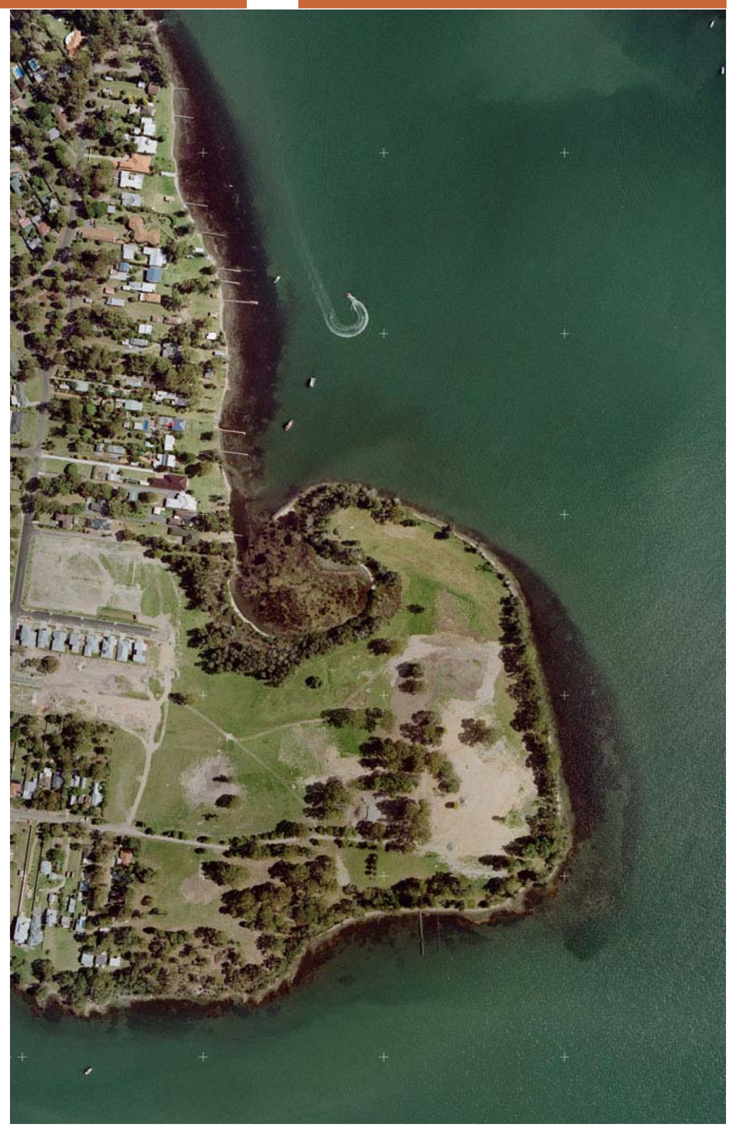
Johnson Property Group

Trinity Point Marina Proposal

Numerical Modeling Investigations



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Patterson Britton
& Partners Pty Ltd
consulting engineers

Trinity Point Marina Proposal
Numerical Modeling Investigations

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1 INTRODUCTION

A development proposal is being prepared by Johnson Property Group *(JPG)* for the Trinity Point site on the south-western shore of Lake Macquarie (***Figure 1***). Lake Macquarie is one of the largest coastal lakes in Eastern Australia and is located between Newcastle and Gosford on the NSW Central Coast some 125 km north of Sydney. The lake has a water surface area of approximately 110km^2 and 170km of foreshore. The Lake extends about 22 kilometres from Cockle Bay in the north to Chain Valley Bay in the south, with a maximum width of about 10 kilometres. The lake is connected to the ocean through a narrow entrance channel located approximately midway along the lake extent at Swansea. A low level bridge with an opening double lifting span crosses Swansea Channel.

The development proposal at Trinity Point is currently in a conceptual stage and broadly consists of the following components:

- residential and tourism accommodation;
- a marina with wet berths;
- a combined marina/tourism village;
- foreshore jetties;
- a marine workshop;
- car parking; and
- a helipad.

The site is within the Lake Macquarie City Council Local Government Area (*LGA*), however the proposal is to be assessed under *Part 3A* of the *EP&A Act* as a ‘major project’, and as such will be referred to the Department of Planning (*DoP*) for approval in two phases - the overall tourism project is currently in the conceptual development phase, and has been submitted as a 'concept plan' application under the Part 3A process. Concurrently, the proponent seeks project approval, under the Part 3A process, for the wet berth marina, marina village and helipad.

Based on comments received following a presentation of the project proposal to the Lake Macquarie Coastal and Estuary Committee on 7th March 2007, the issue of the effect of the proposed marina on flushing, circulation and sediment transport characteristics of Bardens Bay is of concern to the Committee. In response to these concerns, JPG commissioned Patterson Britton and Partners (*PatBrit*) to undertake a detailed numerical modeling investigation to determine the likely effect of the proposed marina on these factors. This involved the comparison of the existing hydrodynamic regime to what will exist post construction of the proposed marina.

Detailed numerical modeling of the local estuarine environment (*hydrodynamic, wave and sediment movements*) also presents the opportunity for optimisation in design elements (*e.g. breakwater structure*) through better understanding and resolution of environmental design parameters. This optimisation in design could potentially produce savings in the capital cost and ongoing maintenance of the marina. Definition of wave design parameters from the undertaking of detailed numerical modeling is also included in this investigation.

2 DATA

A range of data items were required to set up the model systems and to undertake hydrodynamic, wave, water quality and sediment transport simulations. This data is described in the following sections. The data was used in various capacities (*individually and/or combined*) throughout the study for model setup, model verification, wave hindcast modeling and wave climate evaluation, and determination of design model scenarios.

2.1 EXISTING RMA MODEL OF LAKE MACQUARIE

A estuary wide finite element RMA model was developed, calibrated and verified for the Lake Macquarie Estuary Processes Study (*AWACS, 1995*) to study general hydrodynamics over the entire extent of the lake. This finite element model is owned by Lake Macquarie City Council (*LMCC*) and has been subsequently refined and used by various consultants for particular site specific studies (*particularly in the Swansea Channel region*). This has improved it's overall representation of physical processes.

The coarse mesh size of the existing model in the main body of the lake does not allow the resolution of processes at the scale necessary for site specific investigations such as those required for the proposed Trinity Point Marina. However, the estuary wide model provides a calibrated base model that includes description of the bathymetry of the lake to a resolution that satisfactorily represents the overall hydrodynamic behaviour of the lake to provide a boundary condition at the study site.

The finite element mesh has be refined by PatBrit in the region of interest (*from Point Wolstoncroft to the south west portion of the Lake*) to allow for the necessary increased computational resolution at the study site to undertake investigations.

2.2 BATHYMETRIC DATA

Bathymetric data was utilised to refine a digital terrain model (*DTM*) of the lake bed for the south-eastern portion of Lake Macquarie. This DTM formed the basis of the bathymetric description utilised for the model systems applied to this study, augmenting the existing estuary wide RMA model bathymetric description in the case of hydrodynamic and water quality modeling.

Bathymetric data was required to describe the lake bed within the study area to develop refined numerical models of the Bardens Bay and the south western portion of Lake Macquarie from Point Wolstoncroft. Bathymetric data for the refined model region was obtained from the following sources:

- digitised data from a PWD survey of Lake Macquarie completed in 1977; and
- more detailed bathymetric information within the immediate nearshore vicinity of the proposed Trinity Point marina development was obtained from site specific hydrographic survey data of this area undertaken in 2006 for the Trinity Point Marina project.

Figure 2 presents the model bathymetry in the areas adjacent to the study site.

2.3 WATER LEVEL DATA

Tidal plane data is available for Swansea Channel Entrance from the Australian National Tide Tables 2006 (Department of Defence, 2006).

Tidal planes to chart datum at the Swansea Channel Entrance are:-

Highest Astronomical Tide	1.7m
Mean High Water Springs	1.4m
Mean High Water Neaps	1.2m
Mean Sea Level	0.8m
Mean Low Water Neaps	0.4m
Mean Low Water Springs	0.2m

Tides at the site are semi-diurnal with two High Water levels and two Low Water levels each day. Normally there is a diurnal inequality. Tidal harmonic constituents are also available from the Australian National Tide Tables 2006 (*Department of Defence, 2006*) and were used to derive water level time series data to force the hydrodynamic model at the offshore boundary location.

The Trinity Point Marina Proposal - Coastal Processes Study (*PatBrit, 2007a*) discusses the significant attenuation of the astronomical tide from the ocean entrance of the Swansea Channel (tidal range of 1.7m) to the main body of the lake (*tidal range of less than 0.2m beyond Coon Point at the inshore end of the Swansea Channel*). PatBrit, 2007 also discusses the variation in average tidal levels and the subsequent difficulty in the description of water depths (bathymetry data) relative to Chart Datum (*or zero tide*). For this reason bathymetry data within the lake is generally described in terms of a height relative to Australian Height Datum (AHD). Offshore water level forcing data was adjusted accordingly to oscillate around 0m AHD.

All wave climate model simulations were undertaken at Mean Sea Level (MSL) which was assumed for the purposes of this investigation to be equivalent to 0m AHD at the inshore study site. The small tidal range and variations of lake average tidal levels at the site are not considered to vary enough to significantly influence the wave climate.

