Wyong Shire Council

Entrance Dynamics and Beach Condition at The Entrance and North Entrance Beaches

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Prepared by

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on behalf of

Wyong Council

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Executive Summary

This study was commissioned to provide further analysis of the sediment transport processes affecting sediment budget and coastal morphology at North Entrance Beach and The Entrance to Tuggerah Lake. The aim of the study was to clarify sediment transport linkages between The Entrance channel and North Entrance Beach and to identify and evaluate potential options for managing sedimentary processes in this dynamic coastal landscape, to reduce risks associated with coastal erosion hazards.

North Entrance Beach lies at the southern end of the zeta curved Tuggerah coastal embayment. The southern extension of the beach is an intermittent spit and berm which forms at the mouth of the Tuggerah lake entrance channel. In historical times the mouth of the estuary closed for periods of up to three years. The sand deposits were scoured out of the entrance area by major flood flows. Since dredging of the outer entrance shoals commenced in 1993, the average channel width has declined compared to the average pre dredging condition. The range of channel conditions has also narrowed. This is in part due to medium term rainfall and storminess patterns.

Coastal hazard studies indicate that over the last 30 years, North Entrance Beach has receded at average rates of 0.2 to 0.5 metre per year. Unlike many other NSW beaches, North Entrance beach has not fully recovered from the storm bite erosion of the 1970s. The apparent sediment budget deficit at North Entrance Beach means that multiple dwellings are situated within the immediate coastal erosion hazard zone.

Since 1993, Wyong Shire Council has dredged sand from the entrance of the lake, placing most of the dredged material on the southern end of North Entrance Beach. There have also been significant changes to the configuration of the full tidal delta, including reclamation and channel straightening.

The study incorporates:

- Review of previous studies and conclusions about hydrodynamic and sedimentary processes affecting ICOLLs and associated beaches, with particular reference to the estuary mouth of Tuggerah Lakes and along North Entrance Beach
- Analysis of historical aerial photographs which reveal the extent of change at The Entrance and North Entrance Beach over the last 40 years, together with a review of factors influencing the condition of the estuary entrance
- Preparation of a longshore sediment transport model for North Entrance beach, extending from The Entrance to just north of Curtis Parade
- Review of the stability of the entrance channel of Tuggerah lakes and its propensity to close.
- Review of recent assessments of the effectiveness of dredging at The Entrance to achieve the stated flood mitigation purpose and other outcomes.
- Consideration of how sea level rise associated with climate change could affect sedimentary processes at the lake entrance
- Consideration of whether construction of training wall(s) at The Entrance could contribute to a neutral sediment budget for the entrance and North Entrance Beach area.
- Evaluation of potential sources of sand that could be used to nourish North Entrance Beach.

- Identification of additional information that is required to provide more certainty around the conclusions of this study.

The study found that refraction of waves approaching North Entrance beach from the north east through to south-south-east focuses wave energy on North Entrance Beach. The Beach has a high wave energy wave climate. The results of two methods of longshore sediment transport analysis indicate that, cumulatively, sand moves south along the spit at the mouth of Tuggerah Lake (area R1). North of Karagi Point (areas R2, R3), the dominant sand transport direction is to the north, with the rate of transport declining as the beach straightens. The exact balance of sand distribution along the beach face will vary seasonally and with longer term cycles such as *el nino/la nina*, but it was not feasible to quantify cyclic variations in this project.

The model results are consistent with the broad landscape character, where transgressive dune fields have accumulated sediment in the northern part of the barrier during the Holocene, decoupling this sand from the active coastal sediment compartment. Some sand continued to be lost from North Entrance Beach by aeolian processes until about 1970. Some sand has in the past been intermittently transported and deposited as lobes on the distal margins of the tidal delta, and then decoupled from the active sediment budget by channel changes and reclamation. Sea level rise has the potential to move additional sediment from the coastal sediment compartment into the lake.

It appears that some sand is lost from the active coastal sediment compartment by deposition in crevices and channels within nearshore rock reefs and also by storm bite erosion during major storms. SMEC consider that North Entrance Beach does not have an equilibrium profile. A combination of vary large waves and strong flows from the estuary mouth can deposit sand offshore in water depths of 10 to 20 metres, outside the normal depth of closure. The volume of sand stored in this location is not currently known.

Some key indicative sediment budget statistics:

- The maximum indicative volume of sediment intermittently stored in the outer part of the tidal delta (outside The Entrance Bridge): **540,000 m^3** (removed and replaced at intervals of 5 to 10 years or more)

- The indicative volume of tidal delta deposits inside Tuggerah Lake, (lakeward of The Entrance Bridge): **more than 1 million m^3** (includes sediment accreted over up to 6000 years)

- The total indicative volume of sediment dredged from The Entrance since 1993: **approximately 1 million m^3**

- The indicative storm bite volume from The Entrance Beach (including Hutton Road and Curtis Parade precincts) during a major storm (such as 1974 or 2007): 250 m^3/m, over 2.5 kilometres or **625,000 m^3 per event**

- The indicative volume of sand that has been removed from the active sediment budget at North Entrance since 1940, by reclamation, dune erosion and stabilisation, channel change and offshore losses: **1.5 million m^3** (over 70 years)

- **Potential** (**not net**) long-shore sediment transport rates, north of Karagi Point (areas 3, 4 and 5): **800,000 to 1,300,000 m^3 per year,** declining northwards to **less than 50,000 m^3 per year**. Potential northward and southward sediment transport rates between Karagi Point and the tip of the entrance spit (areas 1 and 2) are 2 to 3 million m^3 per year. Net sediment transport rates will always be less than the potential rates indicated by the models.

Conclusions

Dredging of the shoals in the outer entrance area at the current rate is appropriate as an interim sediment budget management option for North Entrance. However, the volume of sediment involved is not sufficient to prevent shoreline recession, particularly as sea level rises.

Access to all other potential sediment sources is constrained by a variety of issues, notably:

- Uncertainty about hydrodynamic processes, sediment transport processes, actual sediment volume and system wide responses to changes to channel and shoal configuration in the estuary entrance and on the beach.
- Uncertainty about how climate change will affect estuary entrance processes
- Ecological values of sediment storages inside the estuary, including the role of the tidal delta in minimising oceanic flooding and maintain estuary water levels and salinity profiles.
- Sediment quality, particularly in relation to organics and ASS materials
- Statutory issues. Extraction of offshore (inner shelf) sand deposits is prohibited in NSW. Stabilised transgressive sand dune deposits are within National Park.
- High costs and practicality of sediment transport from potential sources to emplacement areas.

Recommendations

Council should continue its existing dredging program.

Council should monitor the behaviour of the entrance and North Entrance Beach to clarify actual responses to storm events and dredging activity.

Council should install (with support from DECCW) a water level monitoring station at The Entrance, to collect quality water level data for the tidal delta area. Collection of field data to clarify current velocities and channel bathymetry is also recommended.

Council should invest in a 3D hydrodynamic model and sediment transport model for The Entrance. The model should consider entrance behaviour with and without key reclaimed areas.

Council should obtain a full set of LADS data for the Tuggerah Embayment and investigate the presence of sand deposits at or near the depth of closure for the beach. Additional survey may be required for areas beyond the reach of LADS data. Sediment sampling will also be required, once sand bodies have been identified.

Council should not construct training walls at The Entrance. None of the investigations to date indicate that construction of training walls would benefit the lake or North Entrance beach. High volume dredging, removing the berm and driving the lake entrance to a permanently wide open condition is also not supported. Enhanced wave penetration into the estuary and increased lake water levels, now and as sea level rises, both have significant risks for lake ecology and flooding.

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1.0 Introduction

This study investigates and describes the processes driving sediment budget issues at The Entrance Beach, North Entrance Beach and The Entrance channel of the Tuggerah Lakes. The project is based on analysis of empirical data from the project area. **Appendix 1** (SMEC 2011) provides the details of how wave, tide, water level and bathymetric/topographic data has been analysed.

The outcome of the study is a conceptual model of sediment transport dynamics and interactions between the tidal delta of Tuggerah Lakes and long shore sediment transport and cross shore sediment movement on North Entrance Beach and The Entrance Beach. With this information, Council can make decisions about the potential to intervene in the sedimentary processes, to obtain sand for beach nourishment to protect development, ecological function and amenity. The report also considers how the construction of a training wall or pair of training walls at the outlet of Tuggerah Lakes would affect the sediment budget at North Entrance Beach.

Residential development on the frontal dune system at North Entrance Beach has been assessed as lying within the immediate coastal erosion hazard zone (SMEC 2010). Residential development at Hutton Road is situated on top of a narrow single frontal dune. At Curtis Parade, residential development is situated on a frontal dune created during stabilisation and reconstruction of a former ‘blow out’ or transgressive dune, which was active until the 1960s. Development at both locations on North Entrance Beach was threatened by coastal erosion in the storms in 1974. There have been periods of recovery and erosion since the 1970s, with the focus of sediment transport varying with the angle of wave approach of storms.

However, overall for North Entrance beach, SMEC has measured 3 to 15 metres recession of the frontal dune system since the 1970s. Ongoing recession is predicted for North Entrance Beach for the 2050 and 2100 planning periods. The predicted recession, linked both to sea level rise and to a sediment deficit at the southern end of the beach, would remove the frontal dune system on which development is currently located.

Wyong Shire Council has dredged a small volume of sand from the entrance channel of Tuggerah Lakes since the 1990s. Dredging is conducted on a campaign basis, averaging around 50,000 m^3 per year. Some sand from the dredging operations has been placed as a slurry on North Entrance Beach, to the south of Hutton Road. The volume of sand placed on North Entrance Beach has not prevented the recession trend on the beach.

To address the erosion threats to residential development at North Entrance, Wyong Shire Council is considering both structural protection options and beach nourishment options. Council is also considering strategic retreat of development from the highest hazard areas. To protect beach amenity, beach nourishment would need to accompany any structural protection option. Beach nourishment is also a management option on its own. Management options to protect existing residential development are therefore reliant on identifying suitable sources of sand which could be used to build up beach and dune volume at North Entrance and provide a short to medium term buffer against long shore transport imbalances, storm bite erosion and recession associated with sea level rise.

General objectives of beach nourishment on open coast beaches, also applying to North Entrance Beach, are:

- To maintain recreational amenity and recreational safety at popular ocean beaches (with or without other management activities).

- To contribute to the protection of assets such as Council infrastructure (car parks, surf clubs, sewerage systems) and private property (homes, fences, swimming pools, etc.) which may be at risk from coastal erosion and recession.

- To support the resilience of coastal biodiversity affected by coastal erosion and recession, by maintaining a positive sediment budget on beaches and frontal dune systems.

- As a corollary of dredging of sand shoals in the entrance area of Tuggerah Lakes, beach nourishment can be seen to contribute to the maintenance of sedimentary processes and features in the entrance area at a level that supports scenic and recreational amenity and recreational safety. Both this recreational amenity objective and an objective to maintain the ecological values of the Tuggerah Lakes would apply to any future dredging proposals.

1.1 Scope of this Study

1.2 Objectives

The specific objectives of the investigation are:

- To better understand the interactions of sedimentary processes operating at the entrance to the Tuggerah Lakes and on adjacent beaches.

- To better understand how the beach/marine and tidal delta sedimentary processes interact at various time scales and likely cumulative impacts on beach volume, beach morphology and associated beach amenity and safety.

- To quantify, as far as possible, the volumes of sand held in the tidal delta of Tuggerah Lakes.

- To quantify as far as possible, the volume of sand that could be removed from The Entrance and placed on North Entrance Beach without compromising the functioning and values of the lakes system.

- To provide clear lines of evidence about sediment dynamics, which can be used to underpin future intervention in sedimentary processes at The Entrance and along North Entrance Beach.

- To evaluate how structural controls at The Entrance, such as a northern training wall, would impact on sediment dynamics and the stability of North Entrance Beach and sand shoals in the Entrance.

- To evaluate the likelihood that other sources of sand will be available for beach nourishment purposes in Wyong Shire in the immediate and medium term.

1.3 Empirical Analysis Method

To address the above issues and objectives, existing data and other qualitative information about sedimentary processes at The Entrance and along North Entrance Beach have been collated, reviewed and analysed. This empirical analysis is essential to provide a sound understanding of how the system operates now and has operated in historical times.

Data analysis and evaluation has included:

- Historical evidence of channel change and changing beach/dune morphology (historical aerial or ground level photography), satellite imagery and existing scientific/engineering studies of sediment distribution and sediment dynamics across the tidal delta in the entrance channel of Tuggerah Lakes. This includes:
    - lake entrance opening and closing events, frequency, extent of scour during opening, periods of closure, height of berm during closure periods, water levels in the lake when open and closed, channel dimensions;
    - patterns of sediment distribution in the entrance channel;
    - estimates of the total volume of sand in the flood tidal delta and the volume which can be considered to be 'active';
    - records of the volumes of sand dredged from the entrance, locations from which sand has been removed, timing of dredging events, sand placement during dredging events;
    - any evidence from aerial photography or survey about how dredged sand has modified the profile of the beach;
    - surveyed bathymetry pre and post dredging, pre and post entrance opening events; and
    - any documented temporal correlations between dredging events, lake open events and sediment patterns on the adjoining beaches.
- Revisit longshore sediment transport processes and patterns on North Entrance Beach (with lake entrance open and closed). This includes review of wave data, patterns of bars and rips, beach profiles. Within the limitations of available data, describe evidence of beach rotation patterns at Tuggerah Beach and how these processes interact with beach profiles and sand volumes; ICOLL entrance stability. DECCW has undertaken a trial project in this area (in 2008-9) using LADS survey (Laser Activated Depth Survey) which is similar to LiDAR, but gathers xyz data beneath the water surface (and can be effective to about 20 metres depth). This data can be used to provide a high resolution bathymetric baseline for current sedimentary process analysis and for comparison with future beach condition.
- Refine understanding of sand losses from beach to dune systems (such as interaction of longshore processes and aeolian processes towards the northern end of the embayment).
- Review studies and models of ICOLL entrance behaviour in conditions of rising sea level and/or limited sediment supply
- Develop a conceptual model, based on the empirical data, for sedimentary process interactions between The Entrance, North Entrance Beach, near shore bars and the dune field. If sand dredged from the entrance channel is used on the ocean beaches, where should it be placed for maximum benefit e.g. to provide enough sand to withstand a storm, to protect recreational amenity, or to maintain a particular alignment.
- Based on the conceptual model, comment on how (a) construction of a training wall and (b) sea level rise may affect sediment distribution between the beach and entrance channel.

  Issues associated with sea level rise include:

    - How will sea level rise affect the sediment dynamics in the entrance channel?

- Would the volumes of sand moving into The Entrance channel change?
- Would the locations of sand deposition change?
- Would rates of sediment transport in and out of the entrance change, and affect the viability of dredging?

  It has been assumed that with a long term stable sea level, there is no net supply of sand to The Entrance either from the ocean or the lake side. A rising sea level would, in theory, drive the tidal delta further into the lake entrance area. A further question is whether recession associated with rising sea level would remove the narrow frontal dune system at North Entrance, creating the potential for a wide or relocated entrance channel.

- Update and expand information about offshore (shelf) sand deposits along the Wyong coastline, together with an update on the results of the Sydney Coastal Councils offshore sand feasibility study.

1.4 Geomorphic Context

The ocean interface of the Tuggerah Lakes at The Entrance is typical of ICOLL entrances. It is located at the southern end of a coastal embayment, adjacent to a bedrock headland which limits southern migration of the entrance channel. Predominant south-east winds and swell waves interact with the sandy landforms in the embayment, creating a barrier system that widens northwards away from the entrance channel.

The following sections provide information about the major geomorphic features of the entrance area of Tuggerah Lake, The Entrance Beach and North Entrance Beach.

1.4.1 North Entrance Beach

North Entrance Beach is situated immediately to the north of The Entrance channel of Tuggerah Lakes.

North Entrance Beach is at the southern end of the Tuggerah Beach embayment, which extends from The Entrance, approximately seven kilometres to Pelican Point. At North Entrance Beach, only a single frontal dune exists with low relief back barrier flats immediately landward.

Short (2007) classifies North Entrance Beach as either Transverse Bar and Rip (TBR) or Rhythmic Bar and Beach Morphology (RBB). Short notes:

> The entire beach picks up most swell, particularly out of the east and south east, resulting in an energetic surf zone averaging 1.6m. This maintains a double bar system running most of the beach, with the inner bar usually being detached from the beach and cut by rips every 300-400m. As a result a continuous trough often runs the length of the beach occupied by rips and their feeder currents. At the southern end south of the surf club, the bar tends to attach during periods of lower waves and rips diminish in size. However, at Karagi Point, the tidal currents from Tuggerah Lake can run along the beach resulting in an additional hazard.

This general description highlights two important sediment transport processes. Away from the entrance area, shore normal rips move sand from the beach face to the near-shore area. These rips mean that long shore transport is regularly interrupted by cross shore sediment transport. Close to the entrance, these shore normal processes may be less important, but long shore transport can be driven both by the angle of wave approach and by (flood and ebb) tidal currents when the lake entrance is open. At the daily scale, sediment transport direction changes frequently.

At the annual or longer time scale, observations from the aerial photographs of North Entrance Beach from 1941 to 2007 show the rhythmic spacing of bars and rips, but the pattern is more obvious in 1961, 1966, 1996 and onwards. The bars and rips are present in 1941 and 1982, but less well developed and more widely spaced. In 1965 (possibly also 1954) and possibly 2001, the bar and rip pattern is replaced by closely spaced cusps along the beach face. The patterns of deposition and transport will vary with dominant wave direction in *el nino* and *la nina* conditions. Further information is in **Section 2.0**.

SMEC 2010 measured storm bite erosion and evidence of recession at North Entrance Beach for the period 1970 to 2007. They identified recession of 3 to 15 metres over this period. The amount of measured recession varies along the beach. The extent of storm bite in individual storms also varies along the beach, depending on the orientation of the beach to the angle of wave approach at the time and the volume of available sand.

Storm bite erosion North Entrance Beach, 1974 and 2007

Location	**1974 storm bite**	**2007 storm bite and evidence of recession**
Block A: Sand spit at The Entrance	Less than 150 m^3/m	**250 m^3/m**
Block B: Residential development at Hutton Road	Less than 150 m^3/m	150-200 m^3/m
Block C: Surf Club	Less than 150 m^3/m	Less than 150 m^3/m **15 m recession of beach between 1974 and 2007**
Block D: Residential development at Curtis Parade	Less than 150 m^3/m	Less than 150m3/m **15 m recession of beach between 1974 and 2007**
Block E: Central Beach, near Magenta Shores	**More than 150 m^3/m and up to 250 m^3/m**	Less than 150 m^3/m

There is a general cyclical relationship between entrance processes and sand supply on North Entrance Beach. When sand is held inside the entrance in the tidal delta, there is slightly less sand available on North Entrance Beach. When sand is scoured out of The Entrance, there is a slight increase in the amount of sand available to be distributed along North Entrance Beach. This sand may be stored within the sub-aerial beach or in near-shore bars as described by Short 2007. Sand in the beach compartment is also available to be moved offshore during major storms.

SMEC attribute (in part) the recession trend on North Entrance Beach to reduced sand availability, with sand being lost from the beach system via local transgressive dune systems and/or deposition of sand eroded during major storms slightly offshore, in water depths beyond the reach of all but the vary largest waves. Sand may also be trapped offshore by rock reefs, such as the reef at the southern end of North Entrance Beach, at The Entrance.

If sand is deposited off shore, then cumulatively, sediment supply to the beach would reduce over time. The presence of offshore sand deposits in water depths up to 20 metres could be tested by detailed analysis of LADS data for the full length of the beach. This data was available for North Entrance Beach during the current analysis.

The Holocene barrier that is the underlying landscape feature at North Entrance widens northwards, and complex transgressive dunes developed on the central to northern part of the barrier in the mid to late Holocene. Pleistocene cliff top dunes at the northern end of this embayment also provide evidence of a general northward drift of sediment in this embayment, driven by exposure to south-east swell and winds. In the long term, the marine sedimentary processes in this embayment have favoured accumulation at the northern end, with sand loss from the southern end.

Some of the substantial reserves of aeolian sand at the northern end of the Tuggerah embayment were exploited for construction sand in the 1960s. Much of the dune field is now protected within Wyrrabalong National Park. The remainder of the dune field is stabilised and developed (e.g. at Magenta Shores).

1.4.1.1 Long Shore Sediment Movement

Preliminary assessment of sedimentary processes at the Entrance (Patterson Britton & Partners Pty Ltd 1991; 1994; Lawson and Treloar 1999, Webb McKeown 1992, Worley Parsons 2008) identifies what the authors describe as a ‘null point’ on North Entrance Beach. The location of this point varies seasonally and with longer term weather patterns, but conceptually, Worley Parsons suggest that south of the ‘null point’, i.e. towards The Entrance, littoral drift is to the south and into the shoals at the lake entrance. North of the ‘null point’, littoral drift is to the north, along the Tuggerah Beach compartment. As noted above, the morphology of Tuggerah Beach and dune system indicates that for this beach compartment, cumulatively over thousands of years, the ‘null point’ on North Entrance Beach and Tuggerah Beach has favoured northward movement of sand significantly over any southward return.

The null point must be considered only as an indicative outcome of long shore sediment movement north and south along the beach, in response to daily changes in wave angle, beach face condition and other factors.

SMEC have revisited the long shore sediment transport analysis in this project, using sediment transport models (see **Section 3.1**). Within the limitations of the scale and level of resolution of the modelling which can be done with available input data, SMEC also found that longshore sediment transport at the southern tip of North Entrance Beach is to the south, forming the spit at The Entrance. For the next 2.5 kilometres along the beach, past Curtis Parade, modelled long shore sediment transport is predominantly towards the north, although the rate of movement varies. Details are in **Section 3.2**.

