidal level (MHL 2009, fig 3.4).

In order to define an appropriate high water boundary for use in this study, the long-term Koonawarra Bay water level time series from January 1995 to June 2010 was analysed (**Figure 4.2a**). The variation in the lake level over multiple time-scales is evident. The short-term spikes in the data are due to freshwater flooding events. There was a change in the behaviour of the water levels in the lake following the entrance works in 2007; as found by MHL (2009), the average lake level fell and the lake level has experienced less elevated water level events as the entrance has been open since 2007 (**Figure 4.2b**).

The cumulative frequencies of water levels since July 2007 are plotted (**Figure 4.3**). The 99^{th} percentile is 0.36 m AHD. It is assumed that water level events exceeding this level are due to freshwater flooding, such as the spike of 0.70 m occurring in February 2008. This level of 0.36 m is applied in this study as the extreme tidal water level, and contains variation due to the tide as well as tidal pumping and long-term variation in the lake level.



(a)



(b)

Figure 4.2 Plot of water levels measured at Koonawarra Bay, Lake Illawarra for the period (a) 1995 to 2010, and (b) 2007 to 2010 (Supplied by MHL).

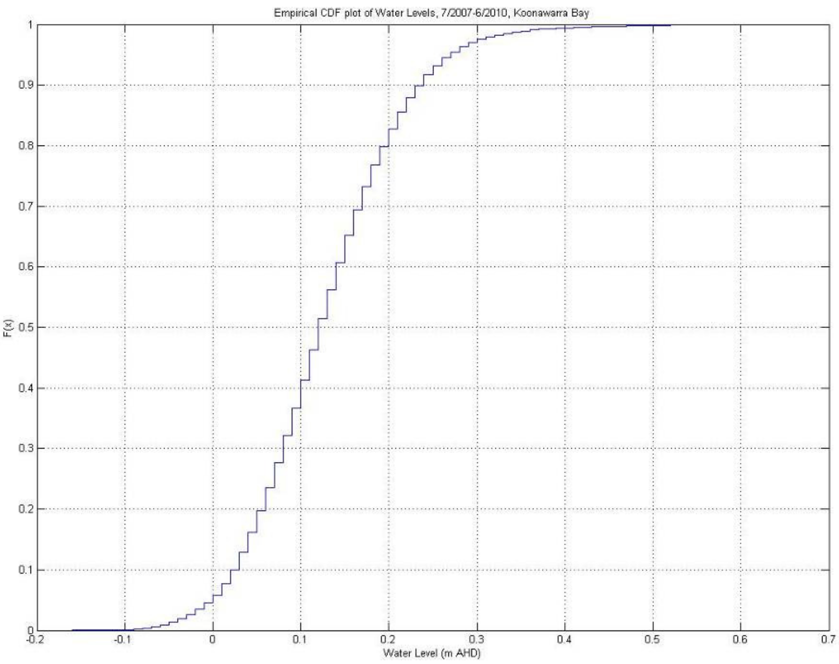


Figure 4.3 Empirical cumulative frequency plot of water levels at Koonawarra Bay, July 2007 to June 2010.

4.3 Entrance Stability

The hydrodynamics of Lake Illawarra and its entrance has been influenced by construction of the entrance training walls. The increase in hydraulic efficiency in comparison to the natural entrance state has enhanced the propagation of the tidal signal into the estuary. The long term behaviour of the lake entrance and channel morphology is unclear, given the limited amount of time since the construction works at the entrance. However, it is thought that the narrow width of the channel limits its potential to exhibit instability and enter a scouring mode where the tidal prism and range may continue to increase over time. Instead, it is thought more likely that once adjusted, the lake entrance will continue shoaling and further closures of the entrance will occur unless dredging continues.

The hydraulic stability of a tidal inlet can be assessed through simplified empirical measures, such as an Escoffier curve (Escoffier, 1940). These equations, utilising the oceanic and lake tidal range and lake and channel dimensions as inputs, were applied to the present configuration of Lake Illawarra. It was found that the dimensions of Lake Illawarra, particularly the very shallow nature of the channel, and the small tidal range in the lake compared with the ocean meant that this generalised analytical approach failed to produce a meaningful curve, as it was not calibrated for such an environment.

The Keulegan Repletion Coefficient (*K*), which indicates the amount by which the tidal inlet is filled by the tide in a tidal cycle (Keulegan, 1967), for Lake Illawarra was calculated to be 0.1. This value lies on the lower boundary of the values of *K* for which empirical relationships are defined. Tidal inlets with $K < 0.3$ have a long tidal phase lag and tend to be relatively shallow with a single inlet (Jarrett, 1975), as is the case for Lake Illawarra. As *K* decreases, the maximum ebb and flood currents occur at the time of high and low tide, as opposed to at the time of the mid-tide level. Therefore, inlets with low *K* values are likely to be ebb-flow dominant, since the strongest flood currents occur when the water is deepest, leading to more distributed flow and less sediment transport potential. During the maximum ebb flow, the water depth is lowest and flow tends to be more channelized with greater sediment transport potential (Mota Oliveira 1970). In addition, bay superelevation (the water level in the bay above the ocean) increases as *K* decreases, which is caused by the frictional dissipation of the ebb flow compared to the flood flow at low *K* values. The bay superelevation approaches 20 % of the ocean tide range, which was the case in Lake Illawarra prior to entrance works.

The peak tidal current velocities measured in the channel by MHL (2009) were 0.72 m/s on the flood tide and 0.84 m/s on the ebb tide (MHL 2009). These values are lower than the empirically-derived 1.0 m/s current velocity required for a tidal inlet to maintain or scour its channel (Dean 1971). This indicates that the channel is more likely to experience shoaling as opposed to scour in the absence of an extreme freshwater flow event. Furthermore, wave breaking processes at the entrance during more extreme oceanic events favour the influx of sediment and subsequent shoaling of the entrance compartment.

4.3.1 Future Variation in Tidal Range in response to Sea Level Rise

Anticipated sea level rise also has implications for the stability of the entrance and subsequent tidal water levels in the lake. If the channel and entrance to Lake Illawarra continue in a shoaling mode (as anticipated), the channel morphology is likely to keep pace with sea level rise through deposition of marine sands and that variations to the tidal range due to sea level rise will be small.

Further speculation on the potential change to the tidal range would require detailed hydrodynamic and morphological numerical modelling and is beyond the scope of this study. An assumption is made that the tidal range will stay close to its present magnitude under sea level rise in the absence of further engineering works or dredging in the channel. However, it must be noted that dramatic changes in tidal range can result in tidal inlets experiencing disruption to their equilibrium state, and such changes would present an issue for the entire lake foreshore.

4.4 Wave Climate (wind generated)

Lake Illawarra experiences wind-generated waves. The constricted nature of the entrance and channel means that ocean swell waves do not propagate into the main body of the lake. The literature review did not reveal any previous study of the wind wave climate within Lake Illawarra. In order to characterise the lake's wind wave climate, a spectral wave model was established. The MIKE 21 SW wave model, part of Danish Hydraulic Institute's (DHI's) coastal modelling system, was used for the wave modelling. MIKE21 SW is a spectral wind-wave model that simulates the growth, decay and transformation of wind generated waves.

The representative wave climate at the Tallawarra Lands site was hindcast using long term measured wind data from the BoM to force the wave model. Since tides and currents are not of high magnitude, and as there is no penetration of ocean waves through the channel into Lake Illawarra, the incident wave climate at the Tallawarra Lands site is a direct consequence of the local wind climate. Water levels were held constant at mean lake level.

Design significant wave heights (H_s) and peak wave periods (T_p) for a range of average recurrence interval wind events (e.g. 20, 50 and 100 year ARIs) were also produced from analysis of the long term hindcast wave climate.

The model setup had a flexible mesh domain (**Figure 4.4**). This model was used to determine wave heights at six inshore locations (**Figure 4.5**) for 16 wind directions x 12 wind speeds values to develop wave parameter hindcast matrices for the selected inshore locations. Wind directions used for the base runs included the full 360^o of the compass in 22.5^o increments to make up the 16 directional sectors. Wind speeds used were 10 min averages values ranging from 2.5 m/s to 30 m/s. A typical model result is shown in **Figure 4.6** for wind conditions over the grid as follows:

Wind Speed (W_S) = 25 m/s

Wind Direction (W_D) = 135^o TN

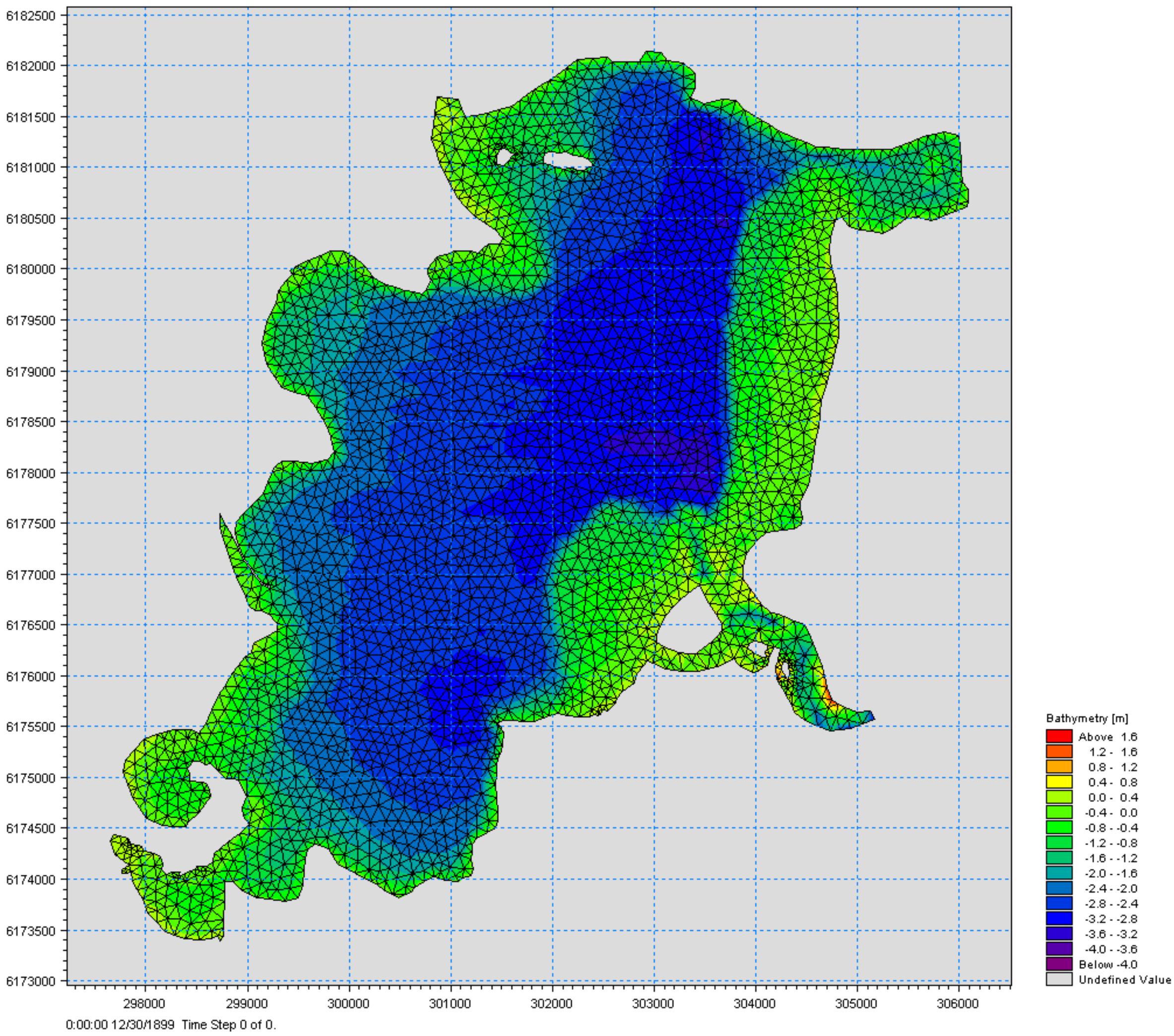


Figure 4.4 Wave model domain showing mesh elements and bathymetry.

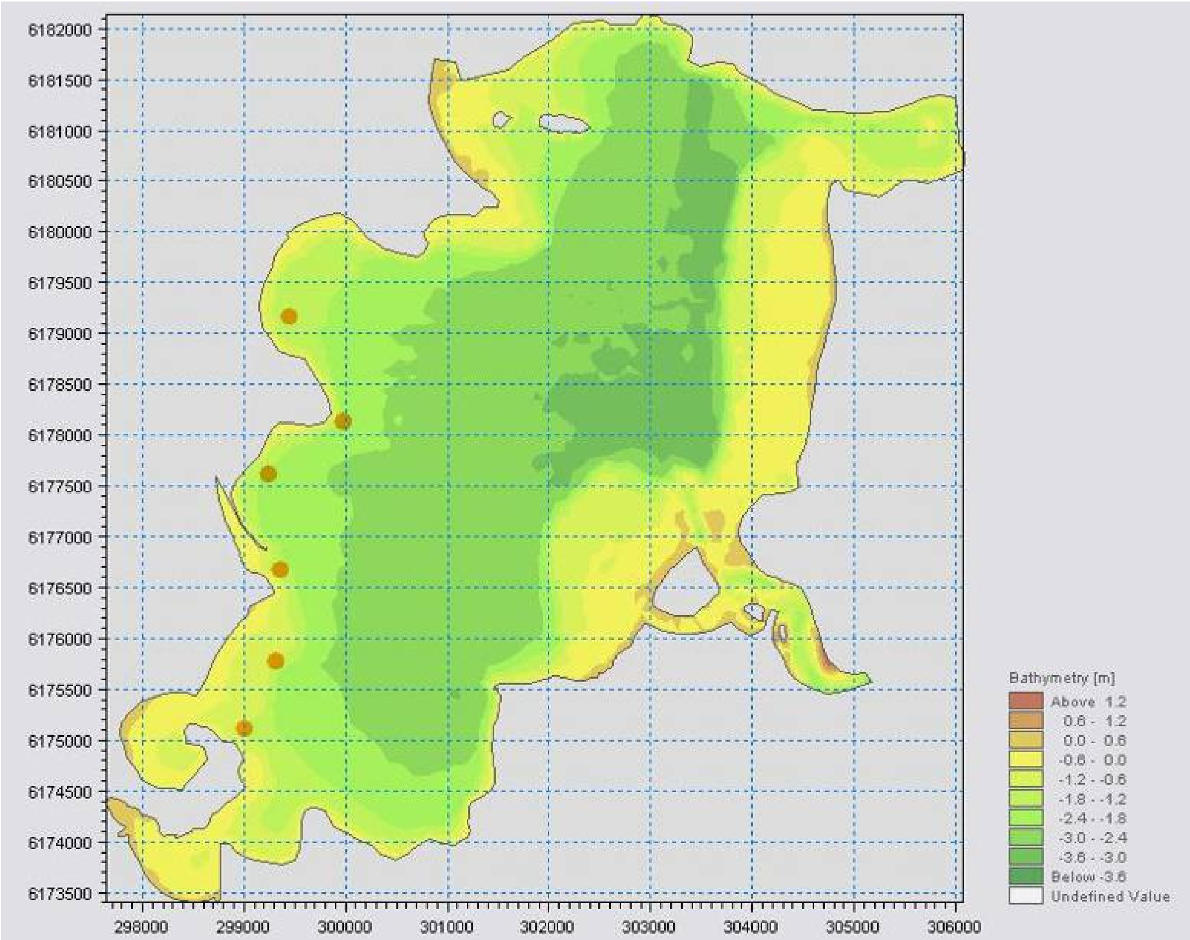


Figure 4.5 Wave model domain showing the location of output points (1 to 6 from south to north).