2.4 WIND DATA

Historic wind data recorded at Bureau of Meteorology (*BoM*) weather station at Williamtown RAAF Base, between 1/1/1989 and 18/12/2006 was identified as being the most comprehensive data set in the region. The 10 minute average wind speed and direction were extracted from the historic data provided by the BoM, the resulting 10 minute average wind speed data set was converted to 5 hourly average wind speeds using wind speed/duration ratios from ***Figure 3-13*** of the *Shore Protection Manual* (*US Army Corps of Engineers, 1984*). This information was then statistically analysed to establish directional (at *45 degree increments*) wind speed exceedance values. **Table 2-1** presents the calculated 5 hourly winds speeds for a range of wind directions and exceedance values. The resulting statistical representation of the wind patterns was used for the numerical modeling of wind driven processes such as waves and wind driven currents.

Table 2-1: Directional 5 hourly average wind speed exceedance values

Wind Direction	50th Percentile	25th Percentile	5th Percentile	1st Percentile
	Average 5 hourly Wind Speed (m/s)			
N	1.3	2.3	3.9	5.5
NE	2.4	3.7	6.1	7.8
E	2.8	4.5	7.2	8.0
SE	3.3	5.1	7.6	9.5
S	4.0	6.3	8.9	10.5
SW	2.9	4.8	7.8	9.9
W	3.1	5.4	9.1	11.7
NW	2.4	4.0	9.0	11.8

3 MODELING SYSTEMS AND OBJECTIVES

The intention of this study is to assess the hydraulic physical mixing and sediment transport processes in the Bardens Bay area and examine the likely effect of the proposed marina on these processes. To aid this assessment numerical hydrodynamic and wave models of Lake Macquarie have been established. Modeling off both the existing conditions and the proposed marina scenario was undertaken to assess the likely effects of the proposed marina on flushing, circulation and sediment transport process in the Bardens Bay area.

3.1 PROPOSED DEVELOPMENT

The proposed marina would incorporate 4 floating pontoon arms and a timber skirt breakwater around the southern and eastern sides of the marina (***Figure 3***). The proposed breakwater would be constructed with slatted timber walls on both sides of the breakwater. The timber slats would extend to depths of -3.7 m AHD on the southern breakwater and -4.7 m AHD on the eastern breakwater. Refer to **Appendix A** for preliminary conceptual design drawings of the proposed marina, including typical section of the proposed breakwater.

Any disturbances to the hydrodynamics of the Bardens Bay would most likely result from the construction of a breakwater which would protrude approximately 260 meters across the entrance of Bardens Bay. As previously discussed, the breakwater would consist of twin slatted timber walls which would extend to a depth or -3.7 to -4.7 m AHD. A recent hydro-survey indicates that Bardens Bays is approximately 6 meters deep, hence it can be assumed that the breakwater would block the upper 75% of the water column. This blockage would form a barrier which could impede convective and diffusive mixing processes.

In order to examine these effects, a RMA 2 hydrodynamic model and a STWAVE wave model of the lake were established to assess the physical mixing process in Bardens Bay. RMA-11 was also used in conjunction with the hydrodynamic modeling to assess water quality impacts. These models are discussed in detail in subsequent sections.

3.2 MODELING OBJECTIVES

The objective of this study is to assess the likely effect of the proposed marina on the existing flushing, circulation and sediment transport characteristics of Bardens Bay and other areas of Lake Macquarie adjacent to the proposed marina. In order to examine the likely effects, hydrodynamic and wave climate models were established to:

- assess the existing hydrodynamics and sediment transport characteristics of Bardens Bay;
- assess the hydrodynamics and sediment transport characteristics if the proposed marina and associated breakwater structure were constructed; and
- define the comparative changes to hydrodynamic and sediment transport characteristics and any possible resulting impacts on the surrounding environment.

3.3 MODEL SETUP

Both the hydrodynamic and wave models have been configured using bathymetric data from two surveys. These are:

- PWD survey of Lake Macquarie completed in 1977 (*digitised*); and
- the recently completed site specific hydrosurvey for the Trinity Point Marina project.

Physical mixing processes in Lake Macquarie are driven by a combination of dynamic meteorological and tidal conditions. As discussed in **Section 2.4**, meteorology conditions (*particularly wind speed and direction*) are highly variable. Hence, the statistical examination of historic wind data was used to define wind velocities for a range of occurrence frequencies. This information was combined with observed tidal trends (*which are less variable*) to establish model scenarios. As mixing of the lake waters is a continuous process driven by day to day conditions only frequently occurring meteorology events were considered in this study.

3.3.1 Wave Modeling

The STWAVE model was used to investigate the growth of wind generated waves within Lake Macquarie and the propagation of these wind generated waves to the Trinity Point site. This model was developed by the US Army Corp of Engineers and has been integrated into the Surface Water Modeling System (*SMS*) by Environmental Modeling Systems Incorporated. SMS is a comprehensive environment for one, two, and three dimensional hydrodynamic modeling. It includes pre and post processors for surface water modeling and includes finite element and finite difference modeling tools.

STWAVE is a steady-state, finite difference, spectral model based on the wave action balance equation. STWAVE simulates depth-induced wave refraction and shoaling, current-induced refraction and shoaling, depth and steepness-induced wave breaking, diffraction, wave growth because of wind input, and wave-wave interaction and white capping that redistribute and dissipate energy in a growing wave field.

For the purpose of modeling the modification of the wave climate due to reflections from the proposed breakwater structure a more detailed model was developed using CGWAVE. CGWAVE can account for the complex interactions of wave propagation processes in the vicinity of the shoreline and the breakwater. CGWAVE is a general-purpose, state-of-the-art wave prediction model. It is applicable to estimation of wave fields in harbours, open coastal regions, coastal inlets, around islands, and around fixed or floating structures. CGWAVE is a two dimensional steady state finite element model based on the elliptic mild-slope wave equation, that is able to resolve the particular reflection and diffraction processes that become important within harbours and enclosed water bodies.

CGWAVE can simultaneously simulate the effects of refraction, diffraction, shoaling, reflections by bathymetry and structures, dissipation due to bed friction and breaking, and nonlinear amplitude dispersion and harbour entrance losses. The governing equations of CGWAVE pass, in the limit, to the deep and shallow water equations, making this model applicable to a wide range of frequencies, including short wind waves, swell, and infra-gravity waves. Both monochromatic and spectral waves can be simulated with the CGWAVE model.

CGWAVE has also been integrated into SMS pre and post-processing for modeling and design.

3.3.2 Hydrodynamic Modeling

The existing RMA-2 finite element hydrodynamic model was adopted as a base model for this study. RMA 2 is a two dimensional (*depth averaged*) finite element hydrodynamic model. Before applying the model, the region of interest is described using quadrilateral and triangular elements. Quadrilateral elements have eight nodes (*four corner and four mid-side nodes*) while triangular elements have six nodes. Linear one dimensional elements (*three nodes*) may also be used. At each of the nodes in the mesh, the model calculates the depth averaged current velocity and water depth by solving the two dimensional momentum and continuity equations. Water level, current velocity or flow conditions may be specified as boundary conditions in order to simulate features such as freshwater inflow or tidal currents. The model may be used for either steady state or dynamic simulations.

As previously discussed **(*Section 2.1*)**, the mesh resolution in the southern portion of the lake was inadequate to effectively define the physical mixing processes. Hence, the mesh over the southern portion of the lake was recreated with an improved resolution (*particularly in and around the Bardens Bay area*). Nodal elevations were defined from the two hydro surveys detailed in **Section 3.3**. The resulting model grid is presented in **Figure 4.**

3.3.3 Water Quality Modeling

Water quality modeling was undertaken using RMA-11. This model may be used to simulate arbitrary constituents, temperature, DO/BOD, nitrogen and phosphate cycles, algal growth and decay, and cohesive and non-cohesive sediment transport. Current velocity and depth results from RMA2 are used as input to the model which solves the advection diffusion transport equations for the specific constituent/s. Individual constituents may be linked to derive growth and decay, and additional terms represent benthic and sediment sources and sinks.

4 WAVE CLIMATE MODELING

The STWAVE numerical modeling system (*described in **Section 3.3.1***) was applied to these investigations. The model was set up using data for this site as described in **Section 2**.

The model setup had a grid size of 10m. This model setup was considered more than adequate to describe the seabed, and to resolve the nearshore wave propagation processes.

This model was used to determine wave heights for 3 nominated inshore locations for16 wind directions x 12 wind speeds values to develop wave parameter hind cast 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 2.5m/s to 30m/s. A typical model result is shown in **Figure 5** for wind conditions over the grid as follows:-

Wind Speed (W_S) = 25m/s
Wind Direction (W_D) = 135^o TN

4.1 EXISTING WAVE PARAMETER EXCEEDANCE

Following the development of the wave parameter hind cast matrices 18 years of directional wind data (***Section 2.4***) was used to hindcast wave conditions by application of the matrices. This produced 18 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. The nature of the SMS post processing tool for STWAVE allows these statistics to be derived for any model grid location. Analysed wave parameter exceedance data for selected inshore locations is presented in **Table 4-1** below. **Figure 6** indicates these locations on a site plan of the proposed Trinity Point Marina. The wave climate at these selected locations is indicative of conditions to be considered for detailed breakwater design, foreshore overtopping and erosion, and sediment transport.