Other factors affecting the patterns of sediment movement along the beach include the period of time since the lake entrance was fully open (i.e. since a major entrance scouring event), and the status of beach rotation which accompanies *el nino/la nina* cycles. The local significance of these factors in terms of the success of potential beach nourishment is not currently known.

1.4.2 The Entrance Beach

The Entrance Beach is a small pocket style beach, with a thin mantle of sand over bedrock. The volume of sand on the beach varies significantly with the location and extent of opening of the Tuggerah Lake entrance and the time since a major storm bite. There are extensive rocks and reefs to the north and south of the east facing beach and there are permanent rips adjacent to the rocks.

A review of historical aerial photos indicates the following:

- In 1941, when the lake entrance was fully closed, with a wide berm, The Entrance Beach was within the same sediment compartment as North Entrance Beach. The sand deposit thinned quickly to the south around the bluff at The Entrance. This suggests that at the time, sediment transport was tending to the north, but not that sand was bypassing around the rocks from the south.

- By 1954, an entrance opening event had separated The Entrance Beach from North Entrance Beach. The Entrance Beach had shrunk in area and sand volume, with rocks clearly exposed throughout the surf zone. Thin sand deposits are visible around the bluffs towards The Entrance pool, but with rock continuously exposed.

- The aerial photos throughout the 1960s show a stable sand area at The Entrance Beach, which was detached from North Entrance Beach by the lake entrance channel throughout this period. The volume of sand in the entrance tidal delta shoals varies over this ten year period, but the exchange appears to be with North Entrance Beach, rather than The Entrance.

- During the 1980s and 1990sThe Entrance Beach was almost always separated from North Entrance beach by the lake entrance. Qualitatively, sand volume appears to have increased slightly in the 1980s and early 1990s, partly because the entrance channel widened and migrated north towards Karagi Point. The Entrance Beach benefits when a shoal is tied to the southern shore of the entrance channel and is cut off from the north. The amount of sand observed on The Entrance Beach decreased in the late 1990s as the spit extended back to the south, eroding the southern bar and cutting off sand moving from the north.

1.4.3 Back Barrier Flat, North Entrance

Low lying land between the frontal dune system and the lake shoreline at North Entrance is nominally a back barrier flat. Detailed stratigraphy from this specific location is not available, but morphologically, this area appears to have been deposited by a combination of wave overwash and tidal delta processes.

The entire entrance channel of Tuggerah Lake is controlled on its southern side by rock, but wide sub-tidal flats have been deposited by wave action along the lake shoreline south of the tidal delta. The alignment of the tidal delta suggests that at least some of the sediments in the back barrier flat at North Entrance were originally part of the tidal delta. Washover units may underlie the tidal delta deposits, reflecting early Holocene barrier formation. However, it is also possible that minor sea level fluctuations during the mid to late Holocene have removed the narrow frontal dune system at North Entrance and allowed wave overwash to occur intermittently.

Skilbeck, Rolph, Hill, Woods and Wilkens (2005) report evidence of multiple cycles of sedimentary characteristics from a core at Pelican Island in the tidal delta of Tuggerah Lake. They attribute these cycles to climatic variations, for instance at about 200-250BP, 350-370 BP, 420BP, 500-530BP and 1250-1450BP.

Further north on the NSW coast, Goodwin, Stables and Olley 2005 also report late Holocene episodic barrier progradation and recession. Their studies at the Iluka-Woody Bay barrier suggest a prolonged recessional phase at about 1500BP, with renewed shoreline progradation on east aspect coastline after about 1400BP. Progradation did not recover on north-east aspect coastline until after 1000 years BP. They also note a rapid recession phase initiated in the last 50 years on north-east aspect coast in their study area.

Although the story at each of these locations is slightly different, the key message is that narrow Holocene barriers, such as The Entrance North, may well have fluctuated in the protection they provide to tidal deltas and back barrier flats at estuary mouths during the late Holocene and until quite recently.

1.4.4 Tuggerah Lakes Entrance

Tuggerah Lakes are an example of an estuary system known as 'Intermittently Closed and Open Lakes and Lagoons' (ICOLLs).

Morphologically, the lake entrance area includes:

- Rock along the southern side, which acts as a natural training wall inside the estuary entrance.

- The Entrance area is sheltered by a large area of offshore rock reef, which protects it from south east swell (see **Figure 1.1**). This rock extends under The Entrance Beach, limiting sand volume. Wave refraction around the reef directs wave energy further along the beach, concentrating at Curtis Parade (see **Section 3.1**).

- The channel in the outer part of the estuary entrance area varies in width from 20 metres to about 100 metres, within a broad potential opening area (from the rock on the southern side of the channel, to Karagi Point) of close to 400 metres. The channel length in the entrance area is approximately 450 metres and channel depth is 0 to 2 metres. SMEC suggest that flood tide currents tend to flow closer to the southern side of the entrance area, with ebb tide currents moving sand along the northern side and across the inner face of the spit/berm.

- An outer active area of sand shoals, seaward of The Entrance Bridge. Prior to about 1970, active sand shoaling occurred further into the lake (in the form of lobate shoals), when the entrance was open (see **Section 2.0**).

- An inner and more extensive conical shaped sand deposit into the estuary. This is also tidal delta material. Activity on this part of the tidal delta appears to be linked to man-made modifications to tidal channels and to sea level. It is probably that some deposition on this landform was associated with slightly high sea level during the late Holocene. Some parts of this tidal delta have been stabilised by aquatic vegetation and provide both habitat for estuarine species and a natural buffer protecting the lake system from storm surge.

An aerial photograph of the entrance area (e.g. see **Figure 2.1**) shows where marine sand has built up in the entrance as the tidal delta. This area is indicative of the area of past and/or current significant tidal influence on the lake system.

The entrance of an ICOLL is often closed naturally. ICOLLs have low natural tidal exchange and circulation beyond the entrance channel area. The large shallow lake area absorbs the energy of tidal flows quickly. In Tuggerah Lakes, the tidal range is 0.2 to 0.3 metre and tidal influences extend only about one kilometre from the entrance – affecting only a small part of the lake. Tidal exchange of the volume of Tuggerah Lakes takes about 100 days.

In periods of low rainfall, and/or with east to north-east shoaling waves directing sand southwards along the beach, sand is driven into the entrance of the lake system by tidal currents and gradually builds up shoals known as a tidal delta. If these conditions continue, a sandy spit and then berm builds up across the entrance, eventually cutting off tidal exchange. Typical morphology at North Entrance Beach includes a wide bar, attached to the

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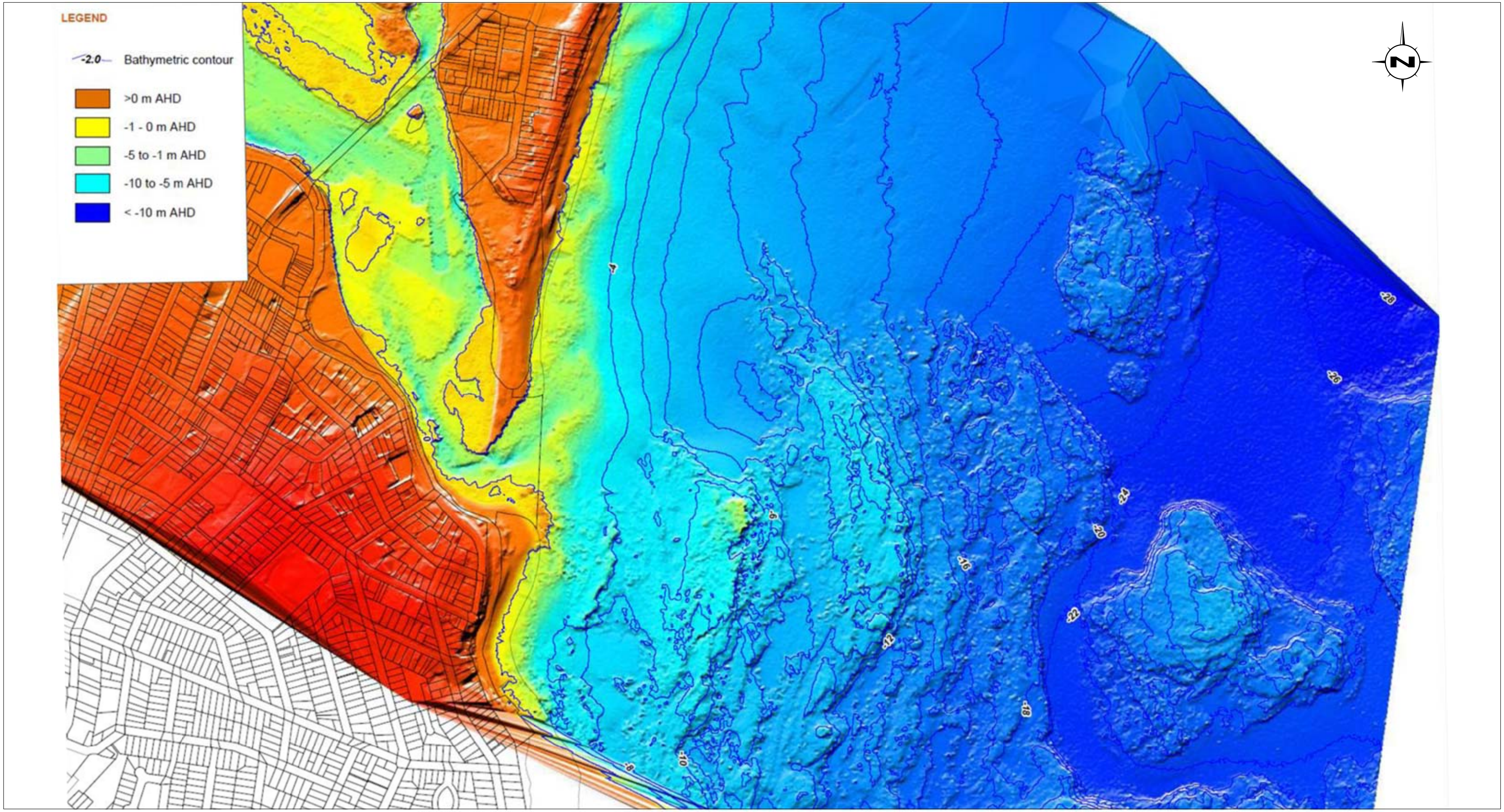


Source: SMEC Australia Pty Ltd (2010)

FIGURE 1.1

Detailed LADS Bathymetric Data

shoreline, at the southern end of the beach and along the seaward side of the spit at The Entrance (see **Figure 1.1**).

In periods of high catchment runoff, water levels in the lake set up above ocean levels and eventually break through the sandy berm at the entrance. In these flood flow conditions, sand is scoured from the shoals in the entrance channel and from the spit and berm and is returned to the open beach. From there it can be carried along the shoreline by long shore currents, or blown into the incipient foredune and frontal dune system, or it returns to the lake entrance as the cycle begins again.

Historical records show that the entrance to Tuggerah Lakes has been fully closed at least 13 times over the last 100 years, sometimes for as much as three years at a time. When the entrance is closed, a large volume of sand of marine origin is stored within the tidal delta of the lake entrance.

The morphology of the Entrance of Tuggerah lakes has changed significantly since the 1940s, and particularly since about 1970.

Reclamation and foreshore realignment has included:

- Reclamation of tidal flats along the south-western foreshore.
- Channel straightening, removal of some channels and reclamation along the northern foreshore.
- Channel deepening.

More information is in **Section 2.0** and **Figures 2.1** to **2.5**.

1.4.5 Existing Dredging Operations

Parts of the tidal delta and intertidal flats near the entrance of Tuggerah Lake have been occasionally dredged for navigation since the early twentieth century.

More recently, WSC has conducted dredging operations in tidal delta shoals at The Entrance using a mobile dredge, to maintain tidal flushing of the entrance area and reduce flood risks.

When a dredging campaign is undertaken, the dredge moves in stages from upstream to downstream. Council has a licence to dredge up to 100,000 cubic metres of clean sand from the entrance channel annually. The actual amount dredged varies with short and medium term weather patterns and sediment dynamics, and therefore the amount of sand which needs to be removed to maintain a slightly open entrance form and maintain tidal flushing. The outer channel (i.e. seaward of The Entrance Bridge) is dredged more frequently than the area upstream of the bridge, along the Terilbah Channel, other channels and sumps. Details of dredging locations are reviewed in Worley Parsons (2008).

Most of the dredged sand (the long term average volume of dredged sand is approximately 50,000 cubic metres per year) is placed on North Entrance Beach, south of the inferred null point (see Patterson Britton 1994), with other sand placed on the Karagi Park foreshore near the entrance or over the rock base of The Entrance Beach. Approximately 30,000 cubic metres of sand was placed on The Entrance Beach in 2004.

Figure 2 in Worley Parsons 2008 shows the current dredging footprint and sand placement areas (also reproduced in **Appendix 1** of this report). Dredge pathways are also clear in **Figures 2.4** and **2.5** of this report. Sand is placed on North Entrance Beach in front of properties at the southern end of Hutton Road, in the vicinity of Hargraves Street. Following placement of the sand slurry, the material is shaped into a 'natural' accreted beach profile by bulldozer and is left unvegetated as mobile beach sand. Council aims to match the crest level of the emplaced material with the existing dune crest level and to achieve a stable slope on the seaward side of the foredune and berm.

Cumulatively, using the average amount of sand dredged per year, the total dredged from the entrance area over twenty years is up to 1 million cubic metres. This is approximately double of magnitude of the estimated maximum sediment storage capacity of shoals in the outer entrance area.

The volume of sand currently dredged in each campaign is a small fraction of the volume of sand which may be scoured from the entrance in occasional major floods, when the entrance can widen to 400 metres (Worley Parsons 2008) with channel depths of up to three metres (Worley Parsons 2008). These maximum channel dimensions, likely to be a very rare occurrence, would give a maximum sediment volume in the outer part of the tidal delta (assuming 450 metres distance downstream of the bridge) of around 540,000 cubic metres. More commonly, the historically scoured entrance channel has had a channel depth of less than 2 metres and a maximum width of only about 100 metres. In this case, the volume of sand moved out of the entrance area is only about 80,000 cubic metres.

Sand scoured from The Entrance during flood conditions forms an ebb tide delta and is delivered to near shore shoals and to both South Entrance and North Entrance Beach. Some sand may also be trapped within the rock reef formations off The Entrance. However, because floods of the magnitude to cause this level of scouring occur very rarely, for most of the time a significant volume of sand is naturally stored in the tidal delta and is not available to create a buffer for storm bite erosion along the beach and dune. The tidal delta processes help to maintain the tidal range and other hydrodynamic processes which underpin the estuarine ecology of the lake system.

1.4.6 Sediment Budget Issues at The Entrance

SMEC (2010) has shown that most of Wyong's beaches have been relatively stable in sand volume over the last three to four decades. For most beaches, measured recession since the 1970s is less than three metres (note however, that this would still lead to recession of approximately 10 metres over 100 years, if the same average rate continued). Some beaches have accreted slightly, as the coast recovers from the impacts of a series of major storms such as those of 1974 and 1978.

For most of the time since the late 1970s, the NSW coast has been dominated by *el nino* conditions, rather than severe *la nina* conditions with stronger easterly trending swell. Moderately strong *la nina* events occurred only in 1988 and 1998. 2010/2011 has been a strong *la nina* year.

SMEC (2010) identified two clear exceptions to the apparently stable beach profile situation. Parts of North Entrance Beach have receded by 3 to 15 metres over the last three decades and Lakes Beach has also receded by approximately 15 metres. Not all of the sand lost from parts of these beaches in the 1970s has returned.

At North Entrance Beach, the largest measured recession (averaging 0.5 metre per year) is immediately to the north of the section which has been intermittently nourished with sand dredged from The Entrance. In the next section north (including Curtis Parade) average recession since the 1970s is 0.2 metre per year. Some long term recession (averaging 0.1 metre per year) has also been measured in the nourished section.

A single major storm has the potential to temporarily remove 250 m^3/m of sand off the southern section of North Entrance Beach. So for the 2.5 kilometre section of beach extending from the southern end of Hutton Road, past Curtis Parade, a single major storm bite would cut approximately 625,000 cubic metres of sand from the beach and dune.

The sand volume eroded during a major storm bite event is of the same order of magnitude as the indicative volume of the shoals in the outer entrance area. Both are approximately half the volume of sand that has been dredged from The Entrance area over the last 20 years.

The current management of this southern part of Tuggerah Beach is not preventing ongoing recession. Sand nourishment with material dredged from The Entrance does not balance the amount of sand lost from the beach and dunes – back into the tidal delta, over the dune field, to deep water offshore (beyond active wave depths/depth of closure), trapped within offshore rock reefs, or along shore to the north.

2.0 Historical Changes to Sand Distribution at The Entrance and North Entrance

Council has collated historical aerial photos of The Entrance area, spanning the period from 1941 to the present. Comparison of these photos shows significant changes to the morphology of the flats, shoals and channels around The Entrance over the last 60 years. These changes reflect a combination of:

- *La nina* and *el nino* southern oscillation events and other medium to long term cycles.
- Occasional extreme storm events
- Sea level rise of approximately 10 centimetres (see Church *et al.* 2007)
- Foreshore reclamation and construction of fixed foreshores.
- Channel straightening and potentially channel deepening, particularly upstream of the bridge.
- Stabilisation of shoals and islands with saltmarsh, mangrove and sea grass.
- Stabilisation of the mobile dune which traversed the barrier at North Entrance until the late 1960s.

2.1 The Tidal Delta – a 60 Year Time Sequence

Table 2.1 summarises the observed changes to the morphology and sedimentary loci within the flood tide delta at the entrance to Tuggerah Lake. **Figures 2.1** to **2.5** show this sequence. **Figures 2.6** and **2.7** indicate schematically the sediment stores and transfers that have functioned over this period.

Table 2.1 - Changing Sedimentary Processes, The Entrance

Year	Morphology and Sedimentary Loci
1941	Active blowout transferring sand from North Entrance beach (current location of Curtis Parade) to the lake shoreline, adjacent to the distal margin of the full tidal delta form. Ripple patterns in lake suggest transport to the west across the lakeward margin of the delta deposits. Entrance channel closed, with wide beach and high berm. Outer entrance shoaled to shallow depths.
1954	**Strong *la nina* events in 1950, 1955 and 1956** Entrance open on southern side Deposition on western lobe of inner delta continues Outer shoals partly removed and spit trimmed from both inside and outside lake entrance – sand appears to be moving out of the entrance rather than in at this time. Sand transfer from beach to lake shore through the transgressive dune continues Wide beach at North Entrance, but low sand volume at South Entrance, now disconnected from main beach sand supply. No attached bars on southern side of entrance channel

Year	Morphology and Sedimentary Loci
1961	New control and alignment of the eastern shore of the tidal delta along the landward side of the North Entrance peninsula. Sea wall constructed and preliminary reclamation. Extension to Terilbah island with dredge spoil cuts off eastern channels. Very narrow entrance channel, with extensive shoaling in outer entrance, recovery of sand volume on The Entrance beach and minor development of a shoal attached to southern shoreline of outer entrance. Large nearshore bars separated by large rip cells along North Entrance beach. Possibly some minor vegetation stabilisation of the entrance spit.
1965	Wide tidal channel delivering sand to western lobe of tidal delta, eastern lobes relatively inactive, other than dredged channel along shoreline. The Entrance Beach trimmed from the south. Entrance spit trimmed from inside and outside, some evidence of overwash. Reduced rip cell circulation on North Entrance beach, but many closely spaced cusps.
1966	Dune blowout at north Entrance still active, diverting sand from the beach back to the lake shore. Entrance channel almost closed and heavily shoaled, but limited sand transfer to The Entrance Beach. The Entrance beach relatively accreted, including south around the rock bluff. Dredged channel controlling flows into the lake.
1969	Entrance open with wide deep channel on southern side, but swinging to north in the surf zone. The Entrance Beach depleted. Closely spaced rip cells on North Entrance beach. Extended dredging and deposition of a barrier along the eastern side of the tidal delta (past Terilbah Island) has cut off sand movement east to west cross the distal margin of the tidal delta.
1978	**Strong *la nina* events in 1971, 1973 and 1975.** This photo is after the 1974 and 1978 storms. Entrance is open with a wide deep channel that has cut through the centre of the spit and berm. North Entrance beach very narrow at southern end. Limited shoals in The Entrance – mostly scoured.
1982	Entrance open, with deep channel on southern side. Intermediate shoal condition in outer part of The Entrance. Spit recurving into entrance, so southern sediment transport. Widely spaced rip cells on North Entrance beach. Inner tidal delta covered with algae/sea grass. The Entrance beach relatively accreted, including sand to south towards the rock pool. Foreshore reclamation commencing on western side of tidal delta.
1986	Entrance channel wide open, on northern side, leaving a large bar attached to shoreline on southern side to feed The Entrance beach. Sand is clearly being delivered to the surf zone. Some evidence of preliminary stabilisation and vegetation at Karagi Point. Further shoreline reclamation on western side of tidal delta. Limited evidence of rip circulation on North Entrance Beach. **Strong *la nina* year in 1988**

Year	Morphology and Sedimentary Loci
1996	Straightening and reclamation of the lake shoreline on the northern side of the tidal delta, with dredging of deep channel between Terilbah island and shoreline. Further reclamation on western shoreline. Entrance open with deep channel in the middle of the entrance spit. North Entrance Beach narrow, The Entrance beach appears to be accreted – from shoal attached to southern shore of The Entrance. Clear shoals/bars in nearshore along North Entrance beach. Limited shoaling in entrance and clear evidence of dredging
1999	**Follows a strong *la nina* year in 1998** Entrance almost closed, with straight spit (seaward alignment) and slight lakeward curve at southern end. Entrance is heavily shoaled. North Entrance and The Entrance Beach both depleted. Very extensive reclaimed foreshore areas (sand removed from system). Most of inner tidal delta also appears to be stabilised by vegetation. Deep dredged channels control flows upstream of the bridge.
2001	Entrance open, with deep dredged channels and discontinuous opening on southern side. Dredged channels in outer entrance area have reduced shoaling. North Entrance Beach more accreted than 1999. Flows and sedimentary processes inside the bridge are controlled by dredged channels and reclaimed foreshore morphology
2006	Entrance almost closed (narrow channel on southern side) and heavily shoaled. North Entrance Beach is narrow (as per 1999). Most of the sand volume appears to be stored in the shoals in the outer part of The Entrance. The Entrance Beach partly accreted- sand moving across the lake entrance?. Dredged channels in the inner part of the tidal delta are still clear from 2001 dredging pattern.