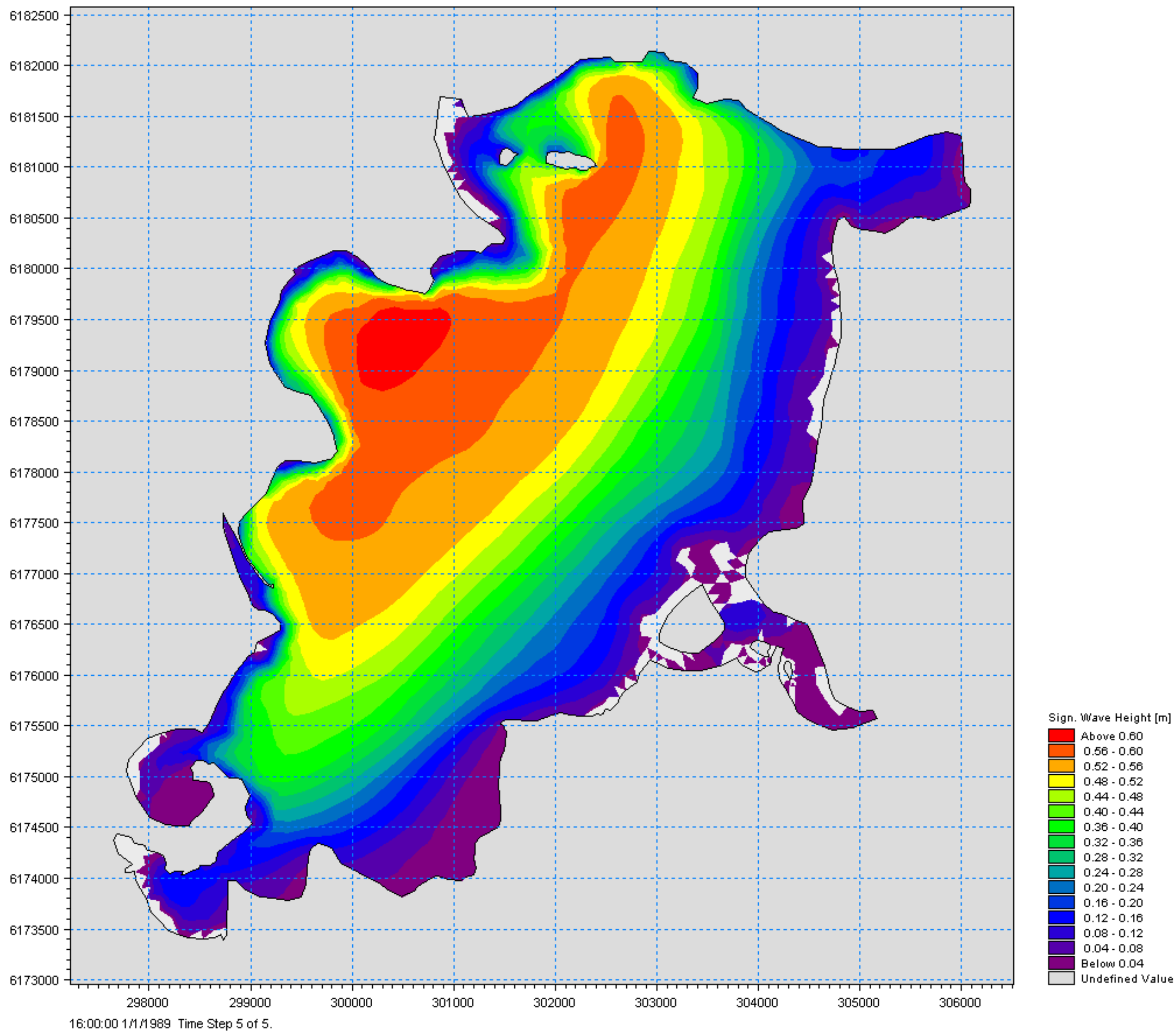


Figure 4.6 Typical wave model output significant wave height (H_s) for a wind speed of 25 m/s and wind direction of 135º TN.

Following the development of the matrices relating windspeed and direction to wave parameters, 21 years of directional wind data for Bellambi (**Section 3.1**) were used to hindcast wave conditions by interpolation of these matrices. This produced 21 years of hindcast wave data at inshore locations that could be analysed to produce existing wave climate statistics for the inshore area at the site.

Analysed wave parameter exceedance data for selected inshore locations are presented in **Table 4.3** below. The wave climate at these selected locations is indicative of conditions to be considered for foreshore overtopping and erosion, and sediment transport.

Table 4.3 Inshore Wave Parameter Exceedance. H_s – Significant wave height. T_p – Peak wave period.

Probability of Exceedance (%)	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
	H_s (m)	T_p (s)	H_s (m)	T_p (s)	H_s (m)	T_p (s)	H_s (m)	T_p (s)	H_s (m)	T_p (s)	H_s (m)	T_p (s)
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
95	0.01	0.26	0.01	0.21	0.01	0.24	0.01	0.21	0.01	0.22	0.00	0.16
99	0.08	1.85	0.08	1.66	0.07	1.71	0.06	1.64	0.06	1.64	0.06	1.64
Max	0.30	2.34	0.36	2.34	0.40	2.33	0.44	2.31	0.48	2.38	0.36	2.31

The wave climate at the Tallawarra Lands site is very low energy as indicated by the 90 % probability of exceedence levels being negligible. The site is protected from westerly winds which are dominant in the winter months and generally have the strongest wind speeds. These winds do not generate waves at this location. The peak wave period is short, around 2.3 seconds for the 99 % exceedence event, given the limited fetch to the site across the lake for wind directions in the easterly sector which do produce waves. The maximum Hs ranges from 0.30 to 0.48 m across the output locations. The shallow bathymetry and flat nearshore slope at the site means that these waves would most likely break and be attenuated before reaching the shoreline.

4.4.1 Extreme value analysis

A Peak over Threshold analysis was conducted on the extreme values of the hindcast wave parameters for each of the output locations and the Generalized Pareto Distribution was fitted the extreme tails. Appropriate thresholds were selected for each parameter at each site, respectively, to give a good distribution fit. The MATLAB toolbox WAFO (Wave Analysis and Fatigue Oceanography) was used for this analysis (Brodkorbt *et al*, 2000). The return levels corresponding to the 10, 5 and 1 % Annual Exceedance Probability (AEP) were extrapolated from the appropriate distribution (**Table 4.4**). The 1% AEP significant wave height varied between 0.33 and 0.51 m and the peak wave period between 2.30 and 2.84 s among the six sites.

Table 4.4 Inshore Wave Parameter AEP. H_s – Significant wave height. H_{max} – Maximum wave height. T_p – Peak wave period. T_m – Mean wave period.

Variable	AEP (%)	Site 1	2	3	4	5	6
H_s (m)	10	0.27	0.31	0.35	0.41	0.41	0.34
	5	0.29	0.33	0.39	0.44	0.45	0.37
	1	0.33	0.38	0.48	0.49	0.51	0.43
H_{max} (m)	10	0.53	0.68	0.72	0.83	0.85	0.73
	5	0.57	0.72	0.77	0.87	0.89	0.76
	1	0.66	0.80	0.87	0.91	0.96	0.89
T_p (sec)	10	2.04	2.12	2.10	2.21	2.28	2.17
	5	2.10	2.23	2.16	2.35	2.38	2.25
	1	2.30	2.69	2.35	2.84	2.59	2.45
T_m (sec)	10	1.98	1.95	2.10	2.01	1.95	2.05
	5	2.09	2.04	2.18	2.16	2.01	2.11
	1	2.50	2.30	2.34	2.71	2.16	2.20

4.5 Elevated Still Water Levels

Elevated still water levels potentially causing inundation of the foreshore within Lake Illawarra are caused by a combination of the following potential factors:

- astronomical tide;
- storm surge: wind set-up and inverse barometric effect;
- wave set-up (*wind driven*);
- flooding (discussed in **Section 4.6**); and
- climate change effects including sea level rise (considered in **Section 4.8**).

4.5.1 Tides

The influence of the tides and tidal pumping on elevated still water levels in Lake Illawarra is discussed in **Section 4.2.1**. The extreme water level accounting for the astronomical tide and also tidal pumping adopted for this study is 0.36 m. This level includes the average elevation of the lake level of 0.11 m above MSL (AHD).

4.5.2 Storm surge

Storm surge is the elevation in still water levels due to two processes: the inverse barometric effect and wind setup. Additionally, for Lake Illawarra, storm surge penetration through the entrance from extreme oceanic events also needs consideration. The Wollongong City Council Coastal Zone Study (Cardno 2010) describes hydrodynamic modelling of the 100 year ARI ocean storm surge event (excluding rainfall or catchment inflows) and the oceanic penetration into Lake Illawarra. At the Tallawarra Power Station site, levels of 0.71, 1.16 and 1.71 m AHD were reported for the 2010, 2050 (+0.4 m sea level rise) and 2100 (+0.9 m sea level rise) scenarios.

The 2010 model result was similar to the result from hydrodynamic modelling undertaken by WorleyParsons as part of this Study which indicated the level was approximately 0.80 m AHD for the present day scenario. Following discussions with Cardno it is considered that the difference of approximately 0.1 m can be attributed to WP modelling using a mean lake level of 0.11 m AHD and the Cardno modelling having a starting lake level of 0 m AHD. For the purposes of this planning study, it is considered prudent to be conservative, and as such the levels of 0.80, 1.25 and 1.80 m were adopted for 2010, 2050 (+0.4 m sea level rise) and 2100 (+0.9 m sea level rise) scenarios.

Still water level responds to atmospheric pressure, through the inverse barometric effect. Water levels increase by approximately 0.01 m for every 1 hPa fall in atmospheric pressure below the mean pressure of 1013 hPa for NSW (Manly Hydraulics Laboratory, 1992). For a severe storm with a minimum central pressure of 993 hPa, the water level setup due to the barometric effect would be approximately 0.2 m. Inverse barometric effect is considered to be implicitly implied by the hydrodynamic modelling results through the use of a maximum water level at the model ocean boundary of 1.5m AHD (the 100 year ARI extreme ocean water level).

Wind set-up generated by a design wind speed of 20 m/s from directions from northeast to south on an average tide water level were also modelled across Lake Illawarra using the MIKE 21 HD model, and results presented in **Table 4.5**. In summary, the design wind set-up ranges from 0.23 m to 0.27 m across the six output points.

Table 4.5 Still water levels (m AHD) generated by wind set-up (wind speed 20 m/s).

Wind Set-up (m AHD) Wind Direction	Output Point 1	2	3	4	5	6
NE	0.15	0.12	0.11	0.10	0.07	0.08
E	0.24	0.23	0.22	0.22	0.20	0.27
SE	0.22	0.22	0.23	0.25	0.24	0.27
S	0.06	0.08	0.10	0.13	0.13	0.16
Max	0.24	0.23	0.23	0.25	0.24	0.27

4.5.3 Wave Set-up and Run-up

Individual waves also cause a temporary increase in water level above the still water level due to the processes of wave set-up and run-up. Wave setup is the superelevation of mean water level caused by wave action. As a general rule, the wave set-up will be 10 to 15 % of the significant wave height (CEM, 2002). In addition, wave run-up is the maximum up-rush of waves above the still water level, and causes temporary inundation of the beach face. Wave run-up was calculated using the formulae of Nielsen and Hanslow (1991), calibrated to NSW open coast beaches. Wave run-up calculations implicitly contain wave set-up, and wave run-up levels should not be added directly to wave set-up.