Table 4-1: Inshore Wave Parameter Exceedance (existing)

Probability of Exceedance (%)	Breakwater		Eastern Foreshore		Northern Foreshore		Associated Wave Period (Tp) (s)
	H_s (m)	Predominant Direction	H_s (m)	Predominant Direction	H_s (m)	Predominant Direction	
0.001	0.82	SE	0.75	SE	0.55	NE-SE	3.5
0.01	0.42	NW, E-SE	0.40	NW, E-SE	0.25	NE-SE	3.5
1	0.21	NW, E-S	0.21	NW, E-S	0.13	NE-SE	3.0
5	0.15	NW, E-S	0.15	NW, E-S	0.09	NW, NE-SE	3.0
50	0.07	All	<0.05	All	<0.05	All	3.0
75	<0.05	All	<0.05	All	<0.05	All	3.0

The wave climate within the proposed marina area is spatial variable, due to varying depths and degree of exposure to certain wave directions. Similar analysis as presented for selected locations above in **Table 4.1** can be readily undertaken at any point within the model grid. Detailed design of the breakwater structure will require a number of locations along the alignment of the breakwater to be described in this way. However, for efficiency of reporting, only one breakwater location has been presented in **Table 4.1**. The point on the extremity of the southern breakwater has the most exposure to all wave generating fetch lengths and is located in the deepest water of the breakwater layout. As a result, the wave parameter exceedance presented for this location is a representation of the limiting worst case wave climate for the breakwater. Optimisation of the breakwater design would be achieve by consideration of the spatial variation in wave climate along the alignment.

4.2 DESIGN WAVE PARAMETERS

PatBrit (2007b) describes the use of AS/NZS 1170.2 (2002) to selected design wind speeds for use in hindcasting of extreme wave events at the site for breakwater design. Wave hindcasting in PatBrit (2007b) used one dimensional algorithms based on those developed in Coastal Engineering Manual (2003) for deep water, fetch limited waves, considered a conservative approach. This numerical modeling study has refined this method by using the STWAVE numerical wave model to hindcast these extreme events. The outcomes from the STWAVE modeling are presented in **Table 4.2** below.

Table 4.2: Design Event Wave Parameters (existing)

Design Wind Direction	1yr ARI		50yr ARI		200yr ARI	
	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)
NW	0.25	3.1	0.40	3.2	0.41	3.2
N	0.21	3.1	0.38	3.2	0.40	3.2
NE	0.23	3.1	0.40	3.2	0.42	3.2
E	0.36	3.3	0.63	3.7	0.65	3.7
SE	0.43	3.3	0.95	3.6	0.95	3.6
SSE	0.41	3.6	0.85	4.0	0.86	4.0
S	0.33	3.3	0.70	3.7	0.72	3.8

As discussed in **Section 4.1**, the wave climate within the proposed marina area is spatial variable, due to varying depths and degree of exposure to certain wave directions and values presented in **Table 4.2** represent the limiting worst case wave climate location for the breakwater. Due to the asymptotic nature of extreme wind events and the fetch limited wave environment, wave events of 50yr ARI, or greater, are of a similar magnitude.

4.3 POST DEVELOPMENT WAVE CONDITIONS

PatBrit (*2007b*) presents the rationale for the selection of a low-reflection double walled partial depth vertical wave screen as a means of mitigating wave energy to provide a wave climate suitable for a marina (*in accordance with AS 3962*(*2001*)). Based on model testing of a similar structure undertaken by Berrington and Cox (*1997*) the wave climate within the breakwater will be of the order of 20% - 30% of the current wave climate represented by **Table 4.1** and **Table 4.2** above.

The impact of this modification of wave climate at the site due to the breakwater structure is examined further in sediment transport modeling described in **Section 6.2.2**.

4.3.1 Wave Reflections

Following the construction of the proposed breakwater, the wave climate within Bardens Bay would be modified. In addition to reduction in wave heights in the lee of the breakwater structure, reflection from the outside can impact on the wave climate on surrounding foreshore areas. The interaction of reflected waves is a complex process and not easily predicted without the assistance of high resolution modeling.

The CGWAVE model was set up with a varying mesh size relative to the transitional wavelength at each point in the model domain, providing six mesh nodes per wavelength (*i.e. as depth reduces in the shoreward direction, so does the wavelength and the spatial resolution of the mesh increases*). Six mesh nodes per wavelength is the minimum required for acceptable resolution. This resolution was necessary to resolve the relatively short wavelength to be considered (*i.e. corresponding to a wave period (T_p) of 3.5 seconds*).

The model domain, refer **Figure 18**, extends from a lake boundary condition located immediately offshore of Bardens Bay, resolving all coastal features within this domain (*coastal bluffs, seagrass benches, foreshore beaches and breakwater structures*).

Due to the large model size, simplistic monochromatic waves were applied along the lake boundary of the CGWAVE model to first assess the possible worst case wave direction for reflections (*to avoid multiple complex model simulations*). A full directional spectral description of the CGWAVE boundary wave condition was then undertaken for the worst case scenario to assess the impact of the breakwater structure on the surrounding foreshore areas of Bardens Bay. The worst case scenario was considered to be a wave direction from the south east.

Model results from the CGWAVE grid for the pre and post breakwater development are shown in **Figure 18** for boundary wave conditions representing the 1 year ARI event as follows:

H_s	=	0.4m
T_p	=	3.5 seconds
W_D	=	135^{o}TN

Output from locations around the foreshore (*as indicated on* ***Figure 18***) from both scenarios (*i.e. pre and post development*) are presented in **Figure 19.** Analysis of **Figure 19** indicates that there is no significant impact on the surrounding foreshore areas in terms of increase in significant wave heights (H_s) as a result of the breakwater (*there is a significant reduction in the lee of the breakwater*). In fact, minor reductions in wave height are experienced in most locations. This is most likely as a result of a combination of factors including:

- a reduction in total wave energy entering Bardens Bay as a result of the breakwater;
- the plan shape of the breakwater introducing complex interactions between incident and reflected wave patterns including spreading of wave energy; and
- a reduction in reflected wave energy from foreshore areas in the lee of the breakwater; and
- possibly attenuation of reflected wave energy from the foreshore to the south of the breakwater which previously would have been directed into Bardens Bay.

4.4 WAVE GENERATED CURRENTS

At the Trinity Point Marina site and nearby shoreline, waves are generated within the lake as a result of local wind blowing across relatively short fetches of shallow water. These type of waves are generally referred to as fetch limited waves and, as the name implies, are limited in magnitude by the lake environment. Waves at the site as a result are generally of relatively small magnitude and short period with resulting limited power. **Section 4.1** discusses the wave climate at the site as a result of detailed investigation.

The passage of waves through the relatively deeper water zones in the main body of the lake (*offshore zone*) results in negligible net translation of water particles. Wave motion in this case is primarily oscillatory, with only the existence of minimal net drift of water particles in the direction of wave propagation due to the existence of the phenomenon of mass transport (due *to radiation stress*). The principle wave generated currents are those which are generated within the shallower water close to the lake edge (*nearshore zone*) by breaking waves. As water depth decreases in the nearshore zone, the wave thrust (*or radiation stress*) increases significantly as wave motion transforms from primarily oscillatory to translational (*in the breaking zone*) causing currents to form. For waves breaking at an angle to a shoreline this driving mechanism can promote alongshore currents in the nearshore zone spreading beyond the wave breaking zone through lateral shear.

Initially it was thought that this nearshore wave driven mechanism may be a significant contributor in the creation of currents within Barden's Bay due to the presence of a shallow bench bed feature in the nearshore zone to the south of the proposed Trinity Point Marina with a relatively large fetch to the south - south east. This east facing foreshore presents the opportunity for relatively large waves from this direction to break at an oblique angle to the foreshore setting up currents promoting the circulation of water into and around the Bay that may be restricted by the construction of the marina breakwater.

Numerical modeling of the wave climate (*detailed in* ***Section 4.1***) indicated that waves of up to 0.75m are possible (*although rare*) offshore of this location. However, further analysis of the nearshore environment (***Section 6.2.1***) shows that the presence of dense and tall seagrass bed in the nearshore zone attenuates wave heights by up to 80% before they reach the breaking zone adjacent to shoreline. As a result, radiation stresses in the breaking zone, and the extent of the breaking zone are reduced markedly. Further to this observation, research (*Wallace et al, 1998*) has shown that mean longitudinal velocities beneath a seagrass canopy are reduced to almost zero with flow redirected over the canopy. Seagrass in this location within the wave breaking zone grows to the water surface creating the maximum resistance to flow being produced through the mechanism of wave induced radiation stresses reducing it to a negligible amount.

Current velocities caused by wave radiation stresses in the deep water zone are at least a magnitude of order smaller than those produced through the effects of wind shear (***Section 3.4***) which act concurrently. As a result, the effect of wave radiation stresses are negligible when considering hydrodynamic flow within this region of the lake.

5 HYDRODYNAMIC MODELING

Hydrodynamic and water quality modeling was undertaken to assess wind and tidal forced currents and the resulting convective mixing, and to examine diffusive mixing processes.