2.2 Outer Entrance Shoaling and Spit Formation

The aerial photos for the period since 1941 suggest some significant changes to the functioning of the entrance over that time.

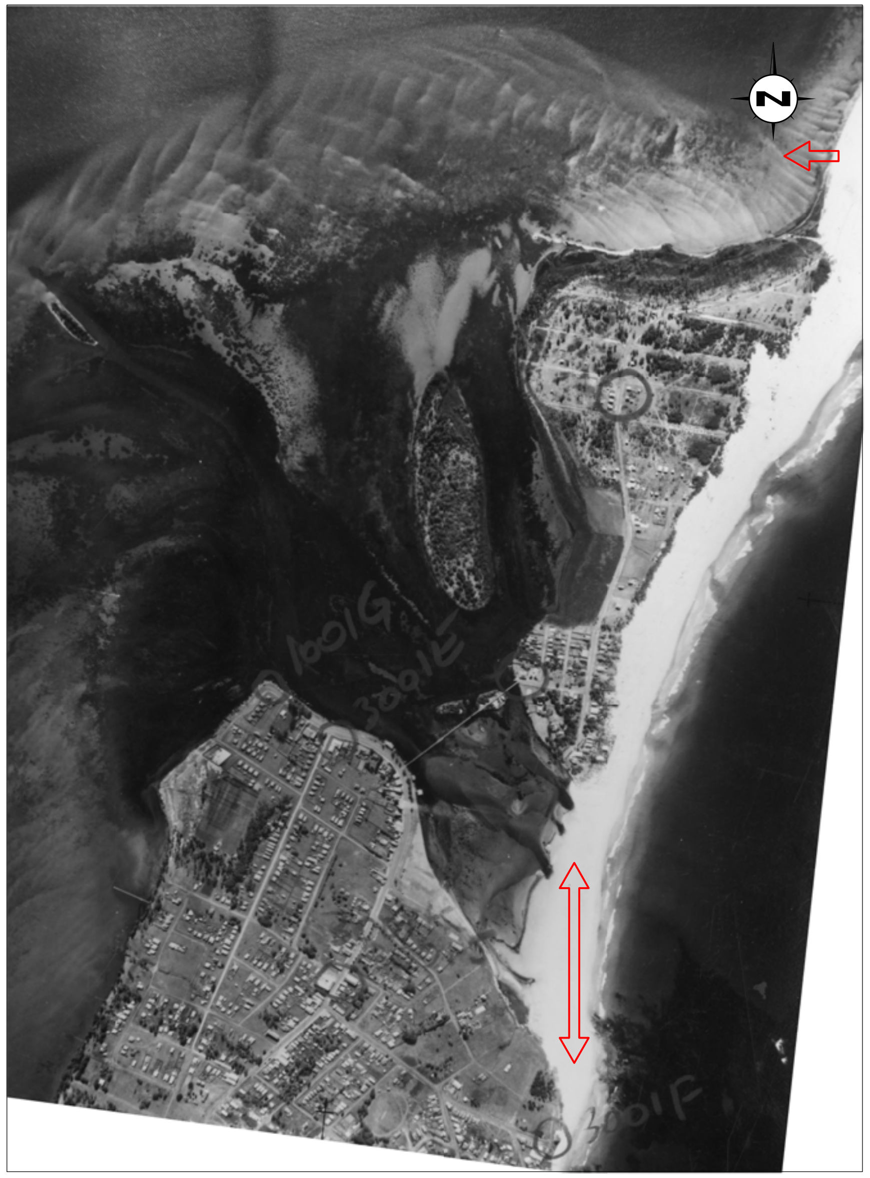
- In the mid twentieth century, there appears to have been a much more active process connection between the outer part of the flood tide delta and the inner part of the delta, including active lobes and splays and channel migration. This has now ceased, probably since the late 1970s.

- The greatest beach widths at North Entrance occurred in the mid twentieth century i.e. the earliest photos in the sequence. The beach does not appear to have returned to these widths since the severe erosion of the late 1970s.

- Spit formation is driven by sand moving south along North Entrance Beach and hooking into the entrance where the rock shoreline along the southern side controls flows.

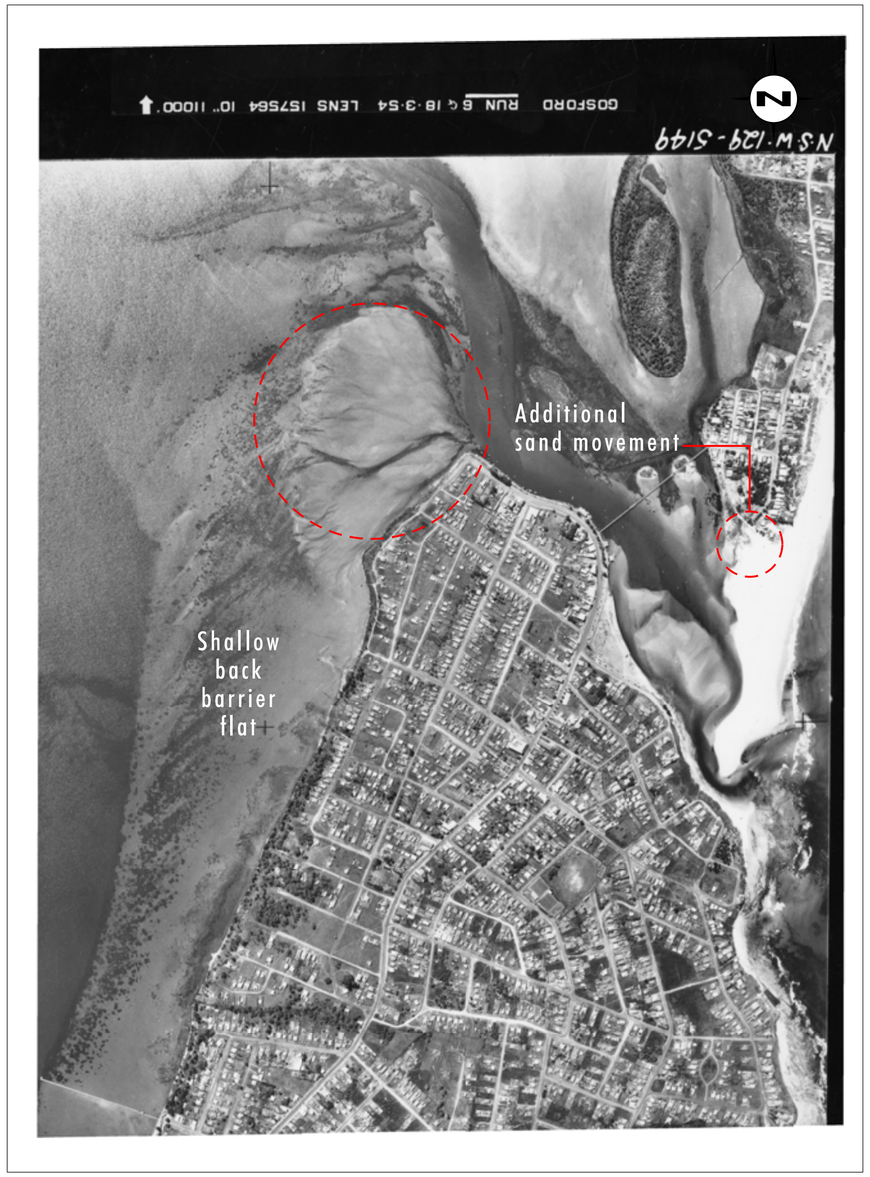
- The volume of sand on The Entrance Beach is linked to both the extent of entrance opening and the position of the entrance channel. When a large bar is left attached to the southern shore of The Entrance, it provides sand to nourish The Entrance Beach and also to accrete south as far as The Entrance swimming pool.

Umwelt
Environmental Consultants



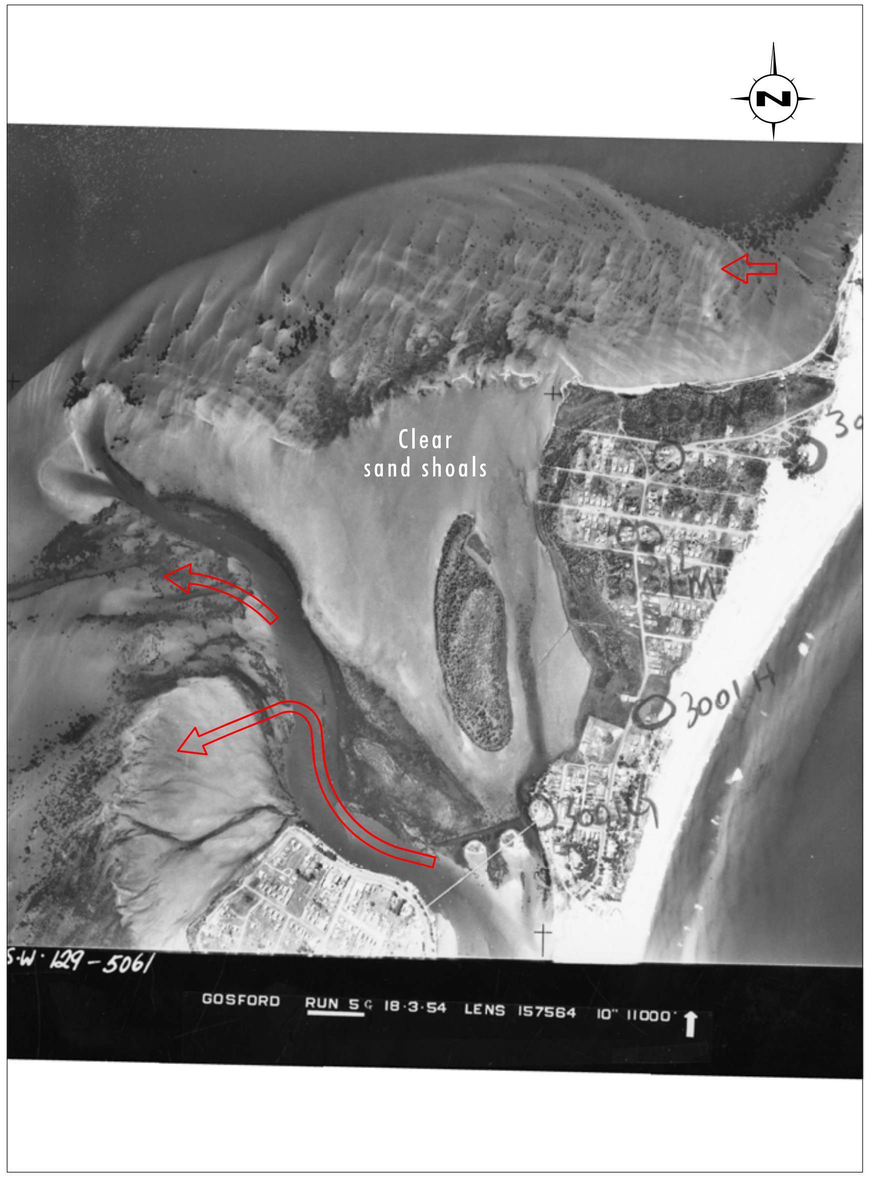
1941

- Active blowout transferring sand from North Entrance Beach (Curtis Pde area) across the barrier to outer edge of tidal delta
- Entrance closed. Long shore sediment transport building The Entrance Beach
- Very wide beach at North Entrance



1954

- Entrance open on southern side
- Sand stripped from The Entrance Beach and from outer tidal delta
- Extensive tidal flats off main channel on western side of tidal delta
- Limited delta activity to northern side



1954

- Active blowout continues at North Entrance
- Sand from blowout moving west across outer margin of delta
- Eastern side of delta strongly shoaled
- Wide beach at North Entrance, but low sand volume at The Entrance Beach

0 0.25 0.5 1.0km
1:20 000

FIGURE 2.1

Channel and Tidal Delta changes at The Entrance

Source: Wyong Council

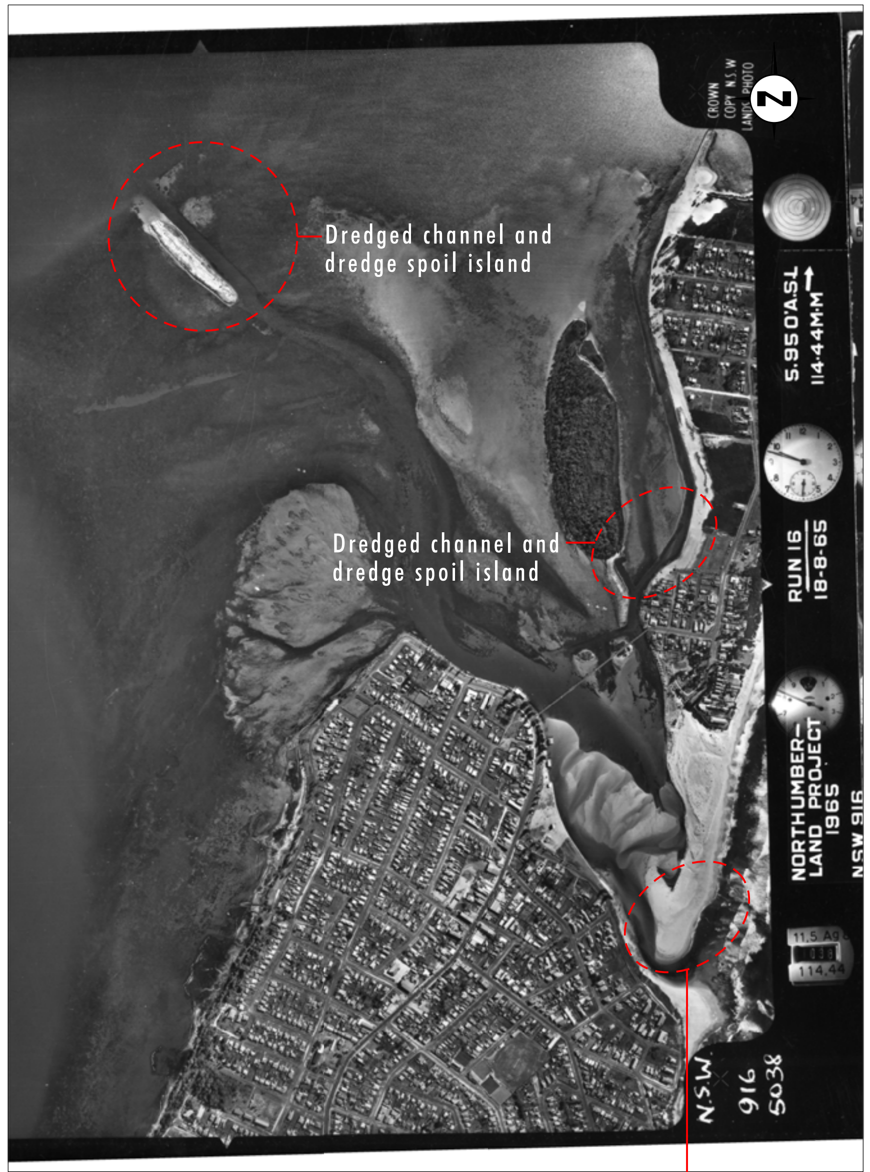
File Name (A3): R05_V1/1869_136.dgn

1961

- New alignment of lake shore at North Entrance, with sea wall
- large bars in nearshore, storing sand; large rip cells off Hutton Rd and in front of blowout

1961

- Limited sand on The Entrance Beach; isolated from North Entrance by entrance channel
- Limited stabilisation of the sand spit across The Entrance - spinifex colonisation?



1965

- Entrance shoal and spit trimmed by migrating channel
- Many small beach cusps, reduced rip cell circulation

0 0.25 0.5 1.0km
1:20 000

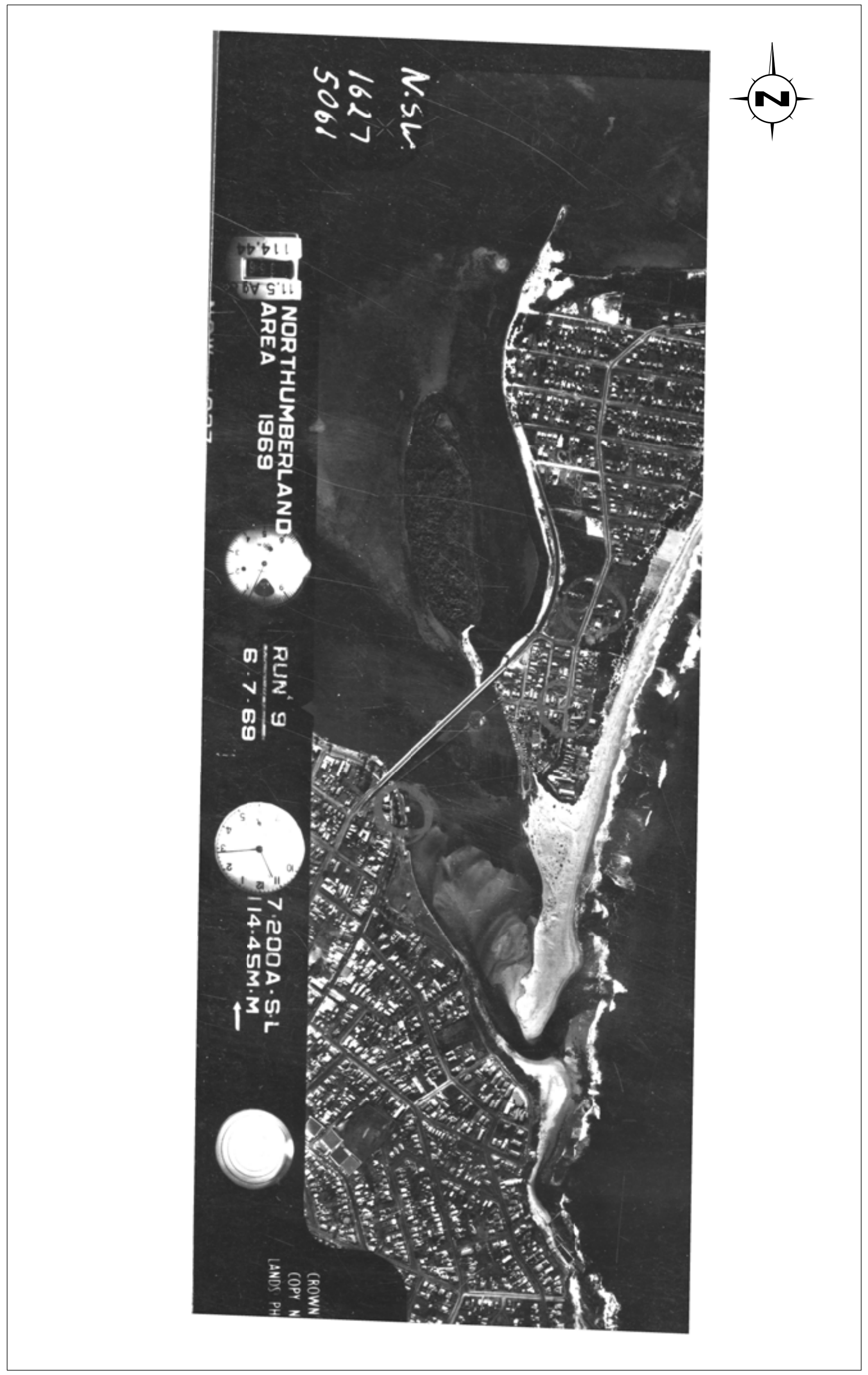
FIGURE 2.2

Channel and Tidal Delta changes at The Entrance

Source: Wyong Council

1966

- Dune blowout at North Entrance still active, diverting sand from the beach back to the lake shore
- Entrance channel almost closed, sand moving south along the southern part of North Entrance Beach and spit, but limited transfer to The Entrance Beach



1969

- Entrance open with wide channel on southern side
- Erosion of shoals in outer tidal delta
- Reduced sand volume south of entrance channel
- Open channel trimming spit to north
- Closely spaced rip cells on southern part of beach. Many cusps in surf club area