Although the foreshore at the site is not on the open coast, the nearshore slope is relatively flat and shallow. Accordingly, during conditions when waves break at the site, wave energy will be dissipated and attenuated across a surfzone in a similar fashion to a beach. Therefore it is considered that the use of methods described above is appropriate and suitably conservative for planning purposes.

Based on the significant wave height values found in **Section 4.5**, the wave set-up across the Tallawarra Lands site is estimated as ranging between 0.05 and 0.08 m between the various output points (**Table 4.6**). The wave run-up varied between 0.19 and 0.26 m across the output points.

Table 4.6 Wave set-up and run-up for the six output points at the Tallawarra Lands site.

Variable	Site 1	2	3	4	5	6
Hs (m)	0.33	0.38	0.48	0.49	0.51	0.43
Tm (sec)	2.50	2.30	2.34	2.71	2.16	2.20
Depth (m)	1.25	1.37	1.50	1.80	2.20	1.38
Wave Set-up (m)	0.05	0.06	0.07	0.07	0.08	0.06

Wave Run-up (m)	0.19	0.20	0.23	0.26	0.23	0.20

4.5.4 Total Stillwater Levels

The 100 year ARI design total still water level, excluding freshwater flooding, was calculated as the 100 year ARI storm surge + local wind set-up + wave set-up, and varied between 1.09 m and 1.13 m along the foreshore of the Tallawarra Lands site (**Table 4.7**). The still water level including wave set-up (and not run-up) is used to estimate the areas at risk of oceanic inundation.

Wave runup levels indicate the level to which an individual wave may reach as it dissipates it energy on the foreshore. If the edge of the foreshore is lower than this level the wave may penetrate some distance landward. However, due to the nature of wave at the site (relatively small height and short period wind driven sea, rather than ocean swell) the wave energy will be quickly dissipated by friction and infiltration over a relatively short distance. This distance is considered likely to be of the order of less than 10 metres rather than large distances.

Table 4.7 Estimated design still water levels for six locations along the foreshore of Tallawarra Lands site.

Variable	Site					
	1	2	3	4	5	6
Extreme water level (m AHD)	0.8	0.8	0.8	0.8	0.8	0.8
Local wind set-up (m)	0.24	0.23	0.23	0.25	0.24	0.27
Local wave set-up (m)	0.05	0.06	0.07	0.07	0.08	0.06
100 year ARI stillwater level (including wave set-up) (m AHD)	**1.09**	**1.09**	**1.1**	**1.12**	**1.12**	**1.13**
100 year ARI wave run-up level (m AHD)	1.23	1.23	1.26	1.31	1.27	1.27

The joint occurrence of oceanic inundation events and freshwater flooding events is not investigated herein. Sea level rise and changes to the various components of still water level due to possible climate change are considered in **Section 4.8**.

4.6 Flooding

The Wollongong City Council Coastal Zone Study (Cardno 2010) refers to catchment flooding levels from the draft Lake Illawarra Floodplain Risk Management Study and Plan and reproduces those levels considered relevant to the coastal zone. These have been reproduced in **Table 4.8** below for the Tallwarra Power Station site.

Table 4.8 100 year ARI Catchment Flood Levels (m AHD)

Foreshore Location	2010	2050 (+0.4 m SLR)	2100 (+0.9 m SLR)
Tallawarra Power Station	**2.24**	**2.49**	**3.04**

Source: Cardno (2010)

From comparison of **Table 4.7** and **Table 4.8,** it can be seen that inundation from catchment flooding has the potential for greater impact on the Tallawarra Lands site than oceanic inundation.

4.7 Potential Sediment Transport Mechanisms and Rates, and Foreshore Stability

The stability of the shoreline position at the Tallawarra Lands site was evaluated through examination of historical aerial photographs (**Section 3.5**) in order to identify any patterns or trends in shoreline erosion or accretion and shoreline position over time. Additionally, a site visit was conducted on the 7th April 2010, documenting bank erosion, shoreline characteristics and boating use surrounding the Tallawarra Lands site.

Much of the foreshore of the Tallawarra Lands site is consolidated in nature, and subject to insignificant erosion on a development time scale. Three sites consisting of unconsolidated sediment were identified for further investigation: Beach 1 (at the northern end of the site), Beach 2 (immediately to the north of the power station) and Beach 3 (at the southern end of the site). The variation in the scarp and shoreline position over time at each of these three sites was investigated. However, the accuracy of the shoreline position in the historical photographs was estimated by measuring its variation along rocky parts of the shoreline which are unlikely to have accreted or eroded over time. The average accuracy was 28.4 m due to distortion of aerial photographs. This was considered at least an order of magnitude larger than any anticipated changes and the use of the historical photos for quantitative assessment was not used.

The assessment was used qualitatively to indicate that Beach 1 and 3 have shown little variation in shoreline position over time within the accuracy of the shoreline position and the water level variation between photographs. Beach 1 is exposed to the northeast and Beach 3 to the south, and neither are likely to encounter significant wave climates. Beach 3 is also protected by shallow depths below

1.5 m extending for a considerable distance offshore, preventing the influx of wave energy. Beach 2 has exhibited more noticeable variation in its shoreline position over the historical photograph record. However, the most significant changes occurred following the development of the Tallawarra Power station and associated land reclamation activities that took place which impacted directly on this embayment. Changes to the shoreline position and orientation are attributed to these anthropogenic influences.

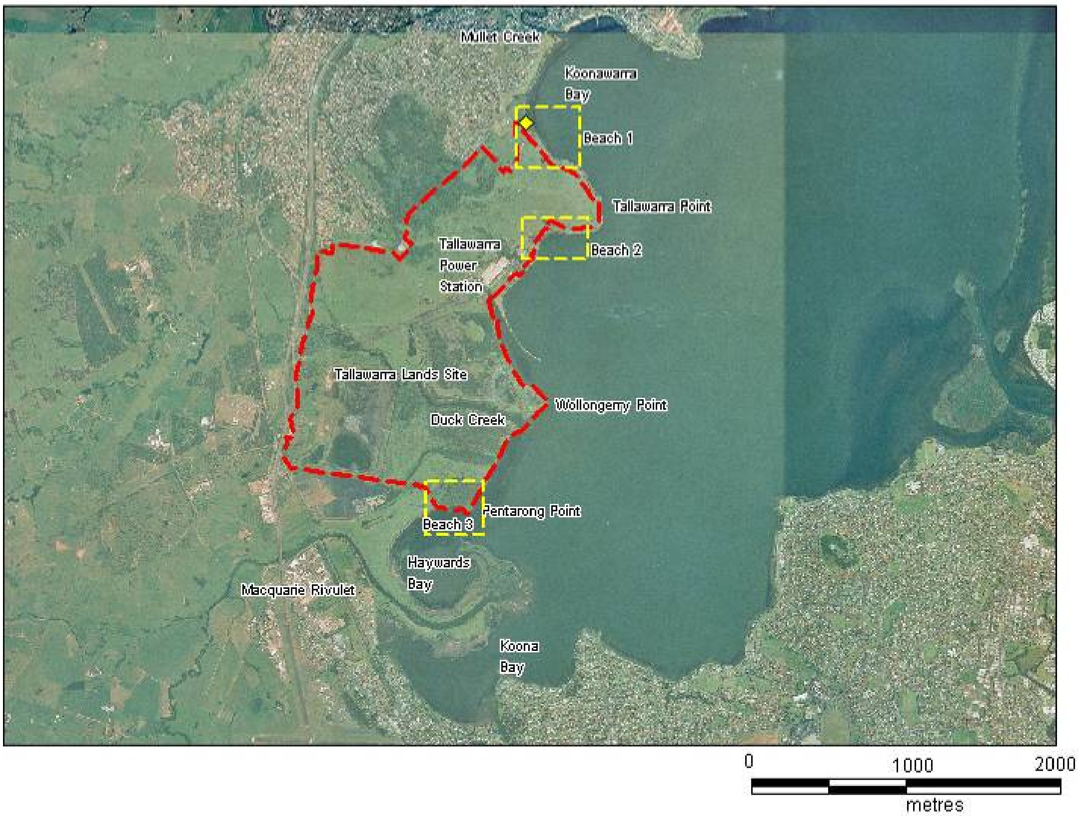


Figure 4.7 Location of Beach 1, Beach 2 and Beach 3 along the foreshore of the Tallawarra Lands site.

From the review of historical aerial photography, there appears to be little longshore sediment transport occurring on the western side of Lake Illawarra. The wave and tidal energy of the environment is too low to generate persistent currents and the wind regime too varied in direction to generate a persistent flow of sediment in a given direction. The deltas at the mouths of Macquarie Rivulet and Duck Creek are not elongated away from their point of deposition, indicating that there is no distinct direction of sediment transport along this shoreline. The lack of long term trends in the shoreline position over the area indicate that any longshore transport processes are likely in equilibrium, with sufficient sediment deposited to replace any eroded.

Within the accuracy of the historical photo analysis it concluded that it is unlikely that foreshore investigated is experiencing long term recession due to net sediment loss.