5.1 WIND DRIVEN CURRENTS

When wind blows over the lake, a portion of the momentum of the wind is transferred from the wind into the lake water. After a sustained period of wind in a certain direction, wind currents can develop in the lake. Typically these currents are strongest on the surface and generally form complex arrays of eddies and return current loops, which are governed by the bathymetry and the shape of the lake. These currents can be simulated using hydrodynamic models (*such as RMA-2*) by applying a directional wind shear to the surface waters of the lake. It is important to note that there is typically very little mixing across the shear zone between eddies. For example, an eddy which develops in the north eastern portion of Bardens Bay would primarily circulate water within Bardens Bay, resulting in minimal mixing with the greater lake. Therefore, it is important to assess the impact of wind driven currents on lake hydrodynamics at an appropriate scale.

In order to assess the wind driven currents, the 50th percentile average 5 hour duration wind velocities were applied from 8 directions (*refer to **Section 2.4** for details on the derivation of wind velocities*) to the surface of Lake Macquarie. The model was run in 'steady state' mode so that the wind currents could fully establish. **Table 5-1** presents the adopted wind velocities adopted for each direction.

Table 5-1: Wind input data.

Wind Direction	5 hour Duration 50th percentile Wind Speed (m/s)
N	1.3
NE	2.4
E	2.8
SE	3.3
S	4.0
SW	2.9
W	3.1
NW	2.4

Refer to **Section 2.4** for the methodologies used to derive the wind speeds

Each wind scenario was run for both the existing and post marina cases. As wind driven currents are strongest on the surface, the area proposed for the breakwater was completely blocked to convective flows, this assumption is considered conservative as some convection may occur below the breakwater. 50th percentile currents resulting from the application of each wind case in **Table 5-1** are presented in **Figures 7A**, **7B** and **7C**. The model results from both existing and post marina scenarios are provided, in which current velocities are thematically mapped as well indicated by a scaled velocity vector, which defines the current flow magnitude and direction.

The following conclusions were made from an assessment of the wind current modeling results:

- During 50th percentile wind conditions, current velocities range from 0.01m/s to 0.05m/s with the higher velocities generally occurring in the shallow shoreline regions of the lake;
- Winds from the south-east to the south-westerly directions resulted in the strongest wind currents in Bardens Bay. This is prominently due to the alignment of the bay however, the 50th percentile wind speeds are strongest from winds with a southerly origin;
- With the exception of the North Easterly wind, modeling indicated that all resulting current patterns would feature a current flowing into Bardens Bay along the western shoreline (*the proposed marina location*). Generally, 'out flowing' currents were observed on the eastern shoreline;
- Generally, a small eddy develops in the northern portion of Bardens Bay. While eddies do form part of the convective mixing process, it is noted that often very little mixing occurs across a shear zone between two eddies. Hence, in some cases convective currents in eddies do not result in any significant mixing between two regions of the lake. For example, the eddy in Bardens Bay simply circulates within the bay; and
- Modeling indicates that the introduction of the marina would have only a minor effect on wind driven currents in Bardens Bay. In some cases (*for example a southerly wind scenario*) the marina modeling case resulted in a stronger eddy forming in the northern portion of Bardens Bay. For the southerly wind case the breakwater causes some disruption of flow into the Bay. The implications of this is further examined in **Section 5.4**, which discusses particle tracking.

The effective of wind driven currents on the total mixing of Bardens Bay is further examined using particle tracking features in RMA. This is further discussed in **Section 5.4**.

5.2 TIDAL CURRENTS

Friction losses in Swansea Channel limit the tidal exchange between the lake and the ocean, resulting in a reduced tidal signal at the lake end of the channel. As a result, tidal flushing has a minimal effect on the hydrodynamics of the lake, especially in areas such as Bardens Bay, which are a considerable distance from the Swansea Channel. Notwithstanding this characteristic of the lake, hydrodynamic modeling of a full tidal cycle was undertaken to assess the tidal flushing in the Bardens Bay area.

Simulations were run for both the existing state and post marina scenarios, and in both scenarios, there was found to be minimal tidal velocities in the south-eastern portion of Lake Macquarie. The estimated peak velocities during a typical 30 day tidal cycle are presented in **Figure 8**. With reference to **Figure 8**, it is clear that the tidal currents are negligible in the Bardens Bay area. Hence, it can be concluded that the construction of the marina would have a negligible effect on tidal movements in Lake Macquarie.

5.3 DIFFUSIVE MIXING

Wind, wave and tidal driven currents transfer a volume of water from one section of the lake to another. These are referred to as a convective mixing processes. Non-convective mixing processes (*often referred to as diffusive processes*) can be significant contributors to mixing in lakes. Often, in areas such as Bardens Bay, where convective mixing is minimal, diffusion can be the governing mixing process.

The term diffusion refers to mixing processes which have a zero average velocity (*i.e. the mixing occurs equally in all directions*). In open water bodies diffusive process are often governed by turbulence created by wind and wave action. This process is stronger near the surface than at the bottom. Often diffusion is measured in the field by releasing a dye and observing the resulting plume over time. Generally, the centre of mass of the plume would represent the net convective current movements and the extent of spreading (*both laterally and longitudinally to the flow direction*) would represent the extent of diffusion. While such experiments have not been undertaken for this study, this process has been assessed using conservative (*i.e. non-decaying*) particle tracking features in the hydrodynamic models.

The rate of diffusion is proportional to both the concentration gradient (*of the tracer in this case*) and a coefficient of diffusion. A diffusion coefficient of 0.1 m^2/s was adopted for both longitudinal and lateral diffusion for all areas of the lake. This coefficient has been used in previous hydrodynamic assessments of regions within Lake Macquarie. As the breakwater would form a significant blockage of the water column the coefficient of diffusion across the breakwater was reduced to 0.01 m^2/s. The following section discusses the particle tracking assessment which incorporates diffusive and convective mixing processes.

5.4 WATER QUALITY MODELING

A RMA-11 water quality modeling was used to combine both convective (*both tide and wind current applied*) and diffusive mixing in the Bardens Bay area. This was achieved by releasing a conservative tracer (*i.e. does not decay*) at the outlet of Lake Petite (*located to the north of Bardens Bay).* The tracer was released at a constant rate for the entire simulation. The resulting plume is then tracked over a four day period, allowing for the combined effect of convective and diffusive mixing processes to be examined concurrently. This modeling exercise was conducted for both the existing conditions and the proposed marina case. As previously discussed, modeling of the post marina scenarios assumed that the breakwater would form a complete blockage to convective processes and a partial blockage to diffusive processes.

Two four day simulations were undertaken to examine and compare the existing and post marina hydrodynamics relating to the water quality of Bardens Bay, these are described below.

<u>High Energy Simulation</u>

The first simulation emulates a ‘higher energy’ meteorology scenario, with wind patterns indicative of a typically southerly frontal change occurring in winter. A 5th percentile south-westerly wind (*7.8 m/s*) was adopted for the first 24 hours of the simulation. Followed by a weaker 25th percentile south-westerly wind (*6.3 m/s*) for day two. Wind speeds oscillated between calm and a 50th percentile south-easterly wind (*3.3m/s*) for the remaining 48 hours. This wind configuration was applied to both the existing and post marina states. The tracer plume from both simulations is presented in 12 hours increments in **Figures 9A** and **9B**.

As shown in **Figure 9A**, the wind currents derived from the strong south-westerly winds govern mixing during the first 48 hours. It is clear in that the disturbance to the flow caused by the marina does cause a diversion to the wind driven currents, reducing the convective mixing in Bardens Bay during a strong wind conditions. As the wind strength reduces, the mixing becomes governed by diffusion. This is evident in both **Figures 9A** and **9B**, in which the tracer plume appears to ‘fatten’ (*in the later 48 hrs*) and well defined concentration gradient forms. The impact of the marina is evident by the increased concentration gradient in Bardens Bay, which results in an increased concentration of tracer in the northern portion of Bardens Bay. However, as shown in **Figure 9B**, this difference is minimal.

<u>Low Energy Simulation</u>

The second scenario simulates ‘lower energy’ meteorology conditions, for which a constant 50th percentile North Easterly wind (*2.4 m/s*) was adopted, this is indicative typical metrological conditions during good weather in summer. This wind configuration was applied to both the existing and post marina scenarios. The tracer plume from both simulations is presented in 24 hour increments in **Figure 10**.

As shown in **Figure 10**, diffusive processes govern mixing during lower wind speed scenarios. Again, the impact of the marina is evident by the increased concentration gradient in Bardens Bay. This results in an increased concentration of tracer in the northern portion of Bardens Bay. However, as shown in **Figure 10**, this difference over time is minimal.

5.5 MARINA FLUSHING

A preliminary assessment of the marina flushing rate was undertaken in order to gain an understanding of the rate of water exchange through the marina breakwater. Estimated flushing rates are to be used as part of the marina water quality assessment which was being undertaken at the time of writing.

As discussed in **Section 5.4**, diffusive processes were found to govern lake mixing during ‘low energy’ average daily conditions, hence, only diffusive mixing processes were assessed (*i.e. any convective mixing is ignored*), this is considered conservative. A steady state 1-D model was used for this initial marina flushing assessment.

The estimated flushing rates would be governed by the rate of diffusion through the breakwater as well as the diffusion out from the western marina entrance. In order to estimate the volume of water transferred through each of the above diffusion paths, the path length (*assumed distance between the marina and the open lake*), path width (*e.g. the length of the breakwater*) and the coefficient of diffusion were estimated. These parameters are presented in **Table 5-2**.