0 0.25 0.5 1.0km
1:20 000

FIGURE 2.3

Channel and Tidal Delta changes at The Entrance

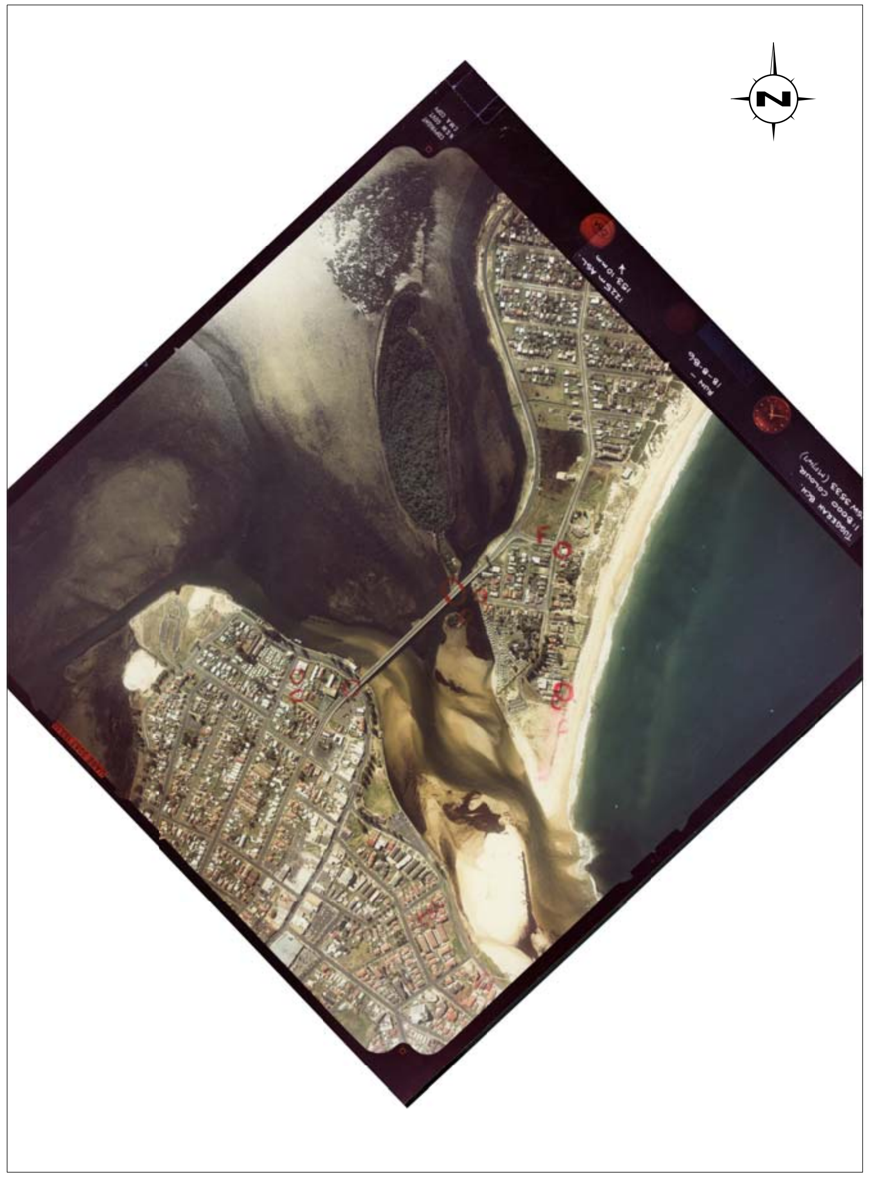
Source: Wyong Council

1978

- Entrance open with wide channel
- Sand spit severely depleted from entrance channel migration and storm bite into the frontal dune

1982

- Multiple dredged channels - outside and inside the bridge
- Accretion on ocean side of the entrance spit. Some recovery of shoaling in the entrance outside of the bridge
- The Entrance Beach in accreted condition



1986

- Entrance channel broken through on northern side of spit, isolating the southern entrance shore and The Entrance Beach from the main beach
- Reclamation and further dredging on western shore, inside the bridge reclamation

0 0.25 0.5 1.0km
1:20 000

FIGURE 2.4

Channel and Tidal Delta changes at The Entrance

Source: Wyong Council

1996

- Straightening and reclamation of lake foreshore and channel dredging to north of bridge, in outer entrance area, and along the western foreshore inside the bridge
- Recurve on spit shows sand moving south and into the entrance. Wide curved entrance channel separates an accreted Entrance Beach from North Entrance

1999

- Entrance almost closed, with straight spit and widespread shoaling in the outer entrance
- Deep channels (dredged) control flows upstream of the bridge
- Reduced sand volumes on The Entrance Beach and North Entrance Bench sand has moved into The Entrance
-
  Significant volume of sand from the tidal delta are locked into the reclaimed foreshores to the north east and west of the entrance (minimum estimate ~200,000m³)

2001

- Dredged channels in outer entrance area have reduced shoaling. North Entrance Beach accreted
- Reclaimed areas and dredged channels control flows and sediment movement inside the bridge

2006

- Entrance almost closed and channels heavily shoaled. North Entrance Beach is narrow (as per 1999)
- Sand volume stored in the spit and entrance shoals
- Shoal areas inside bridge vegetated and relatively stable
- Sand also accumulating in nearshore area of North Entrance Beach

0 0.25 0.5 1.0km
1:20 000

FIGURE 2.5

Channel and Tidal Delta changes at The Entrance

Source: Wyong Council

File Name (A3): R05_V1/1869_140.dgn

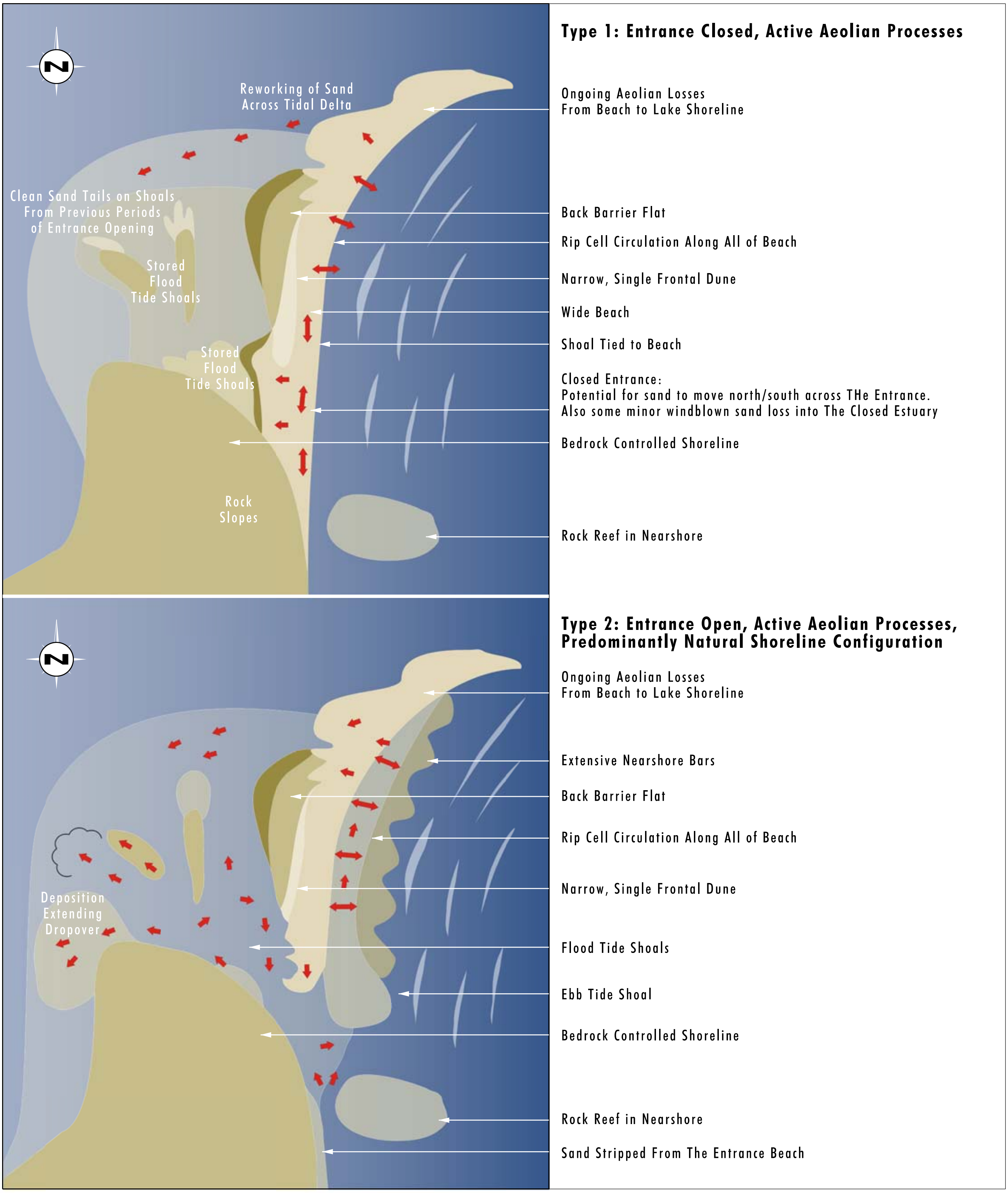


FIGURE 2.6

Sediment Stores and Pathways at
The Entrance, Type 1 and Type 2, Pre 1970

FIGURE 2.7

Sediment Stores and Pathways at
The Entrance, Type 3 and Type 4, Pre 1970

- Dredging of channels and reclaiming foreshore has conspicuously controlled tidal flows through the inner and outer tidal delta since around 1990.

- Qualitatively, there appears to be a relationship between dredging and the volume of sand on North Entrance Beach (southern end) when the entrance has not been widened by a flood flow scour event. For instance, in 2001, the southern part of North Entrance Beach (Hutton Road) is more accreted than in 1996, 1999 or 2006. Deep dredged channels and restricted shoaling are evident in the entrance area in 2001.

  However, in 2001, the sand volume in profiles north of Hutton Road was depleted, so sand was not moving into further north along the beach and dune system.

  Section 3.0 considers how wave transformation and sediment transport modelling can at least partly explain the observed sediment patterns on North Entrance Beach.

3.0 Long Shore Sediment Transport, North Entrance

This section presents a summary of the findings from long shore sediment transport modelling conducted by SMEC 2010. A copy of the SMEC report is in **Appendix 1**. The modelling looked at how variations in the angle of wave approach affect the movement of sand north and south along Tuggerah/North Entrance beach.

The balance of north and south sediment movement affects the volume of sand available to be deposited in the tidal delta and entrance berm of Tuggerah Lake and also affects the volume of sand that is available to accrete into the frontal dune system from the beach.

3.1 Wave Climate Analysis

SMEC 2010 used the SWAN (Simulating Waves Nearshore – Cycle III version 40.11) wave transformation model and bathymetry from Admiralty charts and local survey to determine how variation in wave climate affects patterns of sediment transport along North Entrance Beach.

The SWAN model takes into account a variety of wave propagation, wave generation and wave dissipation processes. The model computes wave induced mean sea surface set up. The SWAN model does not model diffraction, so is not accurate within harbours or near significant obstacles; it is however a good model for open coast situations. SWAN does not calculate wave induced currents, but these currents can be provided as an input to the model.

The wave analysis found the following:

- The predominant swell direction is 157.5 degrees TN (True North). 70 per cent of waves approach from the south-east.

- Swell waves approach the shore from a wide variety of directions (85 -118 degrees TN), due to wave refraction. Wave energy is refracted towards North Entrance Beach, resulting in a high energy wave climate. Due to local bathymetry, wave energy is focused at specific locations, including the section along Curtis Parade.

- The significant swell wave height can reach Hs=1.8 metres at the northern spit of the Entrance due to south-south-east swells and Hs=1.5 metres along the northern part of North Entrance beach due to easterly swells. This is a high wave energy coast.

- The direction of approach of wave energy along North Entrance Beach would mostly favour northward longshore sediment transport for the swell waves, while a southern sediment transport would be generated at the northern spit of the Entrance (i.e. the lake entrance spit and berm)

3.2 Potential and Net Long Shore Sediment Transport Rates

SMEC split North Entrance Beach into five sections of relatively uniform shore angle for the analysis (**Figure 3.1**). They used two different methods to derive **potential** long shore sediment transport rates at different points along North Entrance Beach:

FIGURE 3.1

Section of North Entrance Beach for Analysis of Long Shore Sediment Transport

Source: SMEC Australia Pty Ltd (2010)

File Name (A4): R05_V2/1869_141.dgn

- Coastal Engineering Research Centre Method (longshore component of energy flux in the surf zone). This method considers sediment grain size, nearshore breaking wave height of the significant wave, wave group speed at breaking, the angle the breaking wave crest makes with the shoreline and the depth of wave breaking.

- Kamphuis Expression. This equation calculates sediment transport rate in m^3/year, using breaking wave height, wave period, nearshore beach gradient and angle of breaking wave crest with the shoreline.

In each case, SMEC has calculated **potential** long shore sediment transport for **'typical conditions**'. The net sediment transport rate is less than the potential sediment transport rate. The potential sediment transport rate does not take into account inputs and losses not related to wave processes. These include input and losses due to aeolian sand transport and the effects of tidal (ebb flow) sand outflow from the lake entrance. The estimates are indicative only: they are based on average statistics and have inherent uncertainties due the limitations and assumptions of the formulae.

Both methods of calculating potential long shore sediment transport indicate a general northward along the beach, away from the lake entrance. However, along the southern corner of the beach, close to the lake entrance, sediment transport tends strongly to the south, providing sand to build the spit and berm at the lake entrance and to accrete into the tidal delta.

Table 3.1 summarises the potential sediment transport rates for locations along North Entrance Beach, as shown in **Figure 3.2**. The magnitude of sediment transport is highly dependent on the shoreline angle. Sediment transport at the entrance to the lake is dynamic and unstable. Sections of beach that are considered to be internally consistent in terms of shoreline angle are much shorter to the south, in accordance with the zeta form of the beach. Further north along the beach, a straighter shoreline angle is maintained, (noting the local scale changes to shoreline angle around rips and cusps).

SMEC 2011 summarise the sediment transport findings as:

> The *potential* longshore sediment transport rates at Region 3 (R3), Region 4 (R4) and Region 5 (R5) are mainly driven by the swell waves from SSE (157.5°TN) and ENE (67.5°TN), resulting in overall northerly sediment transport with a local southerly reversal of littoral drift moving sands along the northern entrance sand spit back to the entrance. The CERC equation predicted northward *potential* longshore sediment transport of up to 4 M m3/yr for R2, 1.1 M m3/yr for R3 and 0.4 M m3/yr for R5, with reduced longshore transport magnitude further north. However, long term beach recession was generally observed to increase northward along the beach, from photogrammetric data analysis in the Wyong Coastal Hazard Study (SMEC, 2010). The increased long term recession further north along the beach may be due to offshore sand transport during storms or aeolian transport into the dune system, as longshore transport rates are relatively low along the northern parts of the beach.

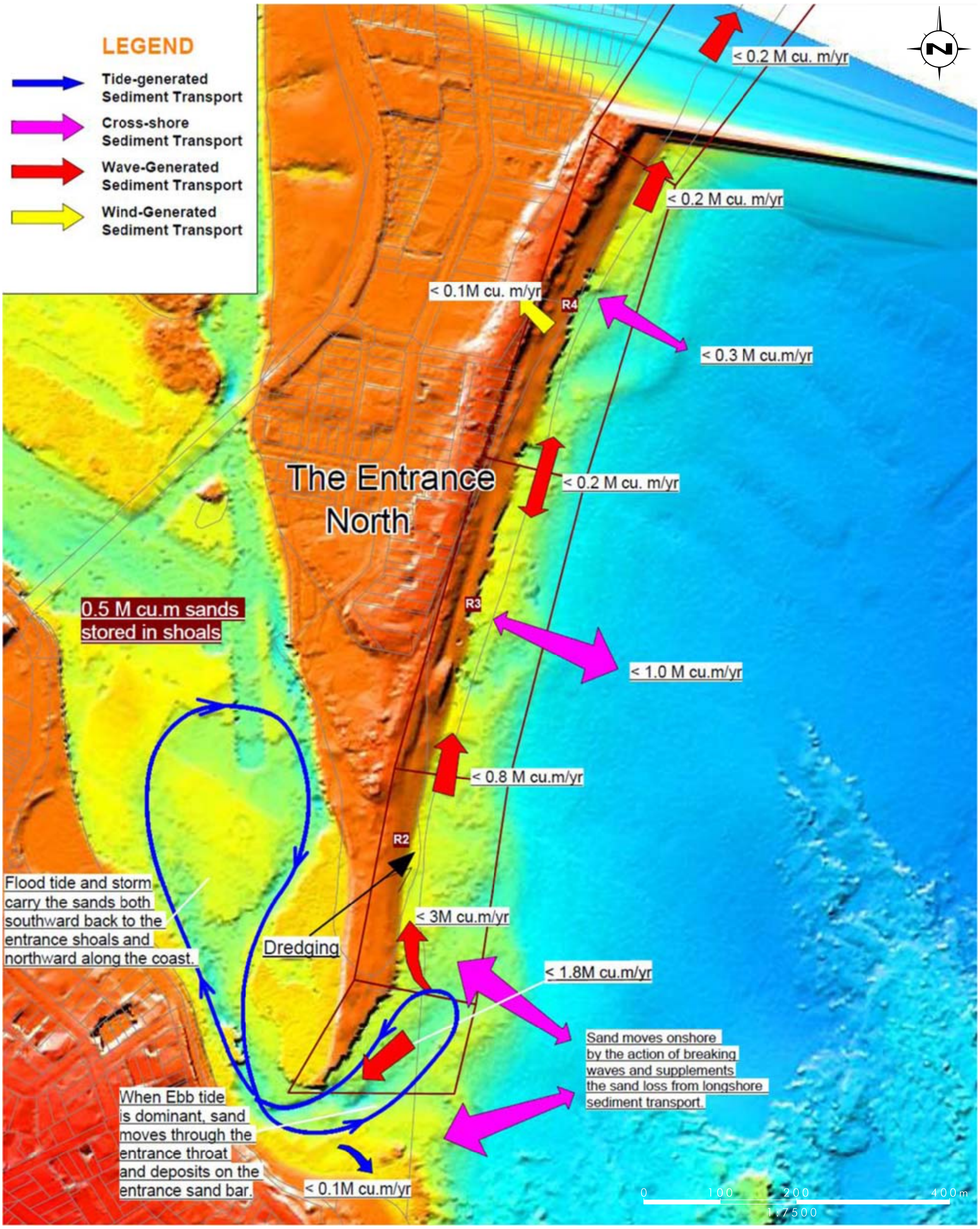


FIGURE 3.2

Longshore/offshore Sediment Transport Along the Entrance North Beach and Tide-Induced Sand Circulation between the Entrance Sand Bar and upstream Sand Shoals

Source: SMEC Australia Pty Ltd (2010)

File Name (A4): R05_V2/1869_143.dgn

Table 3.1 - Potential Long Shore Sediment Transport Rates, North Entrance Beach

Site/Locality	Location	CERC total potential rate, 000 m3/year, incorporating the occurrence of four wave periods	Kamphuis total potential Rate, 000 m^3/year, incorporating the occurrence of four wave periods	Comment
R1	Southern end of entrance spit	1770 south	2771 south	Both methods indicate a strong southerly movement of sand along the spit at The Entrance
R2	Northern end of entrance spit, extending to approximately Karagi Point, off the southern extent of vegetation at North Entrance	3178 north	3631 north	Both methods indicate a strong average northerly movement of sand. However, this is a dynamic area, and the entrance channel occasionally passes through this part of the spit. Offshore bar development is less than further north along the beach.
R3	Hutton Road to Hargraves Street	805 north	1123 north	Both methods indicate northerly movement of sand, but at a reduced rate as the shoreline straightens. There is no evidence of significant accretion in Section R3.
R4	North Entrance Surf Club area	188 south	267 south	Average sand movement in Sections 4 and 5 is at a relatively low rate along these straight sections of sandy coast.
R5	Curtis Parade and open space	236 north	454 north	As above. Historically, sand has been lost landward from this section of beach, in active transgressive dunes. In this section of the beach, sand is stored in dual offshore bars, separated by large rip cells.

The results from SMEC are consistent with previous findings (Patterson Britton 1994 and Worley Parson 2010) which also reported a local southerly reversal of littoral drift on North Entrance Beach. Patterson Britton and Worley Parsons refer to a ‘null point’ at which sand transport direction reverses. At different times since 1941, this point has moved along the beach at approximately Hutton Road.

These studies all report on 'typical' or average conditions for North Entrance Beach. However, it is clear that other conditions have applied in the past. Shorter term time series analysis would be needed to facilitate better understanding of beach responses to cyclic events.

For instance, in 1941, the entrance to Tuggerah Lake was closed and had been for approximately three years. The spit and berm connected The Entrance Beach to North Entrance Beach. Sediment transport to the north or to the south could occur along the entire length of the beach.

All models report that sediment transport direction and volume is sensitive to the angle of the shoreline and angle of wave approach. This means that during the extremes of southern oscillation cycles, significant differences in the dominant angle of wave approach are likely to affect the direction of sediment movement. The analysis so far at North Entrance beach has not linked the southern oscillation cycles to the snapshots of beach condition that are available from the aerial photos. Neither have they examined closely how decadal or other variations in dominant wave direction would affect the beach.

Longshore sediment transport modelling would need to be extended to the full length of Tuggerah/North Entrance Beach to understand the magnitude of these events.

Studies from long barrier beaches elsewhere along the NSW coast (e.g. Goodwin *et al.* 2005) have clearly demonstrated that sections of beaches with north-east aspect have accretion and erosion patterns broadly the inverse of east aspect or south-east aspect coastline, as angle of swell wave approach shifts from more southerly to more east-south-easterly.

3.3 Interaction of Long Shore Sediment Transport and Cross Shore Sediment Movements

Further work is needed to follow up on the interaction of long shore and cross shore processes at North Entrance. Conceptually, some associations can be observed and predicted, but the evidence needs to be confirmed.

Where sand is moving to the south along North Entrance Beach, there is clear evidence that it feeds sediment into the flood tide delta in the outer part of the entrance channel. The spit progrades to the south and recurves into the estuary. Relatively high potential sediment transport rates to the south (along the spit) suggest abundant sand for construction of a high berm.

Cross shore sediment movement occurs episodically, in major storm events. A combination of strong storm bite and strong discharge currents from an open and flooding estuary may move some sand offshore into water depths beyond the depth of closure, so it is not available to return to the beach. As sea level rises, deposits just at the depth of closure will become less accessible.