Historical bank erosion at the Tallawarra Lands site is apparent from the scarp and eroded bank features observed during the site visit (**Figure 4.8**). This bank erosion is likely the result of elevated water levels associated with freshwater flooding events and simultaneous wind wave action. These scarps have been subsequently vegetated, indicating that they were cut by historical water level events and an event with a water level of such elevation has not occurred recently. The presence of the scarps also indicates that the shoreline is likely not actively retreating due to long term net sediment loss, or the scarp would likely have been eroded since its formation.

Erosion events at the site are likely to be episodic and minor in nature, consistent with the nature of fetch limited wave climate and flooding events. The rate of shoreline recession as a result of these episodic events is likely to be insignificant in comparison to shoreline recession due to sea level rise (see **Section 5.2**).

We note that vegetation of the banks will improve foreshore stability at the site, and recommend the Lake Illawarra Authority and Tallawarra Lands implement preservation and restoration management actions to establish and maintain foreshore vegetation. Such management action would also assist mitigation of bank erosion due to boat wake. Boat wave impacts can be significant for shorelines in fetch limited wave climates where natural wave conditions are typically relatively small wave heights and short wave periods.

Figure 4.8 Photographs showing bank erosion scarps, Tallawarra Land sites, 7th April 2010.

4.8 Impacts of Climate Change

Climate change may affect water levels within Lake Illawarra through sea level rise, and also through changes in the intensity and frequency of extreme wind and rainfall events.

4.8.1 Sea Level Rise

The most recent (Fourth Assessment) estimates for sea level rise (SLR) due to climate change are provided in Intergovernmental Panel on Climate Change (IPCC) (2007) and Meehl *et al.* (2007). Sea level rise estimates were not significantly different to those presented previously in 2001. Based on Meehl *et al.* (2007), the latest IPCC sea level rise predictions are shown in **Table 4.9** for the six adopted illustrative emission scenarios (so-called Special Report on Emission Scenarios [SRES] marker scenarios).

Table 4.9 Sea level rise predicted by Meehl *et al.* (2007) from 1980-1999 to 2090-2099 (5% to 95% intervals characterising the spread of model results).

Scenario (IPCC 2007)	Sea level rise, excluding scaled-up ice sheet discharge	Scaled-up ice sheet discharge	Total sea level rise including scaled-up ice sheet discharge
B1	0.18 to 0.38 m	0 00 to 0.09 m	0.18 to 0.47 m
B2	0.20 to 0.43 m	0 00 to 0.11 m	0.20 to 0.54 m
A1B	0.21 to 0.48 m	–0.01 to 0.13 m	0.20 to 0.61 m
A1T	0.20 to 0.45 m	–0.01 to 0.13 m	0.19 to 0.58 m
A2	0.23 to 0.51 m	–0.01 to 0.13 m	0.22 to 0.64 m
A1FI	0.26 to 0.59 m	–0.01 to 0.17 m	0.25 to 0.76 m

The *Draft Sea Level Rise Policy Statement* (DECC 2009) adopts a sea level rise planning benchmark for NSW. The benchmark's primary purpose is to provide guidance to support consistent consideration of sea level rise impacts, within applicable decision-making frameworks. The NSW sea level rise planning benchmark is an increase above 1990 mean sea levels of 0.40 m by 2050 and 0.90 m by 2100, which incorporates a regional variation in the rate of sea level rise. The planning benchmark of 0.9 m increase by 2100 is similar to the high-range sea level rise estimate of 0.91 m previously adopted by DECC (2007).

For this investigation, coastline hazards are estimated for the:

- immediate planning period;

- 50 year planning period with a sea level rise of 0.4 m; and
- 100 year planning period with a sea level rise of 0.9 m.

Sea level rise will increase the inundation hazard level at the Tallawarra Lands site, and may also cause shoreline recession for parts of the foreshore composed of soft sediments. Inundation levels are quantified in **Section 5.1** and shoreline recession is quantified in **Section 5.3**.

The penetration of oceanic storm surge in to Lake Illawarra was modelled for the 50 and 100 year planning period (with +0.4 m and +0.9 m SLR, respectively) using the existing bathymetry and entrance configuration. A storm surge amounts of 0.85 m (1.25 m AHD including 0.4 m SLR) and 0.90 m (1.80 m AHD including 0.9 m SLR) were adopted for the 50 and 100 year planning period, respectively. These are considered conservative as due to the shoaling nature of the entrance (discussed in **Section 4.3**) it could be expected that the entrance compartment will continue to shoal at the same rate as SLR. Accordingly, water depths in the entrance channel will remain constant relative to mean sea level and the conveyance of the storm surge wave would be similar regardless of the mean sea level. However, due to the uncertainties in the change to forcing mechanisms as a result of climate change (discuss in **Section 4.8.2**); it is considered prudent for planning purposes to retain this conservatism.

Increased sea level would likely result in lower local wind setup levels, as this parameter is inversely related to water depth. Local wind setup levels under sea level rise was assessed by simulating scenarios using the model described in **Section 4.5** with the water level elevated by 0.9 m. The local wind setup levels were found to decrease up to 10 cm (**Table 4.10**).

Table 4.10 Still water levels (above mean water level including +0.9 m SLR) generated by wind set-up (wind speed 20 m/s).

Wind Set-up (m AHD)	Output Point					
Wind Direction	1	2	3	4	5	6
NE	0.14	0.11	0.08	0.07	0.04	0.04
E	0.15	0.14	0.14	0.14	0.13	0.14
SE	0.13	0.13	0.14	0.15	0.15	0.17
S	0.03	0.04	0.06	0.08	0.08	0.10
Max	0.15	0.14	0.14	0.15	0.15	0.17

A progressive rise in mean sea level would result in shoreline recession. Coastal hazard lines incorporating SLR and shoreline recession due to SLR are discussed in **Section 5**.

4.8.2 Other Climatic Change Considerations

Another potential outcome of climate change is an increase in the frequency and intensity of storm events. Modest to moderate increases in average and maximum cyclone intensities are expected in the Australian region in a warmer world. However, cyclone frequency and intensity are strongly associated with the El Niño/Southern Oscillation (ENSO) phenomenon. How this phenomenon will vary in a warmer world is currently unknown (CSIRO 2001; CSIRO Marine Research 2001). Mid latitude cyclones, which affect the NSW coast, have been predicted to increase in intensity but decrease in frequency with global warming (CSIRO 2002), due to a reduction in equator to pole temperature gradients. However, as with tropical cyclones, climate modelling at present lacks the resolution to accurately predict changes associated with global warming that may affect NSW.

Both rainfall and windspeeds, and hence wind-waves, may vary in their frequency and intensity under climate change. The wave modelling exercise described in **Section 4.4** was repeated using the Bellambi windspeed time series scaled up by 10 %. The resulting statistics are given in **Table 4.11** and extreme value statistics in **Table 4.12**. In comparison with the base case, the maximum significant wave height increased by 4 to 5 cm across the six sites, and the maximum peak wave period increased by 0.07 to 0.09 seconds. The 1% AEP significant wave height increased by 0 to 4 cm across the six sites, and the 1% AEP peak wave period increased by 0.02 to 0.31 seconds. These changes are within the range of of preset day natural variability and are not considered significant.

Table 4.11 Inshore Wave Parameter Exceedance with a 10% increase in windspeed (and +0.9m SLR). H_s – Significant wave height. Tp – Peak wave period.

Prob. of Exceed-ance (%)	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
	H_s (m)	Tp (s)	H_s (m)	Tp (s)	H_s (m)	Tp (s)	H_s (m)	Tp (s)	H_s (m)	Tp (s)	H_s (m)	Tp (s)
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
95	0.01	0.78	0.01	0.51	0.01	0.70	0.01	0.51	0.02	0.77	0.01	0.51
99	0.14	1.85	0.13	1.85	0.10	1.85	0.10	1.85	0.10	1.85	0.10	1.85
Max	0.34	2.43	0.41	2.43	0.44	2.41	0.48	2.38	0.52	2.45	0.40	2.40

Table 4.12 Inshore Wave Parameter AEP with an 10 % increase in windspeed (and +0.9m SLR). H_s – Significant wave height. H_{max} – Maximum wave height. T_p – Peak wave period. T_m – Mean wave period

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Variable	AEP	Site 1	2	3	4	5	6
Hs (m)	**10**	0.30	0.37	0.44	0.44	0.48	0.37
	5	0.31	0.38	0.45	0.45	0.49	0.38
	1	0.37	0.41	0.48	0.47	0.51	0.43
Hmax (m)	**10**	0.62	0.73	0.78	0.91	0.93	0.74
	5	0.64	0.75	0.80	0.95	0.95	0.78
	1	0.71	0.78	0.84	1.05	0.97	0.88
Tp (sec)	**10**	2.11	2.21	2.22	2.34	2.41	2.16
	5	2.18	2.32	2.35	2.48	2.47	2.26
	1	2.40	2.72	2.69	2.86	2.56	2.57
Tm (sec)	**10**	2.11	2.09	2.05	2.11	2.14	2.18
	5	2.21	2.16	2.14	2.23	2.22	2.26
	1	2.62	2.36	2.35	2.61	2.45	2.51

These wave statistics from the increased wind speed were then used to recalculate the wave set-up and run-up (**Table 4.13**). In comparison to the base case, the increase in wave set-up and run-up was not significant, increasing by 1 or 2 cm.