Table 5-2 – Diffusion Parameters

	Breakwater	**Marina Entrance**
Coefficient of Diffusion	0.01 m^2/s	0.1 m^2/s^
Path Width	665 m	250 m
Path length	30 m	150 m

^The marina entrance isn’t impeded by the breakwater so the coefficient of diffusion adopted for the greater lake (*as discussed in **Section 5.3***) were adopted.

Note: a flow path length of 30 meters was adopted for the marina breakwater despite the actual structure being only 5 meters wide. This was intended to account for the increased flow path resulting from water having to pass under the breakwater, which extends to a depth of -3.7 to -4.7 m AHD.

Using the parameters defined in **Table 5-2**, the daily flushing rate was estimated to be **7.4%** which equates to 25.2 ML of water exchanged between the marina harbour and the greater lake each day (*Marina volume estimated to be 400 ML, using 12 D CAD software*). Full calculations are provided in **Appendix C.**

Given there is uncertainty in the estimation of this diffusion rate through the breakwater a sensitivity analysis was conducted using a low , medium and high coefficients of diffusion for the breakwater. The associated parameters adopted and resulting daily flushing rates are outlined in **Table 5-3**.

Table 5-3 – Diffusion Sensitivity Analysis: Parameters and Results

Diffusion Scenario	**Coefficient of Diffusion** (*Through the marina breakwater*)	**Daily Flushing Rate**
Low diffusion	0.005 m^2/s	5.3 %
Estimated diffusion	0.01 m^2/s	7.4 %
High Diffusion	0.02 m^2/s	11.6 %

As shown in **Table 5-3** the preliminary flushing rate estimations are sensitive to the coefficient of diffusion adopted for the marina breakwater. It is recommended that this uncertainty be considered if these estimated flushing rates are to be used for any marina water quality impact studies.

5.6 CONCLUSIONS

Hydrodynamic and water quality modeling of both convective and diffusive processes was undertaken to examine the impact of the proposed marina on mixing in Bardens Bay. The modeling concluded that the disturbance to the water column caused by the proposed marina would have a minimal impact on mixing in Bardens Bay during 'low energy' meteorological conditions, where diffusive processes govern mixing. During 'high energy' meteorology scenarios, the marina was found to potentially divert the wind driven currents (*especially from winds with a southerly origin*), resulting in a moderate reduction in mixing in Bardens Bay.

However, the moderation due to high energy events would not significantly impact on the overall average mixing regime of the Bay because of the rare nature of these more extreme events.

The influence of the proposed development within Bardens Bay on the hydrodynamic and water quality condition of adjacent regions of the main body of Lake Macquarie are therefore considered minimal.

6 SEDIMENT BUDGET MODEL

Due to the extensive presence of vegetation (*both sea grasses and foreshore vegetation*) at the Trinity Point site, the modelling of sediment movements using direct application of generic shoreline change models is inappropriate. These models assume a full sediment availability over the entire extent of the active beach profile and would provide a gross over-exaggeration of sediment movements. This methodology would provide an unrealistic representation of processes and changes due to development of the marina.

To account for the influence on sediment movements by near shore and foreshore vegetation, a custom process-based sediment budget model (*based on the result of numerical modelling of individual elements involved in the overall process*) has been developed. This model provides a more realistic representation of actual sediment movements and has been verified through analysis of historical aerial photography of the site.

Comparison of the existing and the post (*proposed*) marina conditions has been undertaken using the model to establish the likely relative changes to sediment movements and shoreline position if the marina was to be constructed.

The model developed was based on descriptions of the wave climate in the nearshore zone at several points along the foreshore and the application of modified alongshore bulk sediment transport formula to calculate potential transport rates. Modifications to the alongshore transport formula included the following considerations due to dense seagrass vegetation in the nearshore zone:

- attenuation of wave heights; and
- the limited availability of sediments to movement.

The formula used for potential alongshore transport rates was derived by Kamphuis (*1991*) based on extensive series of hydraulic model tests and takes into account the following variables:

- breaking wave heights and angle to the shoreline;
- wave period;
- beach slope in the breaking zone; and
- typical sediment grain size.

The Kamphuis formula was shown to be valid for available field results for sandy beaches as well as gravel beaches. Although these verification results were primarily for open ocean beaches the development, model testing and field verification of the formula over a wide range of all the influencing variables gives confidence for it's application at the Trinity Point site.

6.1 WAVE CLIMATE DESCRIPTION

Section 4 describes the numerical modeling undertaken to produce wave climate statistics in the vicinity of the proposed Trinity Point Marina site. **Figure 11** indicates locations at which the nearshore wave climate was analysed from the wave climate modeling to produce joint occurrence of wave heights and wave directions in terms of percentage probability. Wave direction was divided into 64 sectors to provide adequate resolution for sediment transport modeling. (*An example of a joint wave height - wave direction probability of occurrence matrix is presented for Location 2 in* ***Appendix B***.)

Using the wave heights, the relative angle of approach to the shoreline and the percentage probability of occurrence, the contribution to annual sediment movements can be calculated for each joint wave height-direction occurrence. The net summation of all these contributing events gives an indication of the potential sediment transport rate. Wave climate joint occurrence matrices were developed for each of the locations in **Figure 11** for both the existing and post marina conditions.

In general the wave climate (*and subsequent potential for sediment transport*) reduces moving north from location 1 as the foreshore become less open towards the large fetch lengths from the South East quadrant and oriented more to the North East. Inspection of wave height exceedance values presented in **Table 4.1** verifies this characteristic.

6.2 NEARSHORE SEA GRASS BED

It was necessary to modify the sediment transport model to account for the presence of dense seagrass beds in the nearshore zone at the site. As discussed above, the effect of the seagrass bed on sediment transport rates is twofold:

- attenuation of wave heights; and
- the limited availability of sediments to movement though binding of the lake bed sediments.

Figure 12 presents a schematic section of the foreshore environment at the site. Long and dense seagrass colonises a relative shallow bench which characterises the nearshore zone. Seagrass densities of 500 - 600 plants/m^2, and lengths of up to 60 cm (*average of 30cm*) are reported by The Ecology Lab (*2007*) in this shallow bench in the nearshore zone.

The width of the seagrass bed varies from approximately 80m at the widest point offshore of the Eastern foreshore to less than 5m along the North Eastern foreshore in what is classed as a “fringing bed”. The magnitude of attenuation of wave heights by the seagrass bed is similarly varied as a result, with the Eastern foreshore offered more protection from the extensive width and densities of the bed in this location.

6.2.1 Wave Height Attenuation

Cox, Wallace and Thomson (*2003*) present a model to determine the rate of attenuation with distance across a seagrass meadow based on identified variables such as seagrass height, water depth and wave period. This model has been applied to the specific environment at the site and incorporated into the sediment transport model to reduce wave heights from the model output location (*at the edge of the seagrass bed*) to the nearshore breaking zone.

For modeling purposes the representative seagrass density chosen was 550 plants/m^2. This assumption was based on site inspections undertaken by PatBrit and information obtained from the Ecology Lab (*2007*).

Wave transfer coefficients (K_w) representing the attenuation of wave heights at the Eastern and North Eastern foreshore are presented below in **Table 6.2**. Sensitivity of wave attenuation to the water depth relative to mean lake level (*taken as MSL*) is also indicated.

Table 6-1: Seagrass wave attenuation

Water Level (m above MSL)	Water Level ARI (yr)	K_w	
		North Eastern Foreshore	Eastern Foreshore
0	-	0.71	0.18
0.5	2.5	0.90	0.59
1.0	20	0.96	0.82
1.5	>100	0.99	0.94

6.2.2 Potential Sediment Transport

The model developed for determining the potential bulk sediment transport rates using the Kamphius formula (**Section 6**) involved the application of wave transfer coefficients due to seagrass attenuation of wave heights in the nearshore zone (**Section 6.2.1**) to wave climate statistics (**Section 6.1**). **Table 6.2** presents the resultant rates for the existing scenario.

Existing Scenario

Table 6-2: Existing potential bulk sediment transport rates (ignoring sediment limitation discussed in Section 6.2.3)

Foreshore Location	Potential Sediment Transport Rate (m^3/year) *(Net direction is reported as positive in the northward direction)*			
(Water Level above mean water level))	*(0m)*	*(0.5m)*	*(1.0m)*	*(1.5m)*
1	82	890	1700	2260
2	85	900	1750	2300
3	84	900	1730	2280
4	300	490	550	590
5	250	350	400	430
6	180	290	330	350

Potential sediment transport rates shown in **Table 6.3** demonstrate the significant increase in the potential to transport sediment along the foreshore at the site with increasing water level due to the corresponding decreasing influence of the seagrass in attenuation wave heights. PatBrit (2007) reports on the variation in mean tidal planes in Lake Macquarie in addition to the possibility of extreme elevated still water level events. The occurrence of these rare water levels when coinciding with any wave height could potentially see high levels of sediment transport in a single event. This phenomena is less pronounced along the north eastern foreshore as seagrass in this location is a less dominant feature in the nearshore zone.

Post Marina Scenario

The breakwater structure for the marina is proposed to be a low-reflection double walled partial depth vertical wave screen. **Appendix A** presents a preliminary concept design for this structure. Numerical models are unreliable in simulating the complex processes and large energy losses due to wave overtopping, breaking and turbulence which would be present at such a structure. For consideration of these factors in the sediment transport model, the use of selected coefficients of reflection and transmission at the breakwater location where applied to the numerical modeling of wave data using STWAVE.