Since the early 1990s, dredging has maintained the entrance slightly open. For most of the time since then, The Entrance Beach has been cut off from any sand supply moving in long shore transport from the north, as this sand enters the entrance. The sand can only migrate onto The Entrance Beach if it ends up in a shoal attached to the southern shoreline inside the entrance, which is subsequently cut off by northern migration of the entrance channel. This has occurred occasionally.

The narrow frontal dune at the southern end of North Entrance Beach is consistent with the morphology expected in situations where the long term net effect of long shore transport is predominantly to the north (away from this area), limiting overall sediment supply. In the long term, without other sediment inputs or other significant losses further north, the rate of recession at this end of the beach would be expected to exceed the rate further north along the embayment.

No long term studies have been conducted of the stratigraphy of North Entrance to determine whether the frontal dune system has actually been removed during prolonged beach rotation events or minor sea level rises and falls in the past. This is possible however, and recent research from some narrow barriers on the mid north coast (Goodwin pers. comm. in relation to the Nambucca) suggest that some narrow frontal dune systems may have been removed and re-deposited in very recent times (200 to 500 years).

The combination of sea level rise, and prolonged or frequent *la nina* events is expected to be high risk for these southern corners of beaches, where dune forms may be quite tenuous.

3.4 Entrance stability

SMEC 2011 used the Escoffier theory (first developed in 1940) to analyse the stability of The Entrance. Details are in **Appendix 1**.

The dimensions of the lake entrance were observed using the historic aerial photographs and available bathymetric soundings. It was found that the channel entrance width was varying between around 20 and 100 metres, its length ranges between 90 and 450 metres and its depth was assumed to range between 0 and 2 metres.

The water level response of Tuggerah Lake was calculated using a difference method from the predicted ocean tide level calculated by the software WXTide 32 over a year. Results were validated by checking against the real-time tidal data recorded at Toukley by MHL available on their website at the time of writing this report showing a lake level of around 0.2 and a negligible tidal range.

A sensitivity analysis was undertaken using the various channel dimension measured from the aerial photographs. The average lake level increases when the entrance is shallower and the tidal range increases when the entrance is wider. The length of the channel slightly reduces the tidal range and increases the water level. The water level in the lake does not exceed 0.15 metre and the tidal range is around 0.20 metre.

However, these values assume the tidal impact only and do not take into account the rainfall and fluctuations in atmospheric pressure that may increase or decrease them. The SMEC results are of the same order as the results of MHL (2010) and confirm the 0.2 to 0.3 metres tidal range found by Worley Parsons (2010).

Given the very low tidal range within the lake and therefore the low tidal prism, as well as the variable dimensions of the channel entrance, the current velocities will be low and this would result in sand deposition within the entrance over time. Therefore the lake entrance tends to reduce and would eventually close.

What would happen if Council stopped dredging? Without climate change, the best evidence of what would happen to the beach if council stopped dredging is the pre dredging configuration of the entrance. Pre 1990, the entrance closed for long periods, but the exact distribution of sand volumes across the spit/berm, in the tidal delta and on the beach/dunes is not known.

4.0 Sand Storages – Temporary and Long Term

This section reviews locations where sand deposits have accumulated and are likely to be stored in the long term, without intervention.

4.1 Local Sand Storages

From **Figure 2.1** a number of sand accumulation areas around the Entrance and North Entrance can be discerned. These are noted in **Table 4.1**. Estimates of the volume of material in these storages are *preliminary and indicative*. They are based on assumptions about the thickness of sand deposits in the entrance area and on rounded numbers for the 2D dimensions of the various deposits

Table 4.1 - Sand Storages at or near The Entrance and North Entrance

Sand Source	Description
Shoaling in the outer entrance area	During periods of limited catchment flows and few significant costal storms, marine sand accumulates in a spit and shoals that infill the outer part of the Entrance channel. This deposition is concentrated outside the Entrance Bridge, although a large active lobe of the flood tide delta was depositing on the western side of the tidal delta, lakeward of the bridge in the mid 20th century. The maximum area of shoaling outside the bridge (not including the berm) is around 260,000 m^2. If it is assumed that the shoals infill the entrance to a depth of 1.5 metres, then the volume of sand in the outer tidal delta deposit can be up to around 390,000 m^3. If a maximum depth of infill of 3 metres across the entire shoal is assumed, the volume of sand stored would approach 750,000 to 800,000 m^3.
The entrance berm	The indicative area of the spit and entrance berm deposit is around 120,000 m^2. If a berm height of 2 metres is assumed, the volume of sand temporally stored in the spit and berm is around 240,000 m^3. This is marine sand, very similar to the current beach.
Sand in recently active lobe on western margin of tidal delta (lake-ward of bridge)	This lobe has an area of around 260,000 m^2. If a thickness of 1.5 metres is assumed, the deposit contains around 390,000 m^3 of sand. The deposit is likely to contain some organic lenses and to be finer sand than the outer tidal delta.
Sand held in the tidal delta, lake-ward of The Entrance bridge	This refers to the full area of the inner part of the tidal delta, not including the tidal flats behind the North Entrance spit and not including the western lobe considered above. Assuming a sand thickness of 2 metres over the area of the inner tidal delta, this area contained around 1.6 Mm^3 of sand, before some material was dredged to fill foreshore reclamation areas. Nonetheless, the inner tidal delta, on very preliminary calculations has more than 1 Mm^3 of marine sand in storage. This sand has a key role in throttling tidal exchange in the lake. The marine sand will be interbedded with organic materials and carbonate.
Back barrier flat, North Entrance	The area of the main back barrier flat area is approximately 350,000 m^2. Assuming a 1.5 metres thickness for this deposit, this gives a deposit volume of more than 500,000 m^3. Most of this is likely to be sand, but there may be units of finer silty material, organics or shell within the deposit.

Sand Source	Description
Sand in foreshore reclamation fill on both shorelines of the entrance, lake-ward of The Entrance bridge	The northern reclamation area holds approximately 70,000 m^3 of sand. The southern reclamation area holds approximately 210,000 m^3 of sand, assuming a fill depth of 1.5 metres in each case. Material in both reclamation areas is likely to include fine grained and/or organic sediments as well as fine to medium grained sand.
Near-shore shoals on the southern end of North Entrance beach	The presence of these shoals which are interspersed with rip current channels is dependent on wave conditions. They can be seen on aerial photos from 1961, 1996. For instance, shoals/bars from the spit north to the blow out in 1961 had an area of around 70,000 m^2. If a thickness of 1.0 metres is assumed, this is a volume of around 70,000 m^3. The 1996 aerial photo shows approximately 25,000 m^2 of near shore bar south of the North Entrance Surf club
Offshore sand deposits in water depths of 10 to 20 metres.	The LADS data reveals (through seaward bulges of bathymetric contours) the potential for offshore morphologies that are consistent with deposits of sand that has been lost from the active wave and beach/dune zone. Where the nearshore profile is not in equilibrium, sediment eroded from the beach during storms will be deposited in water deeper than shoaling waves can access and move back onto the beach. The actual volume of sand in these deposits is not known at this time. Further studies of the sea bed (with a full set of LiDAR data, sonar and/or coring) would help to clarify the nature and extent of the deposits. New LADS data, collected at the same time as the next LiDAR run for the coast, would also allow analysis of changes to the morphology of the sea bed and any relationships between sea bed accretion and foreshore/dune losses.
Sand trapped within offshore rock reefs	Offshore images and LADs data indicate considerable local scale topographic variability within rock reef areas off The Entrance, including sharp steps, deep narrow slots and channels between rock outcrops. This morphology is of the type that would trap sand transported offshore in flood flows from the entrance and/or eroded by storm waves. For instance, sand dropped over a step break in slope may not be able to move back up into shallow water. The volume of sand trapped in these storages is not known. The deposits are likely to be multiple discrete parcels of sand, not a continuous mass. Indicatively, the volume could be in the 100,00 m3 range, but would need further investigation to provide any certainty around this number.
Former transgressive dune forms at North Entrance	The transgressive dune lobe extending to the lake shore from the frontal dune in the mid twentieth century detached approximately 150,000 m^3 of sand from the active frontal dune system (assuming 1.5 metres sand depth across the blow out area). This material may be too fine for beach nourishment purposes.
Relict transgressive dune forms in the northern part of the Tuggerah Embayment	These dunes are now in National Park. The area of dune forms is at least 2.5 kilometres by 2.5 kilometres, with variable crest and swale topography. This area is estimated to hold more than 1 Mm^3 of former marine sand, reworked by aeolian processes. This material may be too fine for beach nourishment purposes.

Sand Source	Description
Offshore sand deposits on the continental shelf (see **Section 4.2**)	Each of the sand bodies off the Central Coast has an area of more than 10 kilometres by more than 2 kilometres. Thickness of the deposit is likely to be more than 10 metres. However, not all material in the deposits would be suitable for beach nourishment purposes. Total volume of potentially suitable grain sizes, assuming only the top 1 metre were to be extracted, is likely to exceed 2 Mm^3.

Detailed grain size distribution information for materials in these sand storages is not currently available.

Broadly, these deposits can be grouped by **indicative** volume:

Deposits with less than 100,000m^3	Near shore and shore tied shoals, southern end of North Entrance Beach Northern reclamation areas on the lake foreshore Sand trapped in rock crevices and beyond step breaks of slope
Deposits with 100,000 to 500,000m3	Entrance berm Entrance shoals (outer tidal delta) Sand lobe on western side of tidal delta Former transgressive dune at Curtis Parade Southern reclamation area
Deposits with 500,000 to 1 million m^3	Back barrier flat, North Entrance Conceptually, offshore sand deposits outside the depth of closure could be of this order of magnitude, but further investigation is necessary.
Deposits with more than 1 million m^3	Relict transgressive dunes, Wyrrabalong National Park Offshore sand deposits (on the shelf) ‘Relict’ or inactive parts of the flood tide delta

4.1.1 Transfers Between Sand Storages

The long shore sediment transport models and storm bite assessments clearly show that some sand deposits are actively associated with each other, with transfers from one storage to another occurring at time frames of decades or less. Examples are the process connections between:

- Entrance shoals, the entrance spit and berm and nearshore bars at the southern end of North Entrance Beach;
- Nearshore bars, subaerial beach sand and frontal dune development;
- Subaerial beach, frontal dune and active transgressive dunes;
- In the mid twentieth century, a transgressive dune across the barrier was feeding beach and dune sand onto the shore of the distal margin of the inner tidal delta. This sand

appears to have been reworked to the west across the inner tidal delta. More work is required to understand the exact volumes of sand involved.

In contrast, some sand deposits appear to be relatively uncoupled from each other in terms of sedimentary processes. Examples include:

- Offshore (inner shelf) sand deposits are largely disconnected from all near shore deposits (certainly beyond about 20 metres water depth)

- Sand deposits eroded from the beach on non equilibrium offshore profiles and deposited offshore.

- Sand trapped within crevices and step breaks of slope in rock reefs

- The inner part of the tidal delta at the entrance to Tuggerah Lake appears to have restricted sedimentary process connection to the active shoaling in the outer part of the tidal delta. This is partly influenced by the effects of past and current dredging (of deep channels and maintaining the entrance in an open condition), but also by long term changes in sea level since different parts of the flood tide delta were deposited. The 1941 aerial photos show active sedimentation of a lobe of sand on the western side of the tidal delta, but this has now ceased and no active sedimentation by marine sands appears to be occurring across much of the inner part of the delta. This area is now vegetated with sea grass.

- Sand which is locked into reclaimed areas or is beneath residential development is uncoupled from active sedimentary processes and further storage transfers. This applies to the stabilised transgressive dunes at North Entrance, to the reclaimed land on either side of the entrance channel (now parkland) and to the residential areas on the back barrier flat at north entrance.

- Relict transgressive dunes on the national park at the northern end of Tuggerah Beach are not part of the active beach sediment compartment and transfers into these dunes ceased in the very late Holocene.

Apart from the relic deposits on the inner shelf, all of these current decoupled storages contain sand which is likely to have been part of the active beach sediment budget within the last 1000 years and in some cases, to within the last 50 years.

Further analysis and detailed checking of the volume and origins of sand deposits are necessary to confirm losses of sand from the sediment compartment at North Entrance Beach/The Entrance, but at a very preliminary level, these losses are likely to be in the order of 1.5 million m^3 within the last century (for the area south from and including Curtis Parade). This volume is in the same order of magnitude as the largest recorded storm bite for this part of the beach, and would be sufficient to explain vulnerability to immediate storm bite, without sea level rise.

4.2 Offshore Sand Deposits – relic shorelines and deep off shore terrain

AECOM (2010) analysed the scope and feasibility of nourishing sand volume on selected Sydney beaches, using sand in offshore (continental shelf) deposits. Although the details of feasibility are specific to the Sydney beaches in their study area, many of the other aspects of the study, such as the nature of the sand deposits on the continental shelf, the statutory context of off shore sand extraction and the techniques that would need to be sued to access sand deposits in deep water, are also relevant to the Wyong situation.

The sand bodies on the continental shelf are deposits associated with former shorelines, when sea level was much lower than its current position during the last Glacial period. The last Glacial was at its maximum 17,000 years ago, with sea level around 140 metres lower than it is now. As sea level rose from 17,000 years ago to about 10,000 years ago, sand deposits on the shelf were pushed landward by waves. In some locations, this shoreward translation of sediment was interrupted by cliffs or other sharp breaks of slope, and sand bodies accumulated at the base of (now offshore and deeply submerged) cliffs. In other locations where the shelf topography is more gradual, sand was pushed into estuary embayments, forming the Holocene barriers, beaches and estuary shoals that characterise the modern coast.

The sand in the offshore deposits is from the same source and has similar characteristics to the sand that forms the Holocene and recent coastline. This means that there is a variety of grain sizes in the material, depending on its original depositional environment and winnowing that may have taken place as it moved across the shelf.

The offshore deposits are in approximately 20 to 40 metres of water (deeper in some places) and at least 1 kilometre offshore. The deposits are 10 to 30 metres thick and are generally convex to the sea floor.

In general, the offshore sand bodies are not functionally connected to modern littoral draft or shore normal sediment transport processes. Field and Roy (1984) report some active (not fully resolved) sediment transport processes on the offshore sand deposits, both shore parallel and shore normal. Albani *et al* (1988) also reports erosion of the top of the sand body and seaward movement of sand in some deposits during major storms.

Two offshore sand bodies are known to be in proximity to the central coast. The southern sand body extends from offshore of Brisbane Water/northern side of Broken Bay to east of Tuggerah Beach. The northern sand body extends from off Lakes Beach/Birdie Beach north to off Blacksmiths Beach (north of the entrance to Lake Macquarie).

Both sand bodies have been subject to Mineral Title applications.

Location	**Application**	**Company**	**Granted**	**Mineral**
Central Coast north	EL3220	Metromix Pty Limited	November 1988, expired November 1994. Renewal sought	Group 4
Central Coast south	MELA 5	Sydney Marine Sand Pty Limited	August 2006, refused December 2009	Group 4

5.0 Entrance Channel Behaviour with Climate Change and Sea Level Rise

Predicted climate change on the NSW coast will result in higher sea levels (up to 0.9 metres above 1990 levels by 2100), as well as changes to the wave climate, rainfall intensity and flood frequency. All of these potential changes can affect the condition of the entrance to coastal lagoons such as Tuggerah Lake.

Hanslow *et al* 2000 present a simple model of a landward and upward shift in the beach profile as sea level rises over the next century. The impact of this landward shift of the shoreline on ICOLL entrances depends in part on whether the entrance is north or south of the headland of the embayment (i.e. the long shore drift regime and the likelihood of accretion). The likely balance between shoreline recession processes and shoreline accretion processes as sea level rises is not known for most ICOLLs in NSW.

Haines (PhD thesis 2006) describes a model for ICOLL entrance response for lagoons where the entrance is at the southern end of a long beach system. He suggests:

- Shoreline recession due to sea level rise driven recession will be compounded by sand losses due to beach rotation. In this case, large volumes of sand would be moved from the entrance area of the ICOLL.
- Sand lost from the entrance shoals may move north along the beach by long shore processes or may accrete further into the estuary at the distal margin of the tidal delta. In these circumstances, overall, the berm height would trend lower and the lake entrance would tend to remain open for longer than is now the case.

In addition to these shoaling patterns, Haines (2006) suggests that a higher mean sea level would tend to decouple the bed controls (such as bedrock outcrop in the channel) from the tidal flows, as the water depth increases. This would reduce flow velocity and may tend the entrance towards more frequent closure.

Clearly, the entrance response is highly dependent on specific locational characteristics and on the sequence of storm events, *El nino*/*La nina* events that affect the local area and other factors that influence sediment volume.

5.1 Evidence of Changes in Tuggerah Lakes

MHL (2010) conducted analysis of water level data from automated water level recorders in the Tuggerah Lakes.

MHL compared water levels from recorders in Tuggerah Lakes with each other (up to 20 years of records) and with long term tide records from Fort Denison. They note particularly:

> Water levels in Tuggerah Lakes cannot be directly related to ocean level, due to the relatively narrow entrance, large lake system and other influences. The diurnal tide cycle is heavily damped by the entrance, but the monthly and longer cycles are clearly visible in the lake.

Because of the anomalous effects of floods on water levels, MHL also removed flood events from the data before examining the trends for Tuggerah Lakes.

MHL found that for the period 1995 to 2009, water level at Toukley had risen on average, 3.9 millimetres per year. At Long Jetty, water rose on average 6.4 millimetres per year between 1991 and 2008. Both rates are much higher than the long term mean for Fort Denison. They are also very different to each other.

MHL note that the complexity of the Tuggerah Lakes system makes it very difficult to understand whether these water level results are real, or to explain the processes that would lead to such disparate results. Factors suggested include entrance conditions, dredging, wind effects, urbanisation of the catchment, as well as rainfall, flooding and oceanic sea level rise.

The limitations to the water level data complicate meaningful investigation of the relationship between water levels and entrance behaviour for Tuggerah Lake.

At a very preliminary level, previous studies (e.g. see Haines 2006, discussed above) have indicated that rising oceanic water levels (driving rising lake levels) would lead to lakeward accretion of the flood tide delta and possibly to a loss of sand from the berm and shoals at the entrance, as sand moves lakeward and along the beach.

The morphology of the entrance to Tuggerah lakes over the last 20 years (and beyond to 70 years) has changed significantly. A narrowing of the entrance berm can be observed. However, other significant changes such as dredging of deep channels across the inner and outer parts of the tidal delta, removing sand from the tidal system into reclaimed foreshore and placing dredged sand onto North Entrance Beach have interfered with natural estuary entrance processes. In addition, until the late 1960s, sand was being contributed to the distal margin of the tidal delta, not from tidal processes, but from a transgressive dune at North Entrance (see **Figure 2.1**). This transfer process has now stopped.

5.1.1 Shoreline recession and entrance processes

As noted in **Section 1.4.3**, there is some evidence from narrow coastal barrier systems on the NSW north coast of recession in the period prior to 1500 years BP, with accretion recovering after 1000 years BP. Limited sedimentary cores from the tidal delta of Tuggerah Lake also indicate multiple pulses of sedimentary activity within the last 1000 years. These pulses of activity at specific locations on the tidal delta may be due to switches in the focus deposition as tidal channels relocate across the delta. They could also be due to medium to long term changes in the frequency and duration of lake opening/lake closing events or to fluctuations in sea level.

Coastal erosion and recession hazard analysis (SMEC 2010) for North Entrance Beach, using the Bruun Rule with 40 centimetres and 90 centimetres sea level rise, indicates that the entire frontal dune at the southern end of the beach is vulnerable to removal and/or roll back over the next 100 years, as the shoreline moves upward and landward.

Such resetting of shorelines also has significant potential implications for The Entrance, including:

- Significant shortening of the length of the entrance channel. Indicatively the channel (seaward of the bridge) could be shortened to two thirds of its current length. This affects current velocity and the throttling effect of entrance sand shoals on lake water levels.

- Sand could potentially be added to the northern shoreline of the entrance from wash-over processes and/or roll back (wave pushed or wind-blown) of the frontal dune

- Nearshore gradients off the spit at The Entrance could decline as the sea bed responds to redistribution of sand from North Entrance Beach. This potential increase in nearshore sand availability would interact with sand trapping in rock crevices and with the stripping of thin mantles of sand from The Entrance beach.

Clearly these are complex interactions and much more detailed investigation and analysis is needed to provide clarity and certainty.

6.0 Sand for Beach Nourishment

This section provides an overview of why beach nourishment is needed and which sources may be suitable and feasible.

6.1 Where is Beach Nourishment a Management Option?

Coastal erosion hazard studies prepared for the draft Wyong Coastal Zone Management Plan have identified recession rates of up to 0.5 metres/year for the period 1974 to 2007, for North Entrance Beach, in the vicinity of Hutton Road. Rates of recession are highly variable during that period and also vary from one profile to another along North Entrance Beach. However, the overall trend is to recession and the beach is recognised by the NSW Government as a coastal erosion hot spot and Authorised Location for emergency coastal protection works.

As discussed in **Section 1.4.1**, measurement of storm bite erosion at North Entrance beach (SMEC 2010) has been conducted for five sectors of the beach:

Block A Sand spit at The Entrance
Block B Residential development at Hutton Road
Block C Surf Club vicinity
Block D Residential development at Curtis Parade
Block E Central Tuggerah Beach, near Magenta Shores

Table 1.1 summarises past storm bite erosion volumes for North Entrance Beach.
In addition to this sand demand for storm bite, SMEC 2010 indicate beach recession in metres and beach volume loss (m^3) due to sea level rise by 2050 and 2100. These are summarised below for the Blocks A to E of North Entrance Beach.