Table 4.13 Wave set-up and run-up for the six output points at the Tallawarra Lands site including 10% increase in wind speeds (and +0.9m SLR)

Variable	Site 1	2	3	4	5	6
Hs (m)	0.37	0.41	0.48	0.47	0.51	0.43
Tm (sec)	2.62	2.36	2.35	2.61	2.45	2.51
Depth (m)	1.25	1.37	1.50	1.80	2.20	1.38
Wave Set-up (m)	0.06	0.06	0.07	0.07	0.08	0.06
Wave Run-up (m)	0.21	0.21	0.23	0.25	0.25	0.22

The wind set-up, wave set-up and run-up calculated for the climate change case considered in this section were then used to recalculate the design still water levels for the site for both the 2050 sea level rise of 0.4 m and the 2100 sea level rise of 0.9 m (**Table 4.14**).

Table 4.14 Climate change case: Estimated design still water levels for six locations along the foreshore of Tallawarra Lands site for a (a) 0.4 m sea level rise by 2050 and (b) 0.9 m sea level rise by 2100.

(a) 2050 Variable	Site 1	2	3	4	5	6
Sea level rise 2050 (m)	0.40	0.40	0.40	0.40	0.40	0.40
Extreme water level (m above mean lake level)	0.85	0.85	0.85	0.85	0.85	0.85
Local wind set-up (m)	0.15	0.14	0.14	0.15	0.15	0.17
Local wave set-up (m)	0.06	0.06	0.07	0.07	0.08	0.06
100 year ARI still water level (including wave set-up) (m AHD)	**1.46**	**1.45**	**1.46**	**1.47**	**1.48**	**1.48**
Stillwater level + wave run-up (m AHD)	1.61	1.6	1.62	1.65	1.65	1.64
(b) 2100 Variable	**Site 1**	**2**	**3**	**4**	**5**	**6**
Sea level rise 2100 (m)	0.90	0.90	0.90	0.90	0.90	0.90
Extreme water level (m above mean lake level)	0.90	0.90	0.90	0.90	0.90	0.90
Local wind set-up (m)	0.15	0.14	0.14	0.15	0.15	0.17
Local wave set-up (m)	0.06	0.06	0.07	0.07	0.08	0.06
100 year ARI still water level (including wave set-up) (m AHD)	**2.01**	**2**	**2.01**	**2.02**	**2.03**	**2.03**
100 year ARI wave run-up level (m AHD)	2.16	2.15	2.17	2.2	2.2	2.19

5 COASTLINE HAZARD ASSESSMENT

The Tallawarra Lands site and the foreshore belonging to Lake Illawarra Authority may be subject to a range of coastal hazards, including:

- coastal inundation (i.e. not including catchment flooding);
- foreshore erosion i.e., storm bite;
- shoreline recession; and
- climate change.

These hazards are assessed in this section.

The foreshore investigated in the Study does not consist of sandy beaches and dune systems typical of open coast beaches and thus there is no risk posed by sand drift. Similarly, risks from slope instability in dunes of unconsolidated sediment (sand) are not relevant. Present day storm water erosion of the foreshore does not pose a risk as creek entrances on the site are contained within fluvial deltas. Sediment is being deposited in the foreshore and nearshore zone. These hazards are not considered further herein.

5.1 Coastal Inundation

Oceanic inundation occurs as a result of elevated still water levels associated with the astronomical tide, storm surge, wave set-up, and sea level rise. **Section 4.5** details site specific investigation in this regard resulting in the following hazard estimate:

- The immediate 100 year ARI hazard for coastal inundation (not including sea level rise) is **1.15 m AHD**.

Considering climate change, the sea level is expected to rise 0.4 m by 2050 and 0.9 m by 2100. **Section 4.8** investigates the impacts of various climate change impacts resulting in the following planning period hazard definition:

- For the year 2050, the 100 year ARI hazard for oceanic inundation hazard level is estimated to be **1.50 m AHD**.
- For the year 2100, the 100 year ARI hazard for oceanic inundation hazard level is estimated to be **2.05 m AHD**.

These levels do not include elevated lake levels due to freshwater flooding.

These inundation hazard levels are mapped on **Figure 5.1**. For the northern part of the site, the inundation hazard lines are located close to the shoreline, due to the steep bank along this part of the site, and the 2100 line encroaches no more than 50 m from the 0 m AHD contour. South of the power station breakwater, the 2100 inundation hazard line is up to 77 m landward of the 0 m AHD contour. South of Duck Creek, the floodplain is low elevation in nature, and the 2.05 m contour is located over 1 km from the 0 m AHD contour. Much of this land will also be prone to freshwater flooding.

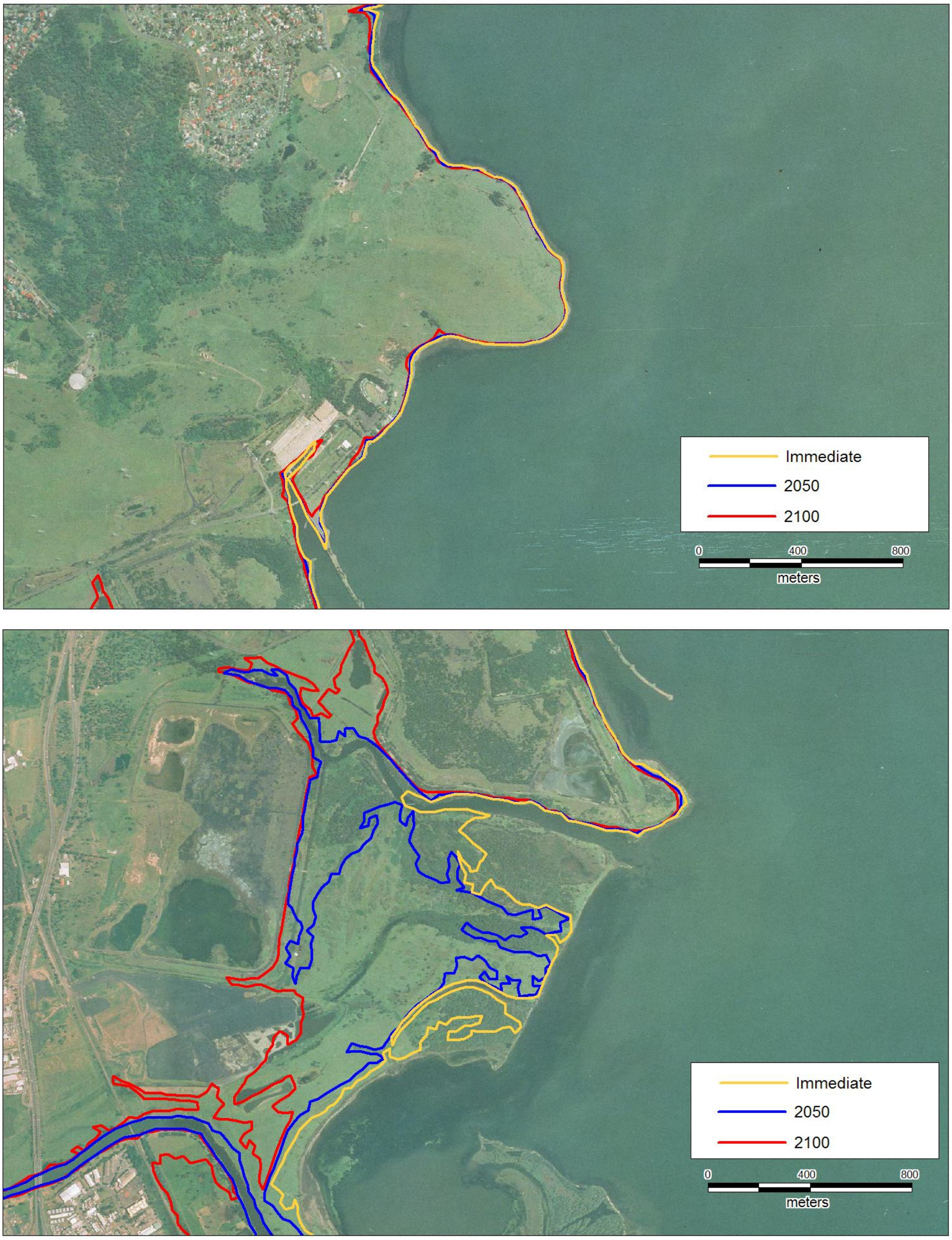

Figure 5.1 Coastal inundation hazard lines for the Tallawarra Lands site (a) North part of site, (b) South part of site.

The crest level of the breakwater, part of the Tallawarra Power Station site, has elevations between 1.5 and 2.0 m AHD along most of its length (**Figure 5.2**). Under sea level rise, the breakwater will become inundated, or overtopped, by events of more frequent return levels. This could have implications for the following:

- the function operation of this area and the outlet channel;
- structural integrity of the breakwater;
- maintenance of the structure;
- safety of people using the area (liability issues); and
- protection of the foreshore on the southern side of the outlet channel.