Berrington and Cox (*1997*) report that a similar double walled structure to that proposed at Trinity Point, maintained a coefficient for both transmission and reflection of less than 0.3. The post marina wave climate in the developed sediment model takes into account a transmission coefficient and reflection coefficient of 0.3 to reflect the current concept design of the marina breakwater structure. The angle of wave reflection (α_r) in simulation is assumed to equal to the incident wave angle (α_i) (both with respect to the breakwater alignment). The wave angle of transmission (α_t) in simulation is assumed to be unaltered by passage through the breakwater.

For all points on the foreshore that are within the zone of reflected energy influence for a particular wave condition, two components for sediment transport are present. The unreflected incident wave height (H_i) and direction, and a reflected wave height ($H_r = 0.3H_i$) and direction. In the case of points within the zone of influence of transmitted energy the transmitted wave height ($H_t = 0.3H_i$) is the only component. As potential sediment transport rates are proportional to the wave height squared, the relative influence of reflected and transmitted wave heights ($0.3H_i$) is effectively 9% of the influence of the corresponding incident wave. However, the impact on bulk sediment transport rates can be significant in areas where:

- the incident wave is blocked (*leeward of the breakwater structure*); or
- the orientation of the breakwater structure to the beach is such that the reflected wave acts in the same direction as the incident wave and is an addition to the transport rate.

Figure 13 demonstrates a schematic representation of this modeling concept. **Table 6.3** presents the resultant potential sediment transport rates for the post marina scenario.

Table 6-3: Post marina potential bulk sediment transport rates (ignoring sediment limitation discussed in Section 6.2.3)

Foreshore Location	**Potential Sediment Transport Rate (m^3/year)** *(Net direction is reported as positive in the northward direction)*			
(Water Level above mean lake level))	***(0m)***	***(0.5m)***	***(1.0m)***	***(1.5m)***
1	82	890	1700	2260
2	75	780	1500	2000
3	70	750	1450	1900
4	570	900	1050	1100
5	-8	-13	-15	-17
6	0	0	0	0

6.2.3 Sediment Availability Limitation

Figure 14 gives a schematic representation of the distribution of potential sediment transport in the nearshore zone.

The distribution and magnitude of the potential alongshore transport of sediment vary within the surf zone, from zero at the shoreline to a maximum at a point approximately 80% of the distance to the wave breaking point. In cases where sediments are limited within this distribution, a proportion of the potential sediment transport remains unrealised. In the Trinity Point case, the limitation to sediment movement is due to the binding of sediments due to extensive vegetation, both in the nearshore and backshore zones. Available sediments for transport are those which make up the narrow beach between these two areas. In general this beach area is of the order of 1-2m in width.

Site inspection and seagrass mapping by The Ecology Lab (2007) indicate that, in general, the extent of seagrass growth is up to 0.1m below the mean lake level. To obtain an estimate of the proportional amount of sediment available relative to the potential sediment transport distribution across the nearshore zone the following were calculated for all representative wave heights within the wave climate distribution:

- wave setup above mean lake level (*and corresponding plan location of this point on the beach face*);
- plan location of the edge of the seagrass bed relative to mean lake level; and
- the overall width of the potential sediment transport distribution.

Subsequently, the proportion of the over all distribution width for which sediment was available was calculated and the proportion of the transport distribution estimated for each wave height scenario. Based on a weighted average of these calculations, the actual sediment transport rates were estimated to be approximately 25% of the potential rate for both the Eastern and North Eastern foreshores. These values have been adopted for both the existing and post marina scenario.

The calculation of the above proportions were undertaken assuming a average mean lake level. PatBrit (*2007a*) reports on the variation in mean tidal planes in Lake Macquarie in addition to the possibility of elevated still water levels. The variation in water level, and the location of this level relative to the available sediments, would influence the actual sediment transport rates along the foreshore significantly. Hence the proportions, and resultant estimated actual sediment transport rates should be considered as indicative of an order of magnitude only. However, for the purposes of studying the relative impact of the proposed marina on existing conditions, this indicative average condition is considered sufficient.

The estimate of actual sediment transport rates is also complicated by the variety of “sediment” that makes up the foreshore. Sediments range from organic materials (*such as dead seagrass and deteriorating tree matter*), to a variety of sizes of inorganic sand material, and litter. The consideration of a representative sediment grain size again gives an indication of relative magnitude of changes to the sediment transport rates with the construction of the proposed marina breakwater structure.

Table 6.4 presents the estimated bulk sediment transport rates for the both the existing and post marina scenario.

Table 6-4: Estimated actual bulk sediment transport rates

Foreshore Location	**Estimated Actual Sediment Transport Rate (m^3/year)** ***(Net direction is reported as positive in the northward direction)***	
(Scenario)	***(Existing)***	***(Post Marina)***
1	10	10
2	20	20
3	30	30
4	75	140
5	60	-2 *(negligible)*
6	45	0

Figures 15 and **Figure 16**, give a overview of sediment transport budgets for the modelled existing and post marina scenarios respectively. These are discussed further in **Section 6.4**. **Table 6.4** presents values for the net bulk transport that occurs per annum. A net annual zero transport rate does not necessarily mean that there is no movement of sediment on a daily basis, or on a micro scale.

6.3 AERIAL AND SITE PHOTOGRAPHY ANALYSIS

Analysis of historical aerial photography data was undertaken to verify the numerical process-based conceptual model of sediment transport at the site. Historical aerial photographs of the site were sourced from Lake Macquarie Council dating from March 1950 to the present day. Ortho-rectification and spatial alignment and a comparison of the shoreline position was undertaken of each. Poor quality and the large oblique angle of some of the photos meant that a number of the photos could not be included in the analysis. However, photos from 1969 onwards were able to be analysed giving almost forty years of shoreline change to assess.

Figure 17 presents the comparison of shoreline position for three of the years that aerial photography was flown during the above mentioned forty years. As indicated by the figure, the shoreline has undergone recession over the period of analysis. The eastern shoreline and north eastern shoreline have undergone recession of the order of 5m (*approximately 0.13m/year*) and 10m (*approximately 0.25m/year*), respectively. The lost sediments from these shorelines is seen to be accreting in Shallow Bay, resulting in the growth of the bay shoreline and shallowing of water depths in the Bay.

This correlates well with the estimates of actual sediment transport rates produced by the sediment budget model for the existing case.

Further evidence of the nature of sediment movements at the Trinity Point site where assessed through inspection of the site. Selected photographs taken during these site visits are included on the following pages to augment modeling outcomes.

Photograph 1 below indicates the general nature of the eastern foreshore with a narrow sandy beach bordered by vegetation in both the onshore and offshore directions. This vegetation provides limitation of the supply of sediments to transporting mechanisms. Collected dead seagrass vegetation along the shoreline also serves to protect the foreshore through absorption of wave energy as it reached the shore. The presence of large trees projecting into the nearshore zone is an indication of the gradual landward recession of the shoreline.

Photograph 2 , also of the eastern foreshore, below indicates this process more clearly with one of these large trees succumbing to the recession. This was common along the entire foreshore and a clear indication of the previous and current recessive nature of the shore.

Photograph 3 below, taken along the transition between the eastern and northern shorelines, shows a fallen tree lying in the nearshore zone perpendicular to the shoreline effectively forming a “groyne” trapping sediments on the updrift side (once the trap is full, bypassing will occur). The build up of sediments on what is the southern side of this “groyne” indicates the general movement of sediments from the south to the north and then north east along the foreshore. This is reflected in the modeling outcomes.

Photograph 4 below gives a representative indication of the nature of the north eastern foreshore with less foreshore vegetation present (limited generally to grass on top of the back beach berm) and a relatively wider strip of sediment in the nearshore zone (due to less seagrass vegetation) . The grass foreshore vegetation is more susceptible to undercutting than larger trees and shrubs and may be one of the causes of relatively larger rates of actual sediment transport and shoreline recession, despite reducing potential transport rates. It is the supply of sediments that govern the actual transportation rates. Further to the west, the shoreline become more vegetated again and analysis of historical photos shows a reduced recession rate in this area.

Variation in the amount of vegetation along the foreshore will lead to differing rates of sediment transport and corresponding recession/accretion rates for sections of the shoreline. Where trees have fallen into the nearshore zone forming “groynes” the build up of sediment on the up drift side will cause an accelerated erosive potential on the down drift side, also locally affecting transport and recession/accretion rates. The sediment budget model does not attempt to resolve these localised impacts but provides a regional representation of the sediment processes. However, the evidence provided by the examination of these local effects provided input to the conceptual model of coastal processes and provides a verification of the predictions of the sediment transport calculations.

6.4 SEDIMENT BUDGET COMPARISON

Figures 15 and **Figure 16**, give a overview of sediment transport budgets for the modelled existing and post marina scenarios respectively. For each scenario estimates of the following are indicated:

- estimated potential sediment transport rates;
- estimated actual sediment transport rate;
- identified zones of erosion and accretion; and
- Indicative future shoreline position.

The following discussion refers in general to the Figure for the corresponding scenario.