North Entrance beach	Beach recession metres) 2050	Beach recession (metres) 2100	Volume of sand loss (m^3/m), 2050	Volume of sand loss (m^3/m), 2100
	11.6 to 18.0	26.1 to 40.4	73.3 to 152.7	164.9 to 343.7

Although structural protection measures may be appropriate as a delaying strategy for beach recession at North Entrance, the draft Wyong CZMP suggests that maintaining beach amenity and protecting residences and infrastructure will require nourishment of the beach compartment with additional sand.

The length of North Entrance Beach from the sand spit to 200 metres north of the northern extent of Curtis Parade is 2.9 kilometres (2900 metres). Therefore, indicatively the volume of sand to maintain the current (already eroded) beach volume with sea level rise to 2050 is approximately 445,000 cubic metres, with different volumes required at different locations along the beach. This assumes no loss of sand through long shore sediment transport or losses into ‘sinks’ such as increased sedimentation on the flood tide delta or activation of transgressive dunes. As sea level continues to rise, the volume of additional sand needed to maintain the current sub-aerial beach volume continues to rise, more than doubling by 2100.

Tidal records from Sydney Harbour indicate that sea level has already risen by about 15 to 20 centimetres over the last century. This means that additional nourishment would be required to return the beach profile to approximately its position at the time that European settlement commenced in The Entrance/Tuggerah Beach area.

In summary, if restoration of a beach profile based on the beach condition in the early to mid twentieth century was the objective for North Entrance Beach, the total volume of beach nourishment required for this one beach to account for losses into temporary or permanent storages, losses due to existing sea level rise is as follows and expected losses due to ongoing sea level rise.

To offset sand lost into sinks	1.5 million m^3 (low level of certainty around this number)
To offset recession (or sediment demand) due to existing sea level rise	Approximately 90,000 m^3 to 200,000 m^3
To offset recession with 40 cm sea level rise to 2050	Approximately 445,000 m^3

6.2 Sand Sources

Potential sources of sand that may be suitable for beach nourishment purposes are noted in **Table 4.1**.

The sources are:

- Outer, active tidal delta, spit and berm;
- Inner, relatively inactive tidal delta, including areas that may accrete as sea level rises;
- Previously reclaimed areas on the lake shore;
- Beach and nearshore deposits within the active wave zone;
- Nearshore sand that has been deposited outside the active wave zone, in waters 10 to 20 metres deep. This sand is eroded from the beach and dunes during major storm events and does not shoal back onto the beach system. It therefore is a net loss to the sediment budget for the beach and dunes;
- Relict coastal dunes; and
- Offshore deposits on the inner shelf.

6.3 Constraints to Use of Sand Deposits for Beach Nourishment

This section provides an overview of the factors that would limit the use of sand from various sources for beach nourishment at North Entrance Beach.

6.3.1 Inappropriate or Incompatible Sand Quality

There is little data available to quantify the grain size of central coast beaches, or the sediment in the tidal delta of Tuggerah Lake. Further sediment sampling and analysis would be necessary to properly compare beach sand characteristics and the character of the various sand storages in the area.

AECOM 2010 note that borrow material used for beach nourishment should be similar in grain size or slightly coarser than the native sand on the receiving beach.

If the beach is nourished with sand that is much coarser than the local natural sand, a steeper beach profile will result. This will make the beach more reflective, will change rip and bar patterns and will modify beach amenity. The nourished sand will tend to accumulate as a steep wedge close to shore.

If the beach is nourished with sand that is finer than the local natural beach sand, the beach gradient will flatten. The volume of sand retained on the subaerial beach and into the dunes will be lower than for coarse sand nourishment, with sand spreading out along the shallow gradient of the cross shore slope.

AECOM (2010) recommend an ‘Overfill Factor’ to allow for differences in grain size; this factor varies with the sediment source.

Most of the sand storages noted in **Table 6.1** are likely to have at least some of the deposit of a finer grain size than the modern beach sand on North Entrance Beach.

In terms of similar depositional processes, the units most likely to have compatible grain sizes are:

- Active shoals from the outer entrance flood tide delta;
- The spit and berm at The Entrance, from Karagi Point;
- Near shore bars along North Entrance Beach;
- Parts of the overall tidal delta and back barrier flat (but detailed stratigraphy would be needed in both of these cases);
- Offshore sediments from former beach and barrier systems.

Of these, Council already places some sand from the outer part of the tidal delta onto North Entrance Beach. The spit/berm and near shore bars are active parts of the North Entrance Beach sediment system. Council already uses these sources to a limited extent through beach scraping activities. Beach scraping moves sand from the beach face/swash zone back to the frontal dune.

Detailed grain size and sediment quality analysis would be required before any of these sources could be considered for large scale beach nourishment activity. Comprehensive assessment of ecological impacts (such as on beach and nearshore fauna) would also be required.

6.3.2 Limited Volume

Only small indicative sand volumes are held in deposits such as the reclaimed foreshores of Tuggerah Lake (east and west of the tidal delta). In addition, the quality of the material in these deposits is likely to be highly variable, and in both cases, the reclaimed area is now well valued community recreation space.

Apart from already being part of the active beach sediment budget, the volumes of sand on the entrance spit/berm and in nearshore bars along North Entrance Beach are not sufficient to justify a dredging program.

Sand that is trapped within the rock reef off The Entrance is likely to be in small discrete parcels and difficult to access.

6.3.3 Coastal Process Considerations

Nielsen and Lord ((Geomarine) reproduced in AECOM 2010) discuss the coastal process factors that should be considered when assessing potential **offshore** sediment sources and designing extraction and placement programs.

They identify multiple principles and criteria which will affect the success of beach nourishment, the side effects on other coastal deposits and landforms, and coastal processes at the placement site. These matters include:

- Extraction should not have a measurable effect on the wave climate of the beaches, reef communities or entrances to adjacent estuaries.
- The extraction should take place beyond the area that experiences the onshore/offshore beach fluctuation and beyond the limit of significant wave induced on shore sand transport. In the Sydney region, the 'absolute limit of offshore sediment transport during storms' is between 22 metres and 26 metres water depth. Extraction beyond this depth would not interfere with beach processes.
- Extraction should be in sufficiently deep water that there will be no change to refraction patterns irrespective of the shape of the extracted configuration.
- Ensure that extraction areas are sufficiently up coast or down coast from beaches so that any edge impacts are limited to rocky shorelines.
- Limiting extraction depth (lowering of the sea bed) to less than 5 metres of sand was considered to minimise impacts on offshore sediment dynamics.

All of these process constraints are also relevant to sand deposits in the near-shore or just at the depth of closure. Given the significance of refraction in determining the angle of wave approach at North Entrance, focusing wave energy at particular locations, any dredging program inside the depth of closure would require very detailed analysis of risks associated with refraction consequences.

6.3.4 Land Tenure

The lake bed and entrance area, including the entire tidal delta, are Crown land.

The ocean floor out to 3 nautical miles is also Crown land.

The old transgressive dunes at the northern end of Tuggerah Beach are within Wyrrabalong National Park. Sand extraction (mineral sands, construction sands) is not permitted in national parks.

Lake foreshore sites are either Crown land or Council community land.

Any proposal for sand extraction or sand placement on Crown land would require the approval of the Minister for Lands, as the land owner.

6.3.5 Environmental Impacts Offshore and on Beaches

The principal environmental impact for both offshore sand extraction and for placement of sand on beaches is the impact on marine ecological communities, particularly benthic communities. The Ecology Lab (Cardno Ecology Lab) conducted a preliminary assessment of potential ecological issues associated with potential offshore sediment dredging (from the inner shelf) for the Sydney region.

In broad terms, Cardno Ecology Lab identified relatively minor ecological impacts at the extraction sites. Impact was limited because of the slow pace of extraction (slow disturbance and then time for recolonisation), and the presence of similar sediments at depth after the surface sand is removed.

Impacts on fish assemblages and marine mammals were also considered and found, at this preliminary level, to be localised and very minor.

In general, when beach nourishment occurs, the sand is placed in the nearshore area, where waves will move it towards the subaerial beach face. There is limited research data to document the ecological responses and impacts of this activity. In general terms, intertidal, subtidal and subaerial habitats may all be affected as the volume of sand increases. However, Cardno Ecology Lab also note that fauna assemblages in these habitats are adapted to major disturbance (such as storms with major scouring impacts). Changes to beach and nearshore ecology are more likely when there is a significant difference in the sand quality (e.g. much coarser or finer, or a larger shell grit content.

For any actual proposal for beach nourishment, detailed studies would be required.

6.3.6 Statutory Controls

This section notes some of the policy and statutory factors that would influence a decision to use any of the above potential sand sources for beach nourishment.

6.3.6.1 National Parks and Wildlife Act 1974 and Amendments

Mining is not permitted in National Parks. It is unlawful to prospect or mine for minerals in a National Park, Nature Reserve, or State Conservation Area or historic sites gazetted under the NPW Act, unless specifically authorised by an act of Parliament. Minerals include coal, shale etc. Mineral sand is also a mineral under the Act.

Sand extraction (not mining) may be permitted in specific circumstances (for instance where it is part of a park management activity).

Wyrrabalong National Park, which covers the northern part of the Tuggerah coastal barrier, was gazetted in 1991. A Plan of Management has been prepared under the National Parks and Wildlife Act.

The Plan of management specifically notes that the eastern part of north Wyrrabalong National Park was mined for mineral sands between 1969 and 1976, before the park was created. Terilbah Island is noted to be a relatively recent (19th century) natural sand deposit in the entrance channel of Tuggerah Lake, while parts of Pelican Island are noted to be the result of placement of dredge spoil from dredging for channel deepening in the 1920s.

6.3.6.2 Environmental Planning and Assessment Act 1979

Any dredging will require at least an approval under Part 5 of the EP&A Act.

Major extraction projects, in sensitive coastal areas, whether in the estuary entrance or offshore are likely to be Part 3A matters under the current legislation.

Maintenance dredging of estuary channels is regulated by the NSW Infrastructure SEPP (2007). The Infrastructure SEPP replaced the previous SEPP 35 provisions.

Clause 128 of the Infrastructure SEPP defines waterway and foreshore maintenance activities as including:

a) riparian corridor and bank management, including erosion control, bank stabilisation, resnagging, weed management, revegetation and the creation of foreshore access ways, and
b) **instream management or dredging to rehabilitate aquatic habitat or to maintain or restore environmental flows or tidal flows for ecological purposes**, and
c) **coastal management and beach nourishment, including erosion control, dune or foreshore stabilisation works, headland management, weed management, revegetation activities and foreshore access ways**, and
d) coastal protection works, and
e) salt interception schemes to improve water quality in surface freshwater systems, and
f) installation or upgrade of waterway gauging stations for water accounting purposes.

Items (b) and (c) are relevant to maintenance dredging of The Entrance. In its current form, this dredging involves both sediment removal from the estuary to maintain tidal flows and placing sand on North Entrance Beach for beach nourishment purposes. A Public Authority may carry out waterway management works on any land without consent. The Public Authority must take into account the provisions of a Coastal Zone Management Plan that applies to the area where the works are proposed.

As part of the feasibility assessment for offshore sand extraction to provide sand for beach nourishment in Sydney, AECOM obtained indicative Director General's requirements and environmental assessment requirements from Department of Planning and DECCW. As noted in **Section 6.3.6.4**, offshore sand extraction is not currently supported by the NSW government, and these requirements would need to be thoroughly reviewed in the context of a future policy change.

For the Sydney offshore sand deposits, a simplified Part 3A approval process would comprise the following steps (see http://www.sydneycoastalcouncils.com.au/sites/default/files/beachsandnourishmentscopingstudy.pdf:

1) Seek confirmation from the Minister for Planning that the proposed marine aggregate extraction (for beach nourishment) is a 'major development' under Part 3A of the Act.

2) Prepare a Preliminary Environmental Assessment.

3) Prepare detailed studies to identify environmental constraints and design parameters.

4) Prepare a detailed project design.

5) Consult with key stakeholders (government agencies, community groups) and community.

6) Undertake detailed environmental assessment and prepare justification of proposal.

7) Finalise the Environmental Assessment.

8) Exhibit and respond to submissions.

9) Minister's determination.

A major dredging program involving extraction of sand from the inner part of the tidal delta at The Entrance is expected to also be assessed under the Part 3A process, because of the volume of sand to be extracted, the sensitivity of the marine environment and the potential for significant environmental change/harm.

6.3.6.3 Fisheries Management Act

For any dredging in the entrance area of Tuggerah Lakes, or offshore within NSW waters, a dredging permit would be required under Part 7 of the Fisheries Management Act. The Department of Planning is also required to consult with Industry and Investment NSW (Fisheries) about the details of any environmental assessment for dredging and related environmental management activities.

The entire inner part of the tidal delta is covered by *Zostera* and *Halophila* sea grass communities. A permit to remove sea grass or macroalgal habitat is also be required under Part 7 of the Fisheries Management Act if these habitats are disturbed. This is already the case for the existing dredging program in the entrance channel of Tuggerah Lake. Any expansion of the dredging program would require a detailed assessment of impacts and offsetting proposals for disturbance of sea grass.

Ecological studies will also be required for any offshore sediment sources before extraction could be approved. This will include assessment of benthic species at source sites and also within the beach and near-shore.

6.3.6.4 Offshore Minerals Act 1999

Sand, or marine aggregate, is considered to be a mineral under Section 22 of the *Offshore Minerals Act 1999*. To extract sand from the sea bed within the NSW 3 nautical mile limit, a licence must hold a licence under the Offshore Minerals Act. There are no regulations under the Act allowing for an application for an offshore mining licence to be made in NSW.

The NSW Government policy currently opposes sand mining (commercial purposes) off the NSW coastline. The Minister for Mineral Resources refused the most recent application from Sydney Marine Sands Pty Limited for an exploration licence offshore of the central coast, using this policy.

AECOM 2010 refer to Patterson Britton and Partners (PBP) 2006 in relation to evidence of the NSW Government policy for offshore sand extraction for beach nourishment purposes. PBP (2006) quote correspondence from the NSW Premier to the Northern Beaches Branch of Surfrider Foundation Incorporated, dated 6 March 2001, which indicates the government would consider sand extraction for beach nourishment purposes:

> As you are aware, the Government does not support offshore commercial sand mining and the areas off the coast are currently protected by reserves under the Mining Act which do not permit exploration or mining activity. Your proposal of dredging for beach nourishment, however, is a different matter, and bears further investigation. (PBP 2006)

The AECOM 2010 study shows that for high value metropolitan beaches, with ‘iconic’ tourism and recreation status and extensive development in the immediate hazard zone, the very high cost of extracting, transporting and placing offshore sand to nourish the beach system can be justified by significant benefits. This will not be the case for many other beaches and coastal development that has local rather than national value. For these beach systems, nourishment with offshore sand is likely to be cost prohibitive unless it is combined with some form of commercial extraction.

Sydney Coastal Councils Group, which commissioned the AECOM Beach Sand Scoping Study, is promoting a review of the NSW Government policy in relation to offshore sand extraction. Their view (Coastal Conference 2009, Media Release 2010) is that the benefit to cost ratio demonstrated in the Scoping Study justifies such a review.

AECOM 2010 provides the following summary of the current situation:

> Due to government policy, acting upon existing exploration licences would be difficult. The Department of primary industries (Mineral Resources) has verbally advised that planning approval would be required for exploration of minerals. Due to the current policy regarding offshore mineral recovery for commercial purposes, the State government is unlikely to grant planning approval under the EP&A Act for such exploration activities. However as these areas (i.e. some of the existing ELs) are excluded from the reserved blocks (that is they would be standard blocks under the Offshore Minerals Act) the Minister may grant a mining licence over these areas. Under Section 198(1) of the Offshore Minerals Act, the holder of an exploration or retention licence may apply to the Minister for a mining licence over all or some of the blocks in the licence area.

6.3.7 Potential to Destabilise Estuary Processes and Estuary Health

For details of the factors controlling the ecological stability of Tuggerah Lakes see the Tuggerah Lakes Estuary Processes Study, Management Study and Management Plan and The Tuggerah Lakes Estuary Modelling report (Brennan *et al.*, DECCW 2010).

In their models, these authors characterised entrance behaviour as bimodal, with closure or restricted ocean exchange during extended dry periods and scouring during major floods. This produces a low water state in the lake during low flow conditions and a high water level when flood water back up behind the partly closed entrance.

The authors note that dredging of the entrance of the lakes over the last 30 years (which forces the entrance to be at least partly open at all times) has resulted in 'marked decreases in water level and waterway area variation in the lakes.' These decreases in water level affect particularly the extent of low lying land that is inundated by lake waters during rainfall events.

It is also clear from observations of changes to the channels, islands and foreshore in both the extended tidal delta and the outer active tidal delta, that dredging activity has already had a significant impact on the processes and ecology of the entrance area. However changes to water quality from higher nutrient catchment inflows have also affected the ecology of the entrance area.

Preliminary analysis of the width of the entrance channel (i.e. the main channel through which tidal exchange is occurring), based on aerial photos from 1941 to 2007 suggests that dredging in the outer part of the tidal; delta, since the early 1990s has also been associated with a narrowing of the rage of channel widths. From 1941 to 1989, channel widths varied between zero and nearly 140 metres. Since 1990, channel widths measured from available aerial photos have been restricted to a range between approximately 35 and 65 metres. Whilst dredging ensures the channel is partly open at all times, the lack of very wide channels may be due to a lack of major flood events since 1990.

6.3.8 Cost

The Tuggerah lakes Estuary Management Plan states that Council spends an average of about $700,000.00 each year to maintain flow through the entrance. This investment is in maintaining the dredge and the use of the dredge for campaigns in the outer part of the tidal delta and along the deep channels upstream of the bridge.

AECOM 2010 have investigated the costs of accessing sand from the continental shelf in the Sydney region. Specialist equipment is needed to access sand in deep water (more than 20 metres water depth) and several kilometres off shore.

Dredging of sand from the inner part of the tidal delta is expected to have costs of the same order of magnitude as dredging in the outer part of the tidal delta, with additional costs for sediment transport.

6.3.9 Other Valued Land Uses

Sand stored in the reclaimed land that is now foreshore reserve is valued for the recreational services provided by the reserves.

The sand deposits in the inner part of the tidal delta are valued for the fishery habitat they provide. The surface of the tidal delta is colonised by sea grass.

The overall volume of sand in the inner part of the tidal delta and its surface elevation are key controls on tidal exchange and lake ecology.

Sand in shoals along the beach is also part of the natural sediment system and beach ecology system, providing both ecosystem services and recreational values for beach users.

7.0 Training Walls

Some local community organisations and individuals have long advocated the construction of training walls at the entrance to the Tuggerah Lakes. Both a single wall strategy and dual wall strategy have been suggested. A major and persistent dredging program could also force the entrance area to stay wide open.

The advocates argue that a permanently open, controlled entrance would provide benefits such as flood mitigation around the lake shore, greater accessibility for recreational boating (particularly deep draught vessels being able to enter the lake system) and enhanced water quality and water circulation for swimming and fishing. Some people also believe that a permanently open entrance would mean that more terrestrial sediment from the catchment would pass through the lake system and out to sea, rather than accumulating in the lakes.

These assumed benefits, if they were real and consistent with the best available coastal science and engineering, would be significant. However, all of the coastal science, modelling and engineering studies for Tuggerah Lakes over the last decade have highlighted that the assumed benefits will not be delivered by construction of training walls at The Entrance. In fact, training walls are more likely to have a detrimental transformational impact on the hydrodynamics and fragile ecology of the Tuggerah Lakes.

For more information about the effects of a trained entrance, see:

- Tuggerah Lakes Estuary Management Study and Estuary Management Plan (2006)
- Tuggerah Lakes Floodplain Risk Management Study (draft 2011)
- Tuggerah Lakes Estuary Modelling (DECCW 2010)
- Water Level Trends at Tuggerah Lakes (Manly Hydraulics Laboratory 2010)

The scientific analysis in these studies provides a moderate to high level of certainty about the following conclusions about the links between lake entrance management and lagoon ecology.

- The lakes are a shallow lagoon system. Shallow water provides a good light environment for aquatic plants, favouring high productivity. Shallow water also creates a high daily and seasonal variability in suspended sediment/turbidity with wind driven resuspension of catchment derived bed sediments a major driver of reduced water clarity.
- Sedimentation in the lakes is driven by catchment runoff. The lakes are sediment sinks, with inflows being greater than outflows. The highest sediment and nutrient loads come from large and complex catchments. Catchment discharge is intermittent. There are long periods with no discharge; system wide mixing by waves continues during these periods.
- Under current conditions, salinity and water levels in the lakes vary with intermittent catchment runoff.
- Over the last three decades, there has been, overall, a significant reduction in the variability of waterway area in Tuggerah lakes. DECCW attribute this to the dredging program at The Entrance. By keeping the entrance slightly open at all times, the frequency of extreme water levels appears to have declined and waterway areas is more stable. It is not clear however, whether the water level effects of *El nino/la nina* events have been taken into account. Worley Parsons (2011) note that there have been limited major flood events in nearby Lake Macquarie since 1995. It is also not clear whether

relative water area stability is ecologically beneficial in a lagoon system which has a natural high variability of water levels and shoreline inundation.

- At the same time as DECCW has suggested relative water level stability in the lakes, MHL analysis of water level trends indicates that water levels in Tuggerah Lakes have risen faster than the Fort Denison record since 1995. MHL also note that the complexity of water level drivers in Tuggerah lakes makes it difficult to distinguish real patterns.

- Decadal changes (such as associated with *El nino /La nina* cycles) in the productivity and health of the Tuggerah lakes are not fully understood

- In theory, the period of high lake levels and the potential for flooding are affected by the condition of the entrance, for a given rainfall event. Worley Parsons (2011) note that theoretically an entrance that is as wide and deep as possible will reduce flood levels for a rainfall induced flood event. However, a wide entrance also exposes the estuary to oceanic flooding.