These risks could be addressed by raising the level of the breakwater in future. A crest level of 2.4 m would be sufficient for the 100 year ARI water level event in the year 2100 following a 0.9 m rise in sea level.

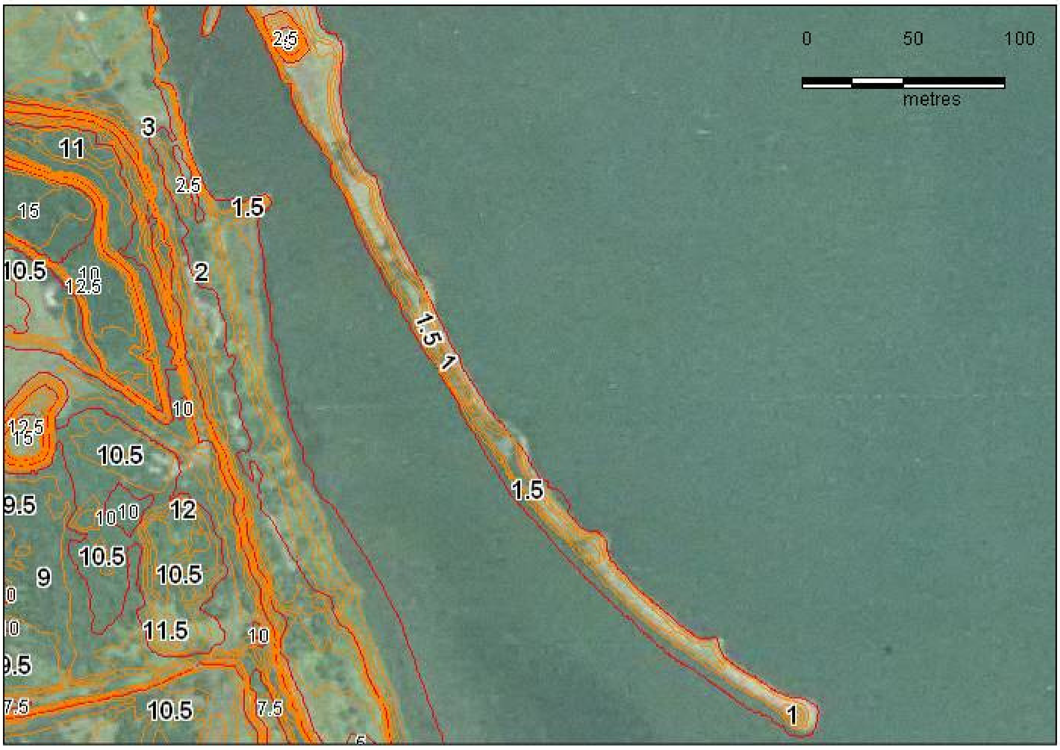

Figure 5.2 Elevation contours (m AHD) along the breakwater at the Tallawarra Power Station site, using data from the aerial laser survey on the 2008 aerial photograph.

5.2 Foreshore Erosion

Foreshore erosion by extreme (storm) wave action was not considered to have a significant impact on the Tallawarra Lands site, and an estimate of storm bite was not made. The height and period of the wind waves affecting the location are depth- and fetch-limited and there would be significant dissipation of wave energy in the nearshore due to the shallow depths and gentle slope. Wave breaking in extreme wave conditions would occur at a distance from the shoreline and storm bite would be not be significant in nature. In addition, the rocky nature of most of the foreshore of the Tallawarra Lands site precludes the occurrence of storm erosion. Thus, no design storm bite or erosion distance was defined for the site.

An immediate erosion hazard zone have not been specified as the rate of shoreline recession as a result of episodic events is likely to be insignificant in comparison to long term shoreline recession due to sea level rise. For a green field site it considered appropriate to locate development behind the 100 year hazard line making the definition of an immediate hazard redundant.

5.3 Shoreline Recession

A progressive rise in mean sea level would result in shoreline recession. This shoreline recession is expected to take place over long periods of time and, as such, the resultant shoreline profile and conditions (such as vegetation) are likely to remain unchanged. However, the recession involved would impact on land based developments, and/or foreshore reserve widths, and should be included in planning and design considerations.

A progressive rise in sea level may result in shoreline recession through two mechanisms: First, by drowning low lying coastal land, and second, by shoreline readjustment to the new coastal water levels. Both these mechanisms are likely to impact the proposed Tallawarra Lands development site if predicted future sea level rise is realised.

For the predominantly protected shoreline south of the Tallawarra Power Station cooling water outlet and the rocky Wollingurry Point, the drowning of low lying land would most likely occur as the mechanism for recession. 2050 and 2100 coastal recession hazard zones have been plotted in **Figure 5.4**, indicating the possible extent of this low level land drowning.

On the more exposed foreshore of the Tallawarra Lands site, north of the power station, the mechanism for recession would most likely be the readjustment of the shoreline as described below.

DECCW (2009) suggest that the amount of shoreline recession on unconsolidated shorelines due to sea level rise be assessed through the use of the Bruun Rule (Bruun, 1962, 1988). Bruun (1962) proposed a methodology to estimate shoreline recession due to sea level rise. The Bruun Rule is based on the concept that sea level rise will lead to erosion of the upper shoreface, followed by re-establishment of the original equilibrium profile through wave action. It only applies to unconsolidated beach profiles where sufficient wave energy occurs to cause cross shore transport. This profile is reestablished by shifting it landward. The concept is shown graphically in Bruun (1983), and can be described by the equation:

$$R = \frac{S \times B}{h + d_c} \qquad (1)$$

where R is the recession (m), S is the long term sea level rise (m), h is the dune height above the initial mean sea level (m), d_c is the depth of closure of the profile relative to the initial mean sea level (m), and B is the cross-shore width of the active beach profile, i.e., the cross-shore distance from the initial dune height to the depth of closure (m). This equation is a mathematical expression that the recession due to sea level rise is equal to the sea level rise multiplied by the average inverse slope of the active beach profile, and is illustrated in **Figure 5.3**.

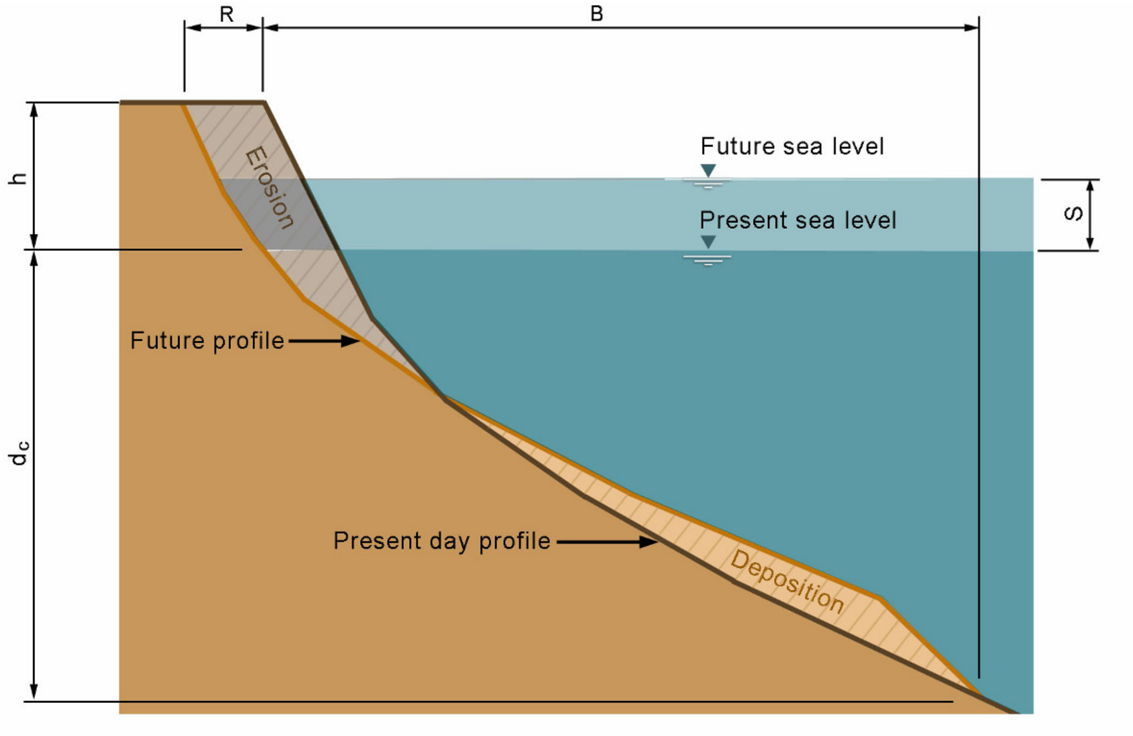

Figure 5.3 Definition of variables used in the Bruun Rule.