*Existing Scenario (**Figure 15**)*

Sediment is supplied to the foreshore from the eroding coastal bluff feature of Bluff Point. Waves erode the base of the bluff, undermining the cliff face resulting in sporadic collapse of sections of the cliff into the nearshore zone. These collapsed pieces of rock are eroded further by wave action supplying sediment for transport along the foreshore. This transport essentially occurs away from the bluff along the adjacent foreshore in both directions (*to west and north*). Little, if any, transport would occur from one foreshore to the other through bypassing of Bluff Point. The supply of sediments to the adjacent foreshores is limited due to the relatively slow process of erosion of the rocky cliff face. The limited supply causes a deficit in the supply of sediment relative to the demand from transporting processes, the coastal plan shape (*recurved spit*) is therefore not in equilibrium with the wave climate and is receding at a reasonably constant rate along the length of the foreshore, supplying further sediment. This recession is retarded relative to the potential rate due to the presence of vegetation limiting the supply of sediments from the length of the foreshore.

Potential rates of sediment transport are from South East to North West along the existing foreshore, reducing in magnitude in the same direction to eventually be effectively zero at the shallow inlet to the west of the proposed marina site. However, because of the reducing level of protection offered by seagrass vegetation and the increasing supply of sediment due to shoreline recession, the actual sediment transport rates increase moving north along the length of the foreshore. These actual rates are significantly less that the potential rates due to limited availability of sediments due to the vegetation (*both nearshore and onshore*).

The Trinity Point site foreshore has the coastal plan form of a recurved spit. This plan form is typical of situations where a net alongshore sediment transport occurs in one direction building a spit in response to the incident wave climate which in turn is refracted around the spit. The spit grows as sediment transported along the foreshore is deposited at the end of the spit where the transport rate reduces to zero. In this case, in the shallow inlet to the west of the proposed marina site.

*Post Marina Scenario (**Figure 16**)*

Along the eastern foreshore the impact of the marina on sediment transport rates is minimal. There may be some reduction in the rate of recession. This would be a result of reflected wave energy from the marina breakwater providing a slight reduction in the net effect of waves from the SE sector. The effectiveness of the built breakwater in terms of reflectivity would influence this possible outcome.

Closer to the marina on the North East facing foreshore the influence on sediment transport is more pronounced. Immediately adjacent to the breakwater the potential for sediment transport is notably increased due to focusing of wave energy through reflection. The proposed breakwater design includes a shoreward section of the breakwater which would allow alongshore sediment movement to pass freely into the marina. If this section spans the surf zone, the actual sediment transport rate would also increase at this location. As a result, a localised increase in shoreline recession may initially occur. Again the effectiveness of the built breakwater in terms of reflectivity and the final design of the shoreward section would influence this possible outcome.

Once inside the protection of the marina breakwater the wave climate along the North Eastern foreshore would be significantly reduced. Sediment transport rates correspondingly would also rapidly reduce. In fact, the potential direction for transport is reversed, however the magnitude of this reversed potential and subsequent actual rate is minimal. As a result of the reduced wave climate within the marina and reduction of sediment transport rates to negligible amounts, the sediments moved northwards along the Eastern foreshore and passed through the breakwater structure would be quickly deposited. The shoreline would accrete immediately up drift of the breakwater and a sand lobe will form at a rate of approximately 60m^3/year (*equivalent to the rate of supply from the south*). The growth of this sand lobe would be relatively slow due to the small volumes of actual sediment transport which occur (*or would occur*) at the site.

Following the construction of the breakwater structure there would be minimal potential or actual transport west of the structure. Growth of the spit and accretion in the shallow bay to the west of the development would stop with the possibility of a minor shoreline alignment change at the end of the spit. There would be no significant change to coastal processes ad sediment transport on the eastern facing foreshore to the south of the breakwater.

6.5 LONG TERM OUTCOMES

Sediment movements at the Trinity Point site have been shown to be largely dependant on the availability of sediments to the processes that drive such movements. Theoretical potential wave driven sediment transport rates are an order of magnitude greater than the actual expected rates at the site. Theoretical erosive potential of the foreshore is significant due to the limited supply of sediments from the longshore transport of sediments from the south of the site at Bluff Point. However, extensive vegetation in the nearshore and foreshore zones significantly limits erosion through a restriction in the sediment supply to satisfy the potential rate.

Despite the limitation of sediments through the natural protection offered by vegetation, some minor recession of the shoreline is still evident at the site. Regardless of the development of a marina and breakwater structure, consideration should be given to enhanced protection of the foreshore through engineered measures. This does not necessarily involve the implementation of hard structures but could involve soft engineering measures such as beach nourishment or enhanced natural vegetation stabilisation of the foreshore. Without foreshore protection, the reserve between the lake and the proposed development would become increasingly narrowed over time. This may be accelerated if the strip of large trees located along the foreshore are allowed to be undermined and lost to erosion of the foreshore (*as demonstrated by Photograph 2*).

Results from the modeling of annual sediment budget at the Trinity Point site indicate that the development of a marina and corresponding breakwater structure would not have a significant impact on the surrounding environment. There may be an initial localised increase in the potential for erosion immediately south of the marina, and a increase in the potential for accretion immediately around the breakwater structure. The design of the breakwater structure and any implemented foreshore protection works would have a significant bearing on the exact location and volumes in the realisation of this potential change. These localised changes to the transport of sediment and resulting shoreline realignment would occur in a section of the foreshore where sea grass exists as a “fringing bed” only, limiting an impact that these changes may have on the overall seagrass community at the site.

The breakwater structure for the marina would generally cause a stabilisation of the foreshore area to the west of the structure and reduce the rate of accretion of sediments from lake sources, and subsequent in-filling of the shallow inlet to the west of the proposed marina site. Despite this stabilisation of alongshore movements, increased boat traffic within the marina area could provide a potential source of continued erosion of the foreshore within the bounds of the marina. This mechanism would result in the formation of an increased erosion scarp in the back beach area and deposition of sediments in the offshore direction. This could cause aesthetic and possible operational issues for the marina, and potential impacts on the fringing seagrass in this location. These potential impacts could be mitigated through the following measures:

- the implementation of a “no wash” zone within the marina area and speed limits along navigational approaches; and
- relatively minor foreshore protection edge treatment such as vegetation restoration and management

6.5.1 Climate Change

PatBrit (*2007a*) describes the possibility of global climate change as it would influence coastal processes for the Trinity Point site. The most significant effect of global climate change on sediment processes may be sea level rise associated with the so called “Greenhouse Effect”. 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. The change to long term actual alongshore sediment transport rates would therefore be expected to be minimal. However, the recession involved would impact on land based developments, and/or foreshore reserve widths, and should be included in planning and design considerations.

On 11th October 2007 a meeting with officers from the Department of Environment and Climate Change (*DECC*) was undertaken to discuss the latest global sea level rise predictions from the IPCC. Based on the latest predictions of sea level rise, DECC advised that, in the absence of a absolute departmental policy, the following levels should be considered as an upper bound estimate:

- a 0.45m rise by 2057; and
- a 0.90m rise by 2107.

These sea level rise levels are considered at the upper end of current predictions and include conservative estimates of sea level rise due to polar ice melt, and localised effects apparent for the NSW coast. In further discussions, DECC officers suggested that a range of sea level rise scenarios, and the corresponding impacts on coastal processes, should be considered. The ranges based on the latest IPCC predictions and discussions with DECC are as follow:

- 0.1m - 0.45m rise by 2057; and
- 0.2m - 0.90m rise by 2107.

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 Trinity Point development site if predicted future sea level rise is realised.

For the protected shoreline within the small unnamed inlet to the north west of the site, the drowning of low lying land would most likely occur as the mechanism for recession. **Figures 20** and **21** indicates the possible extent of this low level land drowning for the 50 and 100 year sea level rise predictions accordingly.

On the more exposed eastern foreshore the mechanism for recession would most likely be the readjustment of the shoreline as described below.

A long term rise in sea level would result in a long term recession of the shoreline which is commonly described by the Bruun Rule. The Bruun Rule assumes an equilibrium beach profile that keeps pace with a rise in sea level without changing it's fundamental shape. To do this the profile is translated both upwards (*equal to the rise in sea level*) and shoreward (*shoreline recession*). The resultant shoreline recession is an amount such that the amount of erosion from the shoreline equals the amount deposited in the nearshore zone to account for the upwards translation of the profile.

Bruun (*1962*) proposed a methodology to estimate shoreline recession due to sea level rise, the so called Bruun Rule. 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. This profile is re established by shifting it landward. The concept is shown graphically in Bruun (*1983*), and can be described by the equation (*Morang and Parson, 2002*):

$$R = \frac{S \times B}{h + d_c}$$

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, that is 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.

Using the Bruun rule formula, long term recession due to sea level rise at the site can be estimated as within the following ranges, based on sea level rise scenarios discussed above:

- 0.75m - 3.5m by 2057; and
- 1.5m - 7.0m by 2107.

Along the length of the shoreline from the eastern exposed foreshore to the western protected foreshore there will be a transition between the mechanisms for foreshore recession due to sea level rise. As the wave climate reduces spatially moving in this direction, due to the natural plan form of the coastline, the upward and shoreward translation of the foreshore profile, described by the Bruun rule, would not occur. With the introduction of the proposed breakwater structure to provide a protected wave environment for the marina, this transitional zone is likely to be moved southward as a result.