- Worley Parsons 2011 suggest that there is no modelling or detailed measurement of flood water levels to provide real evidence that dredging of the entrance of Tuggerah lakes will significantly reduce the duration or the peak level of flooding. Sophisticated models to provide accurate and certain predictions of complex entrance scouring are not currently available. As both flooding events and dredging are intermittent processes, the benefits of dredging for flood level and duration are limited. Worley Parsons 2011 conclude that dredging the entrance since 1993 *may* have prevented minor flooding, but it has not prevented flooding during 10 year ARI events. Indicatively, Worley Parsons conclude that dredging in the entrance may slightly reduce peak flood level and duration. The cost of dredging, if conducted solely for this purpose is expensive (requiring upfront dredging works and ongoing maintenance dredging). A very large dredging program (much more extensive than the current program) would be required to achieve a significant flood benefit.

- Separate to dredging within the entrance channel, Worley Parsons (2011) have also considered the potential benefits of removing the ocean berm, so that the entrance area is as wide as possible (assume 250m wide to -1m AHD). If this could be achieved, peak flood levels in a 100 year ARI would be significantly reduced. There are serious practical and environmental issues associated with forcing the entrance berm to stay wide open to the ocean. These include:

  - Very significant and ongoing dredging costs to continually remove/lower the berm on a system that naturally trends to closed. An alternative is to force the entrance to stay wide open by constructing training walls. This also has very high costs, of the order of $60 million
  - Environmental consequences for Tuggerah Lakes. In principle, forcing the entrance to stay very wide would reduce (non flood) water levels in the lakes, exposing shallow mudflats around the shore that are adjusted to a lake water level set up above ocean levels. Conceptually, a wide open entrance would increase salinity in the lakes in non flood times.
  - Lack of certainty about the potential interactions of lake water level lowering due to entrance management and lake water level increases due to other factors (including climate change), especially given the lack of robust water level data.
  - A wide open entrance will not improve recreational boating potential in the lakes, because of the overall shallowness of the system. The Tuggerah Lakes have an average depth of approximately 1.4 metres.

- If sand were dredged constantly from the entrance channel and placed on North Entrance Beach, long shore transport processes are likely to move at east some of it away to the north.

SMEC 2011 has considered the potential impacts of training wall construction at the Entrance on hydrodynamic and sedimentary processes. They specifically consider a training wall on the northern side of The Entrance, as the southern shore is largely controlled by natural bedrock outcrop. Based on their modelling analysis of sedimentary processes, SMEC conclude:

- A training wall at the northern side of the entrance could result in the widening and deepening of the entrance channel and significant scour of the existing entrance bar. The sand circulation between the entrance sand bar, upstream shoals and the entrance channel would be cut off by the training wall, as southerly sediment transport into the entrance channel would be blocked, and the ebb tide would continue to scour upstream shoals through the substantial opening entrance throat.

- The creation of a strong ebb tide jet would build up a new entrance sand bar further offshore. Wave action would be unable to move this offshore sand back onto the beach as readily as it does under existing conditions, and the nearshore wave climate at the southern section of North Entrance Beach would be altered due to changes in nearshore bathymetry, which could cause changes in sediment transport patterns and possible erosion of the entrance spit.

- The existing entrance sand shoals would erode due to a permanent loss of sand from littoral drift along northern entrance spit back to the entrance obstructed by the northern training wall. Sand moving onshore by flooding tide and breaking waves would tend to be trapped by the training wall and the ebb tide would continue to scour the upstream sand shoals, transporting sand through the entrance throat onto the new sand bars. Hence the sand deposited onto the upstream shoals would be greatly reduced. However, increased tidal currents would tend to bring sediment further into the estuary and extend the flood tide delta upstream.

- The construction of northern training wall perpendicular to the beach would interrupt the local southerly reversal of littoral drift back onto the entrance upstream shoals. The sand captured against this wall would accumulate so as to form a fillet of sand. If the training wall were to be constructed for the purpose of keeping the entrance channel open, the northern training wall would need to be of a sufficient length that the naturally occurring equilibrium plan alignment of the beach in this fillet results in no sand being able to be swept by waves around its end (and into the mouth of the entrance) during periods of southerly sand transport. This sand is no longer available to be moved onshore from the entrance sand bar due to the scour of the entrance sand bar. This would exacerbate the North Entrance beach erosion due to lack of sand supply to feed northward longshore sediment transport. There would be massive sand relocation from the upstream shoals to the margins of adjacent beaches.

- Continued scour of the entrance channel would result in an increasing trend in the tidal range and tidal prism of the Tuggerah Lake. The entrance channel would evolve toward an equilibrium following entrance training, and allow ocean swell to propagate through the entrance. Scour in the entrance channel as a result of increasing tidal flow could threaten the foundations of the road bridge resulting in expensive remedial works to the bridge abutments. The Wilfred Barrett Drive would be exposed to sediment scour of the bridge piers by swift tidal currents.

- The ecological environment within Tuggerah Lake would be influenced greatly by the rate at which water in the lake is exchanged with oceanic waters through the entrance, as well as changes to the natural tidal regime, changing the natural assemblages of vegetation communities in the area. Marine sand may penetrate further into the lakes, smothering sea grass communities that are important fishery habitat.

- The gradually removal of upstream shoals would have an adverse effect on entrance stability. An extreme flood event could split the main channel of the entrance into two with one channel along the southern bank and one along the sand spit. A training wall in front of the northern entrance spit would therefore need to extend upstream along the entrance channel toward the bridge so as to prevent breakthrough of the entrance spit in a large flood event.

- Experience from other lake entrances provides clear evidence that training walls have dramatic and detrimental impacts on the recreational and tourism values of what are naturally shoaled entrance areas. For instance, construction of the training walls at Wallis Lake lead to major scouring of the entrance shoals, high velocity tidal currents, scouring of bridge foundations (this has also occurred at Lake Macquarie) and scouring of estuary banks upstream.

8.0 Conclusions

The results of analysis conducted during this project reinforce the need for great caution when managing hydrodynamic and sedimentary processes at The Entrance and North Entrance Beach.

Some assumed benefits of dredging in the lake entrance area may not be as significant as previously thought. The hydrodynamic and sediment transport processes in this environment are complex, and sensitive to changes in sea level, lake level and cyclic variations in wave energy and angle of wave approach.

The current evidence indicates that there is very limited benefit for significant risk and therefore no justification for training walls at The Entrance. There are also significant risks with any strategy that aims to maintain a persistent wide open entrance.

Whilst the current limited dredging program and placing sand from the entrance channel onto the southern part of North Entrance Beach provides some benefits in buffering the beach profile against storm bite erosion, the volume of sand in the current dredging program is not sufficient to prevent coastal recession.

The preliminary sediment budget analysis suggests that some sand has been and continues to be lost to the active beach sediment budget in the North Entrance area – offshore into deeper water, landward in mobile dunes and lakeward in intermittently active lobes of the tidal delta. Details of these losses should be further investigated.

For planning purposes, the NSW Sea Level Rise Policy uses best available science to set benchmarks of 40cm above the 1990 sea level by 2050 and 90cm above the 1990 level by 2100. Predicted sea level rise is expected to modify the hydrodynamics of the entrance channel and the locus of active sedimentary processes within the channel and tidal delta. Sea level rise and other aspects of climate change are also expected to modify the rates of loss of sand offshore and/or movement of sand along North Entrance Beach. More detailed modelling, supported by long term monitoring of real change, is needed to confirm how sea level rise will interact with existing complex sedimentary processes.

8.1 Short Term Options

8.1.1 Continue intermittent dredging of the entrance, not sufficient to force a persistent wide open entrance condition

This review indicates that in the short term, the best option for managing sand volume at the southern end of North Entrance Beach is the continue the program of occasional dredging of the shoals that build up in the outer part of the entrance.

When this sand is dredged, there are at least two options for where it is placed:

- If it is placed onto North Entrance Beach, no further north than Hargraves Street (i.e. in areas R2 or R3), the historical evidence suggests it will provide a temporary increase in the volume of this part of North Entrance beach and the associated frontal dune. The current placement method includes pushing the sand up to reinforce the frontal dune in area R3. This should mean that more sand is retained in the placement area during normal conditions, rather than being moved northwards along the beach by longshore processes.

It is unlikely that this dredging and sand placement will provide a significant buffer for the frontal dune at Hutton Road in a major storm. In major storms, it appears that there may be some 'leaking' of sand from the active sediment budget, into deeper water. This should be further investigated.

- If sand is placed further north along North Entrance Beach, such as at Curtis Parade, the preliminary long shore sediment transport analysis suggests a relatively small proportion will move further north along the beach and away from the eroded dunes at Hutton Road and Curtis Parade. In this area, some sand is still being lost into the dune field (the southern part of R5, between the surf club and Curtis Parade) and some may be lost offshore into deeper water during storms. There are significant transport challenges associated with placing sand in area R5 – sand would either need to be moved by truck, or through a fixed line along at least 1 kilometre of beach.

- In the short term, the best option is to continue to place sand in the Karagi Point to Hutton Road area of the beach.
- Council should also set up a monitoring program to record accurately the volume of sand in different parts of the tidal delta, near shore and beach system, and link changes to monitoring of changes in sea level, lake water level, wave height and other factors.
- Council could consider additional investigations such as tracer studies at The Entrance and North Entrance beach to confirm the inferred tidal circulation models.

Council's main justification for dredging has been to reduce flood risk in the lakes. However, Worley Parsons 2011 suggest that the benefits of dredging for reducing flood risk are not as certain as thought when the dredging program was initiated. Although more sand could potentially be moved from the outer part of the tidal delta, it should not be done until more detailed modelling has been undertaken to better inform the hypothesis that a persistently open entrance could reduce significant flood risks. Detailed modelling would also allow analysis of the limits of sand extraction from this area without destabilising lake ecology that is dependent on a specific level of tidal or flood inundation.

8.2 Investigating Sources Further

8.2.1 Sand deposits at the depth of closure

It may be possible that sand in the deeper water sections of the non equilibrium profile could be dredged and placed within the wave zone, so that it shoals back onto the beach. This could result in temporary increases in the sand volume in the subaerial beach and dune system. However, before such dredging could take place, much more information is needed about the extent of any offshore (10 to 20 metres water) sand deposits in the non equilibrium profile and their influence on nearshore wave energy and sediment transport processes. There are also potential ecological issues associated with this nearshore dredging. It is expected on a non equilibrium profile that any major storm will scour this sand back off the beach and into deeper water. Ongoing dredging would be required.

The volume of sand in offshore deposits on non equilibrium profiles is not well defined.

Council should further investigate sand deposits that appear to have been moved offshore on non equilibrium profiles. A combination of new LADS data, sonar survey and drilling would clarify the extent, thickness and character of these deposits.

When the deposits are better defined, Council could also conduct more detailed modelling of sediment transport systems, to understand the likelihood that replacing this sand on the beach will make a material difference to beach and dune volume.

8.2.2 Inner tidal delta

Preliminary analysis of sediment volumes indicates that a substantial volume of sediment of marine origin is stored within the inner parts of the tidal delta, on the lake side of The Entrance Bridge and extending around the shoreline as tidal flats. Some parts of this feature appear to have been decoupled from active tidal processes since the late 1970s.

In the longer term, using some of the sand that has accumulated in the deposits of the inner part of the tidal delta is an option for beach nourishment.

There are, however, significant constraints to accessing this material for beach nourishment purposes, including

- It is mixed with large amounts of organic matter, so the quality is unlikely to be suitable for use on the open beach without treatment
- The tidal delta form is important to protecting the lake from oceanic flooding and to maintaining lake levels that support the estuarine ecological systems. Any sand removal would need to maintain these functions of the tidal delta. Detailed hydrodynamic studies would be needed to assess how sand removal and reshaping of the shoals would affect water levels and ecological processes in the lakes.
- The surface of the tidal delta is colonised by seagrass and other important estuarine habitat
- Islands in the tidal delta, which contain some material that could be dredged, are protected.

As sea level rises, the conceptual models suggest that deposition on the inner parts of the tidal delta will increase, as water depths and current velocities increase. Sand accreting across and at the distal margins of the tidal delta will come from the nearshore and sub-aerial beach/dune deposits of North Entrance beach and potentially from the shoals in the outer entrance area being driven lake ward.

So over time, less sand may be available in the outer shoals, and more in the inner shoals. Clearly this requires much more detailed modelling and analysis.

- Council should invest in a 3D hydrodynamic and sediment transport model of the entrance area, to test a range of flood tide delta deposition and sediment extraction scenarios, including with sea level rise.
- Council should seek more detailed stratigraphy and sedimentology information about the structure and development of the inner part of the flood tidal delta and its links to previous sea level fluctuations and to the back barrier deposits at North Entrance.
- Modelling should consider the hydrodynamic role and impacts of large reclaimed areas such as the area in the lake immediately west of Curtis parade. This is the area that received wind-blown sand from North Entrance Beach for many years.

8.2.3 Sand on the inner shelf

In the long term, offshore (inner shelf) sediment storages may also become a feasible option. Before this could happen, at least the following conditions are required:

- More detailed assessment of sediment quality and location
- Changes to the NSW government policy in relation to exploration and extraction of offshore sand bodies.
- More detailed cost benefit analysis for the specific circumstances of the central coast. Extraction, transport and placement costs will be very high.

- Council should monitor the statutory reforms that would allow access to offshore sediment sources for beach nourishment purposes
- Council should work with the NSW Government to develop a better understanding of the quality, area and accessibility of offshore sediment sources

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APPENDIX 1

SMEC Report

Longshore Sand Transport and Tidal Inlet Stability Study for The Entrance and The Entrance North

For: Wyong Shire Council

Project Name:	Longshore Sand Transport and Tidal Inlet Stability Study for The Entrance and The Entrance North
Project Number:	3001053
Report for:	Wyong Shire Council

PREPARATION, REVIEW AND AUTHORISATION

Revision #	Date	Prepared by	Reviewed by	Approved for Issue by
1 (Draft)	17/12/2010	M. Glatz, A. Xiao	C. Adamantidis	C. Adamantidis
2 (Final Draft)	15/3/2011	C. Adamantidis, M. Glatz, A. Xiao	C. Adamantidis, D. Lord, P. Dean-Jones	C. Adamantidis

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1 INTRODUCTION

The Entrance at Tuggerah Lake is a highly dynamic area with complex coastal processes. This report documents a coastal process investigation at The Entrance, to understand in greater detail the dynamics of The Entrance and thus inform Council Policy on management of the entrance and adjoining beaches.

This investigation:

- Documents a review of existing information to estimate potential longshore sediment transport rates and understand coastal processes;
- Presents a conceptual sediment transport model of the entrance area and adjacent North Entrance Beach, in the form of a sediment budget with "best estimates" of average sand transport rates and sediment transport pathways;
- Presents wave transformation modelling using detailed LADS bathymetric data in the entrance area to help understand coastal processes and calculate net average alongshore sediment transport rates; and
- Provides a review of the existing studies and techniques for analysis of the entrance stability.

The wave transformation modelling has been used to calculate order-of-magnitude estimates of net alongshore sediment transport, based on a median swell wave height and wave period. A range of offshore wave directions has been modelled to derive a range of nearshore wave approach angle for use in the longshore sediment transport calculations. Two recognised approaches are used to derive the estimate of longshore transport rates – the CERC formula and the Kamphuis formula. These approaches are based on various assumptions which are described in detail within this report. Based on the above approach, a conceptual sediment budget is derived for The Entrance and surrounding coastline.

The study area covers The Entrance and several kilometres north of the Entrance along the Entrance North Beach, with a tidal inlet connecting Tuggerah Lake to the Tasman Sea. This tidal inlet interrupts the longshore drift and is likely to be associated with fluctuations in the shoreline of the adjacent beach. Sand is deposited on and removed from the tidal inlet under the combined action of waves and flood tide currents. During the flood tide, more sand is transported onto the upstream entrance shoals and generates the heavily shoaled nature of the entrance. The absence of wave stirring inside the entrance means that less sand is transported out of the entrance on the ebb tide then is transported in on the flood tide. This tends to lead to the entrance shoaling over time, with the entrance naturally tending to closure. Floods due to heavy rainfall then scour the entrance, transporting sand out and widening the entrance channel again, whereby the process of entrance shoaling begins again.

Existing studies (Worley Parsons, 2010; PBP, 1994) suggest that a local southerly reversal of littoral drift causes the northern entrance sand spit to grow southwards which would result in the narrowing and finally closure of the entrance followed by flood level increase in the lake (Worley Parsons, 1994).

The tidal inlet is controlled by wave energy, tidal range, tidal prism, sediment supply and direction and rates of sand delivered to the inlet. Longshore sediment transport in the vicinity of tidal inlets is complex, where sand moves under combined action of waves, currents, superimposed on highly variable bathymetry with constantly changing water levels.

The tidal inlet acts both as a sediment source and a sediment sink, as the sand drift that filled the entrance during high littoral transport was released into the beach system during flood events. The imbalance of this sand circulation between the tidal inlet and adjacent beach system would tend to cause the inlet channel to shoal over time.

Much of the NSW coast is subject to prevailing southerly winds and high year-round Southern Ocean swell, resulting in overall northerly sediment transport. It is estimated by Dyson et al. (2001) that the longshore sediment transport in northern New South Wales (NSW) can reach 500,000m^3y^{-1}. However, on the central coast of NSW, sand transport magnitude is much lower and more compartmentalised, with sand tending to stay within the main embayments. NSW Government (1990) estimates sand transport rates for nearby Wamberal Beach of 12,000 m^3y^{-1}, and Soldiers Beach of 5,000 m^3y^{-1} toward the north. This has led to historical sand accumulation in transgressive dunes at the northern ends of the embayments, such as at the northern end of North Entrance/Tuggerah Beach.

During early investigations, the historic condition of the tidal inlet of the Entrance was found to be highly variable and typically open most of the time. However, the inlet channel is relatively shallow – consequently, Wyong Shire Council conducts dredging operations at The Entrance using a mobile dredge. The dredge is moored in the Wyong River when not in use. Dredging of the active tidal delta shoals has been conducted since about 1990, to maintain tidal flushing of the entrance area. The dredging has secondary benefits such as restoring eroded foreshore and improving recreational amenity.

The aim of this investigation is to provide a better understanding of the entrance sedimentary dynamics to enable Council to evaluate its options for beach nourishment using sand from the Entrance, without de-stabilising the entrance channel leading to major morphological changes to the lakes.

Options available for management of the entrance and channel include:

- Dredging of the entrance area and periodic nourishment of the adjacent beach with dredged sand;
- Protection works in and around the entrance, such as entrance training walls and engineered shoreline protection for properties at threat from coastal erosion at Curtis Parade

The impact of the littoral processes on the viability of the potential management options is examined within this report.

2 REVIEW OF EXISTING INFORMATION

SMEC's project team undertook the review of the existing data, reports and documents relevant to the Tuggerah Lake entrance stability analysis. This review is documented below.

2.1 Tuggerah Lakes, Entrance Training Walls: Technical Discussion (PBP, 1994)

This report documents the entrance evolution and the various options available for the development of Tuggerah Lake entrance. It was found that a flood event would largely scour the channel through the entrance sand spit and the entrance shoal upstream. The entrance bar sand moves onshore due to a local southerly reversal of the littoral drift that causes the entrance sand spit to grow southwards. The flood tide deposits sand on the upstream sand shoals while the ebb tide removes sand from the entrance channel and pushes it back on the entrance sandbar. However, there is more sand moving onto the upstream entrance shoals on the flood tide than leaving them on the ebb tide. This generates some build-up of the shoals that narrow the entrance and eventually lead to closure of the entrance.

The tidal range within the lake was found to be relatively small, between 0.2 and 0.3 m MSL (Mean Sea Level) due to a narrow entrance channel and the extended shoals. However, this range can double during a flood event. There is a low storm surge penetration within the entrance. The tidal flow is 100-150m^3/s and tidal velocities are 1-2m/s. Cost estimates of the dredging work and maintenance were provided.

Under average tidal conditions, the throat of the entrance is around 25-35m wide and 2.0-2.5m deep (at mid-tide).

The entrance was advised to be maintained open to avoid flood, water quality and habitat issues. It was recommended to undertake less regular larger dredging work instead of regular small volume removal to better stabilise the throat dimension. The recommended dredge would be capable of moving 60,000m^3 over a dredging period of 12 weeks.

The report also discussed impacts of measures for stabilising the entrance, such as construction of training walls. However, such measures are not considered viable today due to their potential for significant impacts on the lakes, such as impact on the lake levels and tidal range, increased flooding, storm surge and wave climate in the entrance and shrinkage of the upstream entrance shoals.

Navigation of large draft commuter vessels could be enabled by constructing twin entrance walls associated with major dredging. The entrance throat would reach dimensions of 60-80m width and 6-8m depth. This would have similar but exacerbated impacts as without the twin training walls without dredging. The lake level would be around mean sea level and the tidal range would be increased. Some reworking of the entrance channel would occur due to the high tidal flow. The increased depth would also increase the wave climate inside the lake entrance. Larger rocks would also be required for this option.

2.2 Tuggerah Lakes Entrance – Technical Advice on Dredging Related Matters (Worley Parsons, 2008)

This report documents the current dredging strategy undertaken at Tuggerah Lake. This strategy consists of the enhancement of the ebb dominant northern channel by creating a

50m-wide channel to a level of -2m AHD by commencing the dredging at the upstream end near the road bridge and using a mobile dredging system.