The limitations of the Bruun rule for use in an estuarine system such as Lake Illawarra are acknowledged. These limitations relate to the Bruun rule assumption that the foreshore profile is in equilibrium with a wave dominated environment (eroded during storm conditions and subsequently rebuilt during ambient conditions) and there is an infinite volume of sandy sediment. For the estuarine site being investigated these assumptions are not met. However, for foreshore exposed to episodic wave impacts there will be a recession due to sea level rise similar to that described by the Bruun rule, in addition to that as a result of inundation. For such shoreline, an adaptation of the Bruun has been applied to estimate recession.

The unconsolidated foreshore areas of the northern portion of the Tallawarra Lands site range from flat creek entrance deltas (Yallah and Koonawarra Bays) comprised of deposited fluvial sediments, to rocky foreshore backed by steep escarpment of approximately 4 m height (Tallawarra Point), and transition areas in between. Site inspection of the nearshore delta areas also indicated significant sea grass meadows which have the effect of further attenuating wave heights in a low energy wave climate and binding the bed sediments limiting movement.

Both areas have flat nearshore slopes; the delta areas as a result of fluvial deposits, and at Tallawarra Point, due to a rocky geological feature. Both of these flat nearshore slopes are not as a result of equilibrium with the wave climate. However, back beach escarpments are present in both these environments (to varying degrees) and are a result of wave conditions at the site. The slope above the mean lake level to the top of the back beach escarpment has been considered as the "active profile" in equilibrium with the wave climate for the purposes of Bruun rule calculation of recession.

The Bruun multiplying factor varied between 2 at the centre of the delta area to 10 at Tallwarra Point. It should be noted that the back beach slopes in the delta areas were not picked up by LIDAR survey information as the features are smaller than the resolution of the data. This slope was estimated based on observations made during the site visit and an assumed angle of repose for the fluvial sediment. Slopes for areas away from the delta were calculated from survey data.

Accordingly, the estimated recession due to the application of the Bruun rule based on sea level rise scenarios discussed above, range between the following values:

- 1.0 m – 5 m by 2050; and
- 2.0 m – 10 m by 2100.

Further deviation from the traditional Bruun rule application was made by adding these recession distances to the geometric translation of the shoreline due to inundation as a result of SLR. This was to account for the dual modes for recession in the transitional environment (not wave dominated). This has more significance for the flat delta areas where inundation is expected to be the more dominant mode of recession.

2050 and 2100 coastal recession hazard zones for the foreshore area have been plotted considering analysis described above (**Figure 5.4**). No immediate hazard zone was defined, as no storm erosion allowance was made (**Section 5.2**).

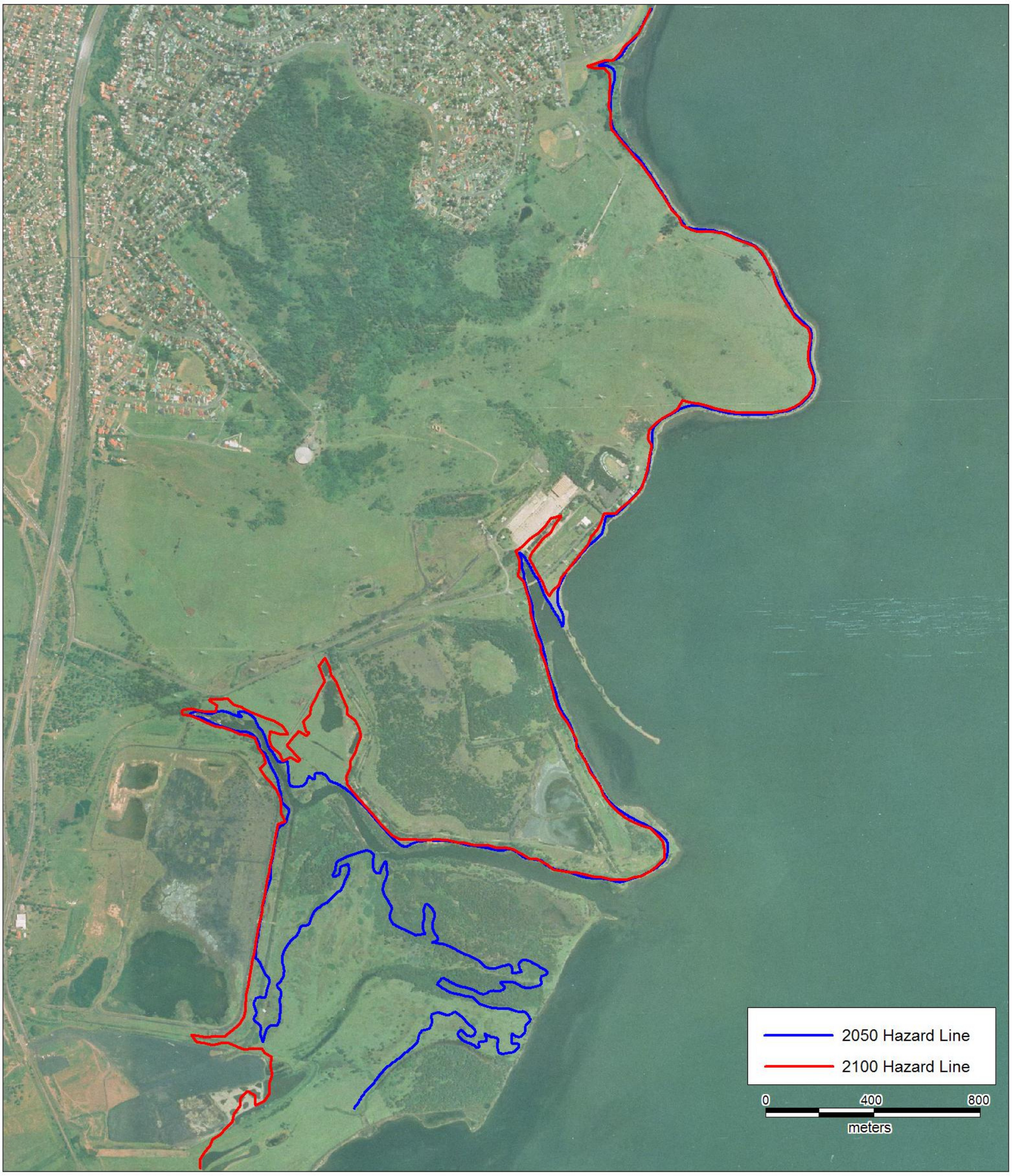

Figure 5.4 Shoreline recession hazard lines for 2050 and 2100.

6 CONCLUDING REMARKS

The foreshore of the Tallawarra Lands site is not at significant risk from coastal hazards. The low wave and tidal energy in the lake, the shallow depths surrounding the site, the rocky nature of much of the foreshore and the steep slopes at the northern part of the site limit its vulnerability to foreshore erosion and coastal inundation. For planning consideration purposes; immediate, 2050 and 2100 year coastal hazard zones have been presented for coastal inundation (not including catchment flooding). 2050 and 2100 year coastal hazard zones have been presented for coastal recession.

In terms of the immediate hazards, storm erosion and shoreline recession do not pose a risk; the shoreline appears stable through analysis of historical aerial photography indicating that sediment loss and longshore drift are not issues at the site, and the low wave energy and shallow depths limit the erosive effect of storm waves, which would likely dissipate their energy as they break offshore.

The immediate 1% AEP inundation level is 1.15 m AHD. Oceanic inundation and shoreline recession may become more of a concern as sea level rises. The 1% AEP inundation level rises to 1.50 m AHD by 2050 with a 0.4 m rise in sea level and to 2.05 m AHD by 2100 with a 0.9 m rise in sea level (**Figure 5.1**). Catchment flooding is considered to pose a much greater risk to the site.

Shoreline recession due to SLR may occur along limited parts of the shoreline with unconsolidated sediments (**Figure 5.4**). The most recent masterplan shows residential development close to the lake foreshore along the northern foreshore of the site. However, current set backs are located well behind the hazard lines shown in **Figure 5.4**. The foreshore itself is managed by the Lake Illawarra Authority. We recommend that vegetation be maintained or restored along the northern foreshore in order to limit erosion (and subsequent recession) and maintain bank stability. Vegetation maintenance and restoration has the additional impact of improving visual amenity, and environmental values of the site and adjacent waterway.

The portion of the Tallawarra site south of Duck Creek is vulnerable to impacts due to sea level rise (inundation and foreshore recession). However, on the most recent Masterplan (7 Dec 2010), this area is set aside as an environmental reserve, hence residential or commercial development would unlikely to be risk in their planned locations.

The most recent Masterplan (Masterplan I, 7 Dec 2010) shows that an area prone to flooding to the north of Duck Creek is now open space (as opposed to sportsfields in a previous Masterplan), which reduces its vulnerability to coastal flooding. The paved cycleway along the shoreline inside of and just south of the powerstation breakwater may be exposed to coastal hazards in the future, but is not exposed to immediate hazard risk. The road connecting the northern residential lots to the rest of the development may be at risk of coastal inundation if not elevated sufficiently; it should have a elevation exceeding 2.05 m AHD (the 2100 100 year inundation level). Shoreline recession should not affect this road if it is built on a rocky causeway.

It is considered that catchment flooding would pose a significant higher risk to development at the site and that planning setback to allow for catchment flooding inundation would be more than adequate to allow for mitigation of coastal hazards estimated herein.

7 REFERENCES

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