Waves at the site are fetch limited *(not depth limited)* and, as such, an increase in mean water level in the lake would not impact on the wave climate at the site, if the foreshore slope and vegetation are able to adapt in kind. Climate change impacts due to a possible increase in the frequency and intensity of storms events are difficult to quantify given the uncertainty (*or whether it will occur at all*) in the prediction of this phenomena. However, **Section 4.2** reports that due to the asymptotic nature of extreme wind events and the fetch limited wave environment, wave events of 50yr ARI, or greater, are of a similar magnitude. This indicates that if increased storminess is realised as a result of potential climate change, the impact on extreme wave events would be minimal. However, the ARI of such events may reduce *(i.e. extreme events may occur more often)*. Increased erosion of the foreshore may be possible if this phenomena is realised due to the episodic nature of wave related erosion. Stabilisation of the foreshore would mitigate this impact.

Changes of shoreline alignment, and resultant erosion and accretion, are possible with the realisation of such a phenomenon. However, the future impacts of this would occur regardless of the development of a breakwater and marina.

7 CONCLUSION & RECOMMENDATIONS

Numerical modeling of hydrodynamic, water quality and sediment transport processes at the site of the proposed Trinity Point marina was undertaken to assess the likely effect of the proposed marina on these processes. These investigation indicate that the proposed marina and associated breakwater structure would be unlikely to significantly impact on the surrounding environment as a result of alterations to these processes.

Hydrodynamic and water quality modeling of both convective and diffusive processes was undertaken to examine the impact of the proposed marina on mixing and pollutant dispersion in Bardens Bay. The hydrodynamic environment at Bardens Bay on a day to day basis could be considered a low energy regime, with driving processes on average causing convective flows of less than 0.05 m/s. The modeling undertaken indicates that any disturbance to flow into and around Bardens Bay caused by the proposed marina would have a minimal impact on mixing and pollutant dispersion in the Bay during 'low energy' meteorology conditions, where diffusion within the water column governs these processes.

During 'high energy' meteorology scenarios, the marina breakwater structure was found to cause a damping of flow caused by wind driven currents, resulting in a moderate reduction in convective mixing in Bardens Bay. The impact on mixing processes during these high energy events results in the increasing of the time required to achieve the same level of mixing as the existing scenario, rather than impeding mixing. This moderation would not significantly impact on the overall average mixing regime of the Bay because of the infrequent nature of these events.

The influence of the proposed development within Bardens Bay on the hydrodynamic and water quality condition of adjacent regions of the main body of Lake Macquarie are negligible.

The foreshore at the site has been shown to be currently of a mildly erosive nature. The implementation of the breakwater structure to protect the proposed marina from wave action would provide stabilisation for the foreshore down drift (*to the north-west*) of the structure. Updrift (*to the south-east*) of the proposed structure there would be the potential for a initial localised relative increase in erosion rates due to the alignment of the adjacent foreshore relative to reflected wave energy. A corresponding accretion of sediments immediately down drift of the structure would occur as the growth of a sand 'lobe'. These localised changes to sediment transport rates would occur along the section of foreshore facing north-east where sea grass is prevalent as a "fringing bed" only, limiting the impact on the main sea grass community.

Mitigation of this change to sediment transport rates may be achieved through the implementation of localised foreshore protection measures. These measures would be minor in scale due to the relatively low to moderate nature of the depth fetch limited wave climate. Minor mitigation measures could include:

- periodic nourishment of the up drift foreshore using sand from the associated sand 'lobe' formed within the marina (*transported most likely by truck*);
- nourishment of the up drift foreshore with an imported sediment of increase mean size to limit actual sediment transport from this location; or
- restoration of foreshore vegetation and vegetation management to ensure maximum stabilising vegetation is maintained.

The potential for increased boat wash to cause erosion within the marina area could also be mitigated by the implementation of relatively minor foreshore protection measures in and around the marina. The enforcement of navigational constraints such as “no wash” zones within the marina and speed limitations and exclusion zones on the approaches to the marina, would also limit any affect on the surrounding environment.

Sea level rise resulting from the “Greenhouse Effect” is now widely recognised as occurring, even if a degree of uncertainty still exists in predictions of actual levels. The implementation of the breakwater structure to protect the proposed marina from wave action may cause the transition zone between flooding of low lying land and shoreline adjustment mechanisms for shoreline recession due to sea level rise to move southward along the foreshore. However, mitigation of sea level rise impacts (*if realised*) and associated flooding regime changes would be required regardless of which mechanism is governing shoreline recession. Recommended mitigation and planning measures for sea level rise include the following:

- stabilisation of foreshore areas through vegetation restoration, replanting and management to limit long term shoreline erosion due to longshore sediment transport;
- provision of a foreshore reserve as a buffer to shoreline recession due to sea level rise allowing the foreshore to adjust in response. The buffer allows for regular monitoring (*of the foreshore at the site and updated scientific information*) to enable the evaluation and continual adaptation of planning strategies against a changing coastal environment. Uncertainty in postulated future increases in the frequency and intensity of storm events and sea level rise due to climate change factors necessitate the implementation of such adaptive management options;
- the setting of development grading and floor levels in accordance with flood levels which take into consideration recommended future sea levels and the expected life span of the particular development component; and
- the design of structures in the foreshore and nearshore areas which allow for foreshore changes and future adaptive design measures to be implemented in response to sea level rise, if realised.

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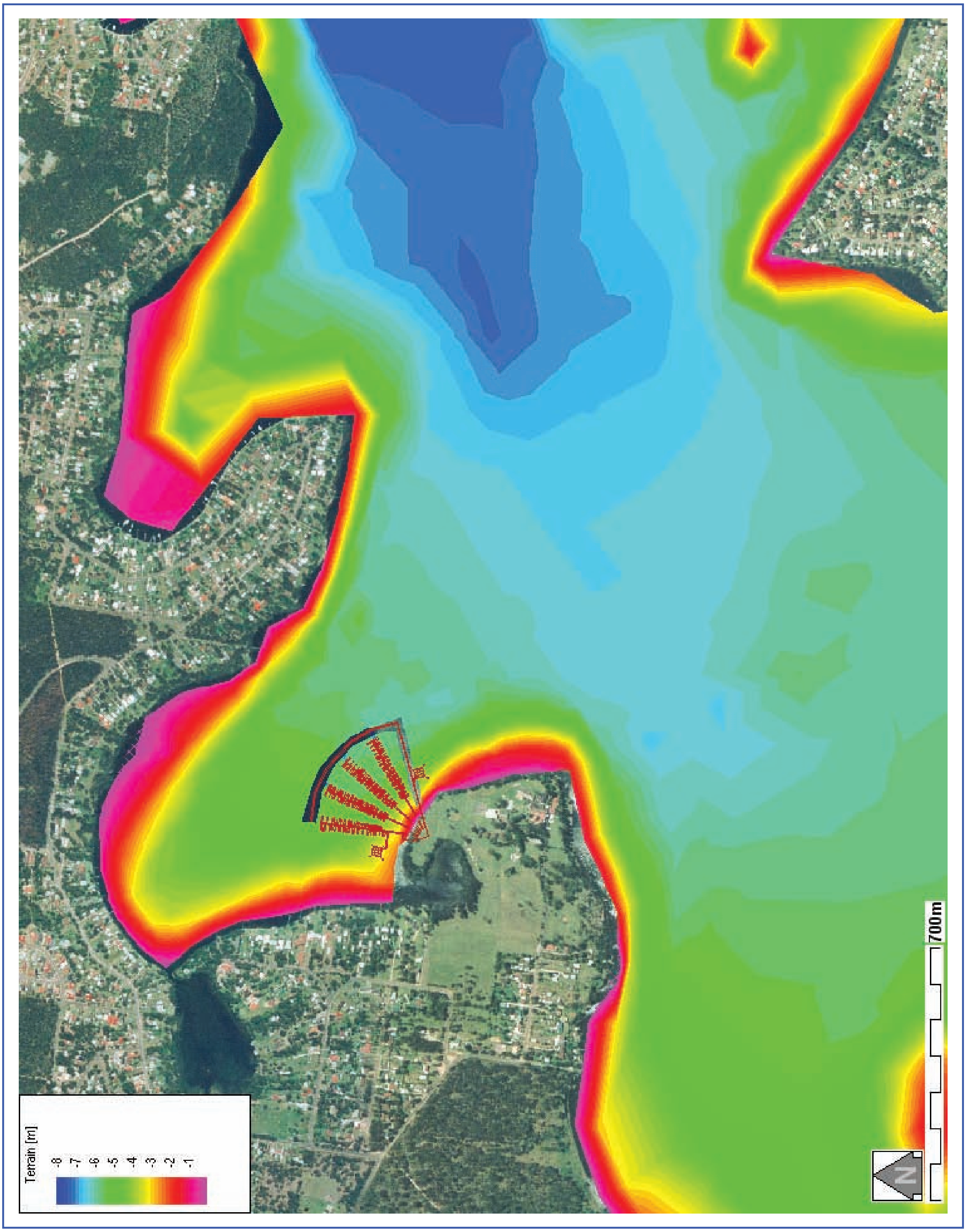
FIGURES

FIGURE 1

SITE LOCATION PLAN

FIGURE 2



J6759.09_F2_TRINITY POINT NUMERICAL MODELLING INVESTIGATION

LAKE MACQUARIE BATHYMETRY