The dredging strategy is undertaken in four stages (as shown in Figure 2.1):

- Creation of a sediment trap across the main channel along the road bridge;
- Enhancement of the main channel with sand placed along the eastern shoreline;
- Enhancement of the ebb dominant channel with sand placed along the eastern shoreline between the road bridge and the caravan park; and
- Enhancement of the ebb dominant channel adjacent to the sand spit with sand placed on North Entrance Beach south of a null point.

This null point was determined qualitatively along North Entrance Beach from the observation of historical aerial photographs. It is located in the vicinity of Hargraves Street. North of this point, some northward sediment transport occurs while south of this point, the sand is worked back to the entrance. Hence, the sand dredged from the entrance is to be placed anywhere south of this null point. The location of this null point from 10 different dates of aerial photography is illustrated in Figure 2.2.

It was recommended to undertake pre- and post-dredging hydro-survey. Beach scraping could be undertaken after a storm event.

It was also observed that it was difficult to maintain the beach along the southern embankment of the entrance.

2.3 Tuggerah Lakes Estuary Modelling (DECCW, 2010)

This report describes the results of a hydrodynamic model undertaken to study the water quality parameters within the lake system, including nutrient concentration, suspended sediment, phytoplankton, etc. Some details about the habitats and ecosystems were provided.

2.4 Water Level Trends of Tuggerah Lake (MHL, 2010)

This report analyses the water level within Tuggerah Lake recorded between 1985 and 2010. Data from 1985 to 1995 appeared inconsistent and was not used. The harmonic analysis of tides was inappropriate for this study. Flood events were removed from the measured data as rainfall higher than 15mm was found to have a significant impact on the lake level, and an average water level rise ranging from 3.9 to 6.4mm/year over the period of data collection was calculated within the lake. However, the accuracy of the calculation is not optimal and more detailed works and data collection would be required to obtain accurate water levels.

Outlines of dredge areas are schematic only.
Based on notes supplied by Wyong Shire Council.

Figure 2.1 – Dredging Strategy at Tuggerah Lake Entrance (Worley Parsons, 2008)

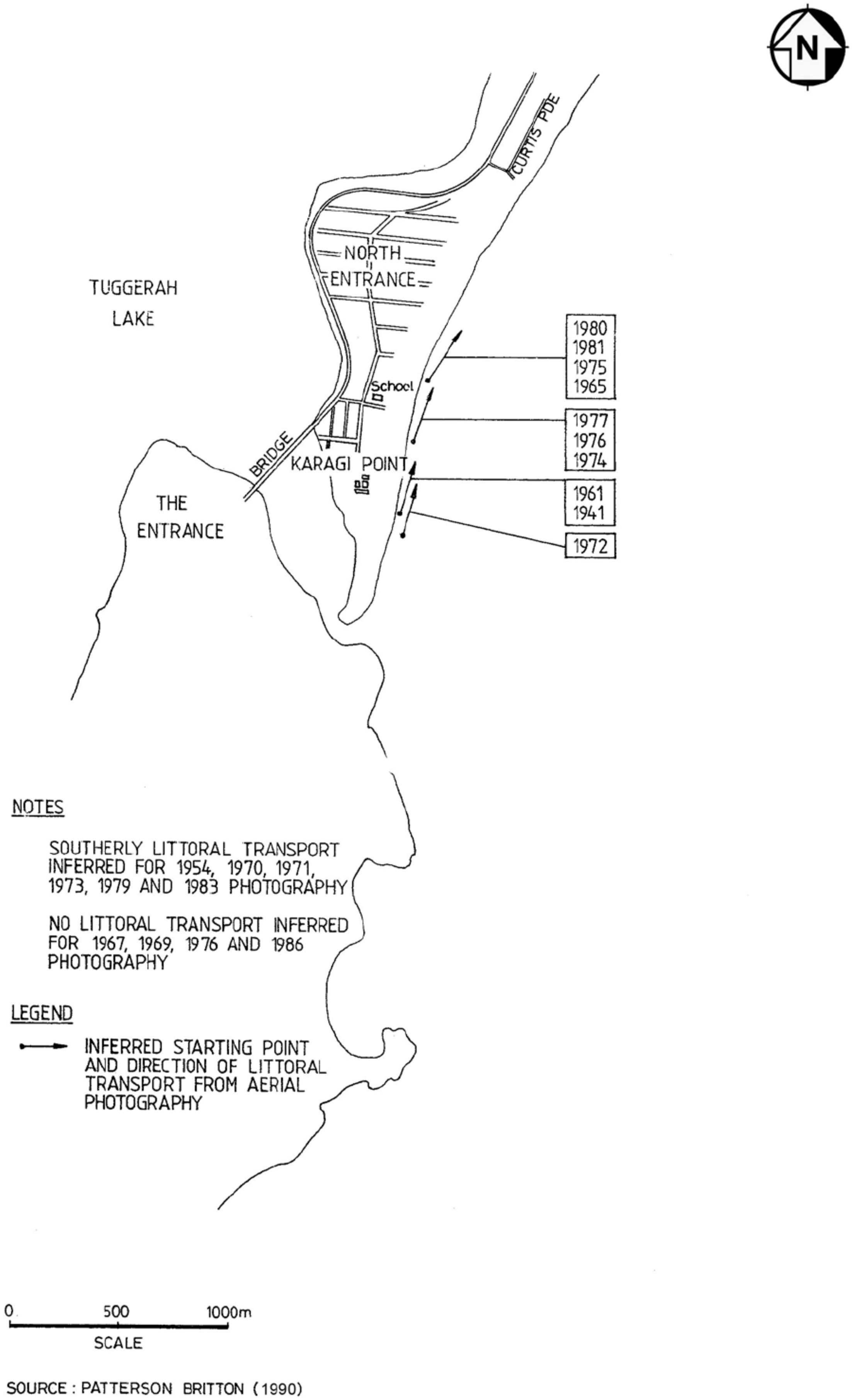


Figure 2.2 – Location of the null point over time (Worley Parsons, 2008)

3 ANALYSIS OF HISTORIC AERIAL PICTURES

Several historic aerial pictures dating from 1941 to 2006 were analysed to determine the evolution of Tuggerah Lake entrance.

November 1941	Tuggerah Lake entrance is closed at this date. There are only a few developments at The Entrance North. A large wind blow-out area is noticeable where Curtis Parade is currently located and most of the beach is subject to wind blow-out. Sand appears to be transported into the lake at this location. The Central Coast Highway has not been built yet. The bridge is located at a different location to present. Terilbah Reserve has not been reclaimed yet. The lake level appears higher due to the closed entrance. Shoals extend over the whole entrance width.
September 1961	There are more developments along The Entrance North. Some patches of vegetation are present on the large blown-out area and the southern end of the beach appears more stable. The channel adjacent to the west of The Entrance North follows the alignment of the existing highway and the main channel at this location appears narrower than the existing channel. The entrance is open on the southern side and has a northwards direction. The main channel of the entrance is split in two with one channel along the southern bank and one along the sand spit. The northern end of the caravan park has been built. A “sand tail” appeared south of Terilbah Island up to the present bridge.
July 1967	Central Coast Highway has been constructed as well as Curtis Parade but there is no dwelling along the latter. The entrance is open with a large entrance channel. The beach appears more stable but some blow-outs are still visible.
May 1970	The entrance is open but is narrower than in 1967 and has a northwards direction. The main channel is located along the southern embankment and there are extended shoals within the entrance. The new bridge has been built and the caravan extended southwards. The southern end of the sand spit stretches landwards.
September 1971	There are some extended shoals all over the entrance and below the northern half of the bridge. The entrance is open in an eastward direction.
June 1974	The entrance is widely open and the entrance channel is relatively large. Some vegetation is growing on the “sand tail” of Terilbah Island.
August 1975	The entrance is narrow and the channel appears very shallow.
August 1976	The entrance is very similar to the 1974 layout with a large entrance and wide channel. Some additional houses have been constructed along Curtis Parade.
August 1977	The channel along the southern embankment behind the entrance is shallower. However, the entrance itself is still wide. Curtis Parade is more developed.
July 1979	The entrance appears very shallow with large shoals south of the entrance. The entrance channel is narrow. More vegetation is observed on the “sand tail” of Terilbah Island.

April 1986	The entrance is very narrow and has a northward direction. The “sand tail” is fully vegetated. A landward movement of the sand spit is visible. Large shoals split the main channel. A large discontinuity in the natural shape of the beach is observed in front of Curtis Parade.
May 1990	The entrance is widely open to the east.
April 1993	Extended shoals are noted within the entrance and split the main channel in two. The sand spit is very large and some dredging works are in progress. Terilbah Reserve has been reclaimed and the channel along it stabilised. The “sand tail” extended westwards and a small ear is visible west of Terilbah Island. A small island has formed north of the centre of the bridge.
February 2002	The entrance is wide toward the east. Some shoals split the main channel in two.
March 2006	Some dredging works are in progress. The entrance has a north-east direction.
General Comments	At the different dates, some large rips were noticeable along the beach. The southern end of the sand spit appears to have a regular westward movement.

4 WAVE CLIMATE ANALYSIS

4.1 Wave Climate

The central coast of NSW experiences high wave energy. The offshore swell wave climate (wave height, period and direction occurrences) has been recorded by the NSW Government Manly Hydraulics Laboratory with Waverider buoys located offshore from Sydney for many years. The Waverider buoy located at Sydney has measured wave direction also since 1992. An important step in understanding the coastal processes at the site is to develop an understanding of the wave climate.

Wave height and direction are the principal drivers of longshore sediment transport at the site. Long period swell waves, which have the potential to cause sediment transport, would not undergo severe refraction when they approach the Entrance and would be expected to arrive at the beach from a wide range of directions with high wave energy. Several nearshore reefs are present, however, that would modify the nearshore wave height and direction, influencing nearshore sediment transport patterns.

To examine this understanding of the wave climate in sufficient detail for estimation of longshore sediment transport rates and seasonal patterns, a SWAN wave transformation model was set up, with detailed bathymetry provided by a combination of survey data at the site and bathymetric soundings from Admiralty Charts.

4.1.1 SWAN Model

SWAN (acronym for **S**imulating **WA**ves **N**earshore – Cycle III version 40.11) is a numerical wave transformation program developed at the Delft University of Technology (Holthuijsen *et al.*, 2000). SWAN can be used to describe wave transformation in shallow water and to obtain realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bathymetric and current conditions.

SWAN is based on the wave action balance equation (or energy balance in the absence of currents) with sources and sinks. The background to SWAN is provided in Young (1999) and Booij *et al*., (1999).

The following wave propagation processes are represented in SWAN:

- rectilinear propagation through geographic space;
- refraction due to spatial variations in bottom topography and current;
- shoaling due to spatial variations in bottom topography and current;
- blocking and reflections by opposing currents;
- transmission through, blockage by or reflection against obstacles.

The following wave generation and dissipation processes are represented in SWAN:

- generation by wind;
- dissipation by white-capping;
- dissipation by depth-induced wave breaking;
- dissipation by bottom friction;
- wave-wave interactions (quadruplets and triads);
- obstacles.

Wave-induced set-up of the mean sea surface is computed in SWAN. In (geographic) 1D cases the computations are based on exact equations. In 2D cases, the computations are based on approximate equations as the effects of wave-induced currents are ignored (in 1D cases they do not exist).

Diffraction is not modelled in SWAN, so SWAN can not be used in areas where variations in wave height are large within a horizontal scale of a few wavelengths. Because of this, the wave field computed by SWAN will, generally, not be accurate in the immediate vicinity of obstacles and certainly not within harbours.

SWAN does not calculate wave-induced currents. If relevant, such currents can be provided as input to SWAN (*e.g*. from a hydro-dynamic model, which can be driven by waves from SWAN in an iterative procedure).
SWAN has been validated using field data by Nielsen & Adamantidis (2003).

Bathymetric data for the model comprised:

- digitised soundings on a 1 km grid as provided by Geoscience Australia (Petkovic & Buchanan, 2002);
- digitised soundings and contours from the *Admiralty Chart Aus 193*, *Port Jackson to Sugarloaf Point*, scale 1:150 000;
- Photogrammetric data along the beach from 1942 to 2002, and including profiles from 1973 and June 1974(immediately following the May 1974 storm event);
- Surveyed soundings to RL -15m AHD along the entire Wyong Shire coastline; and
- Laser Airborne Depth Sounder (LADS) data at the level of the lake entrance.

Long term wave statistics were derived from a Waverider buoy operated by the Manly Hydraulics Laboratory, DPWS offshore of Sydney as published in Lord and Kulmar (2000).

The domain of the wave transformation model extended from Port Stephens in the north to Port Hacking in the south, extending some 50 km offshore into water depths in excess of 100 m (Figure 4.1). This region was schematised onto a 2 km square grid from data derived from the soundings on the 1 km grid.

A 200 m nested grid, covering all of the Wyong Shire coastline and the surrounding coast out to 100m depth, provided a more detailed schematisation of the study region (Figure 4.1). Data for this grid was derived from the 1 km grid as provided by Geoscience Australia supplemented with detail from the *Aus. 809* Admiralty Chart *Port Jackson to Sugarloaf Point*, as well as the surveyed soundings along the Wyong Shire coastline.

A 40 m nested grid is centred at Curtis Parade (Figure 4.2). Data for this grid was derived from soundings and contours from the *Admiralty Chart Aus 193*, *Port Jackson to Sugarloaf Point* and surveyed soundings along the Wyong Shire coastline.

To obtain detailed wave transformation information around the area of interest, details in the nearshore area of The Entrance and adjacent North Entrance Beach were finally schematised on a 15 m grid based on soundings and contours from the *Aus. 193* Admiralty Chart Port Jackson to Sugarloaf Point, and the surveyed soundings adjacent to The Entrance North and are depicted in Figure 4.2.

Detailed bathymetric data in the nearshore region available for the modelling are shown in Figure 4.3.

4.1.2 Offshore Swell Waves

Summary wave statistics are available from the Manly Hydraulics Laboratory (*e.g.*, as published in Lord and Kulmar, 2000). The wave data show that the predominant swell wave direction is south-southeast (SSE, 157.5°TN) with over 70% of swell wave occurrences directed from the SE quadrant. The average deep water *significant* wave height, as measured at Sydney, is around 1.5 m (Figure 4.4) and the average wave period is around 10 s. Analysis of storms recorded at Sydney has provided wave height/duration data for various annual recurrence intervals, which are presented in Figure 4.5. Detailed analysis of the percentage of swell waves from offshore directions in 22.5° increments from SSW to NE is provided in Kulmar et al. (2005). This information has been used to estimate net longshore transport rates at various locations along North Entrance Beach.

The transformation of offshore swell waves with a *significant* wave height of H_s = 1m to the area of The Entrance and adjacent North Entrance Beach was undertaken using the SWAN model, to examine the range of nearshore wave angles and magnitudes that is possible at the site. Nine locations along North Entrance Beach, as shown in Figure 4.6 were examined in detail. It can be seen in Figure 4.7 that, due to the effect of swell wave refraction for swell waves with a period of 10 seconds and for all offshore wave directions between NE and SSW (45°-202.5°TN), the range of wave approach directions possible at North Entrance Beach is between 85° and 118°TN. This compares with a shoreline orientation angle of 97.5° to 119°TN, indicating that swell waves typically approach the shore at an angle of -20.5° to +12°(positive value represents a northward wave approach direction and negative value represents a southward direction), which would induce some southward or northward sediment transport at different sites.

A vector diagram of offshore waves approaching from the SSE with a 10s wave period is given in Figure 4.6. It can be seen that the swell wave vectors mostly approach North Entrance Beach at a positive angle to the shoreline, which would tend to induce northward longshore sediment transport. At the northern spit of the entrance, the wave vectors approach at a negative angle to the shoreline, which would indicate that at this location, the longshore sediment transport would be southward entering the tidal inlet.

Vector diagrams indicating the refracted wave paths and wave transformation coefficients due to wave refraction of average swell waves (H_s offshore = 1m) at The Entrance and North Entrance Beach are provided in Appendix A. It can be seen that wave focusing occurs, particularly from S-SSE (135° to 180°TN) at RP6 – RP9 areas and, in particular, that the offshore wave height can be increased by up to 1.2 times its original value. At the RP1-RP3 areas, offshore swell waves approaching from the ENE to ESE (67.5°-112.5°TN) have a wave refraction coefficient of around 1 while the waves approaching from the S to SSE range between 0.8 and 0.95. The wave transformation modelling has shown that extensive wave energy is refracted towards the nearshore areas along North Entrance Beach, resulting in a higher wave climate. These coefficients can be applied to the offshore wave heights to determine the design *significant* wave height used to calculate sediment transport rates.

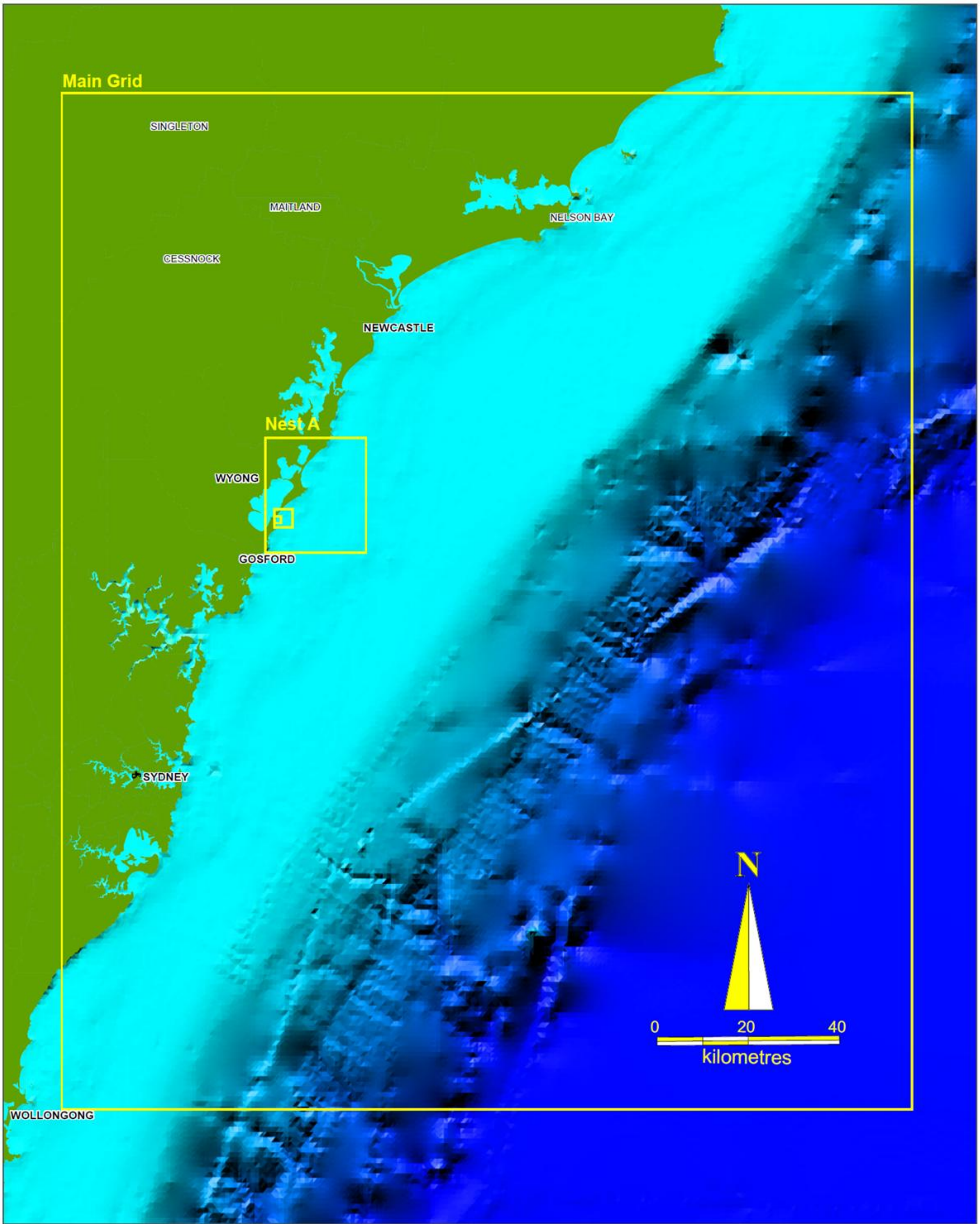
While the average swell wave period for the NSW coast is around 10 seconds, swell wave period can vary between 8s and 18s. The variation in wave period would have an effect on the nearshore wave approach direction, as wave period alters wave refraction. The sensitivity of the nearshore wave angle to variations in swell wave period has been examined in the SWAN model (Figure 4.8). It was found that, for swell waves of 8s wave period, nearshore wave directions can vary from 80° to 138°TN along North Entrance Beach within the study area. For swell waves of 15s period, nearshore wave directions can vary from 88° to 132°TN within the study area. This compares with a shoreline orientation angle of 85° to 130°TN measured at wave breaking depths, indicating that short period swell waves would strike the shore of study area at a range of oblique angles larger than the angles that long period waves generate due to less refraction effect. While the swell waves with long period contain higher wave energy, they undergo more severe refraction from offshore to nearshore to arrive at the beach close to perpendicular to the shore, thus reducing the sediment transport potential when compared with shorter period swell waves.

The above nearshore wave approach angles are used in the estimation of *Potential* longshore sediment transport. The conceptual sediment transport model is set up based on the division of coastal areas into five compartments (as shown in Figure 4.9) within which shoreline angle is relatively uniform. Within these compartments, "best estimates" of average sand transport rates (order of magnitude) and sediment inflow/outflow pathways have been calculated.

4.1.3 Summary Of Wave Climate

From the above analysis of the wave climate for the site, it was found that:

- For the range of swell wave periods experienced on the Central Coast of NSW, nearshore wave angle can vary from -38.5° to 27.5°(positive value represents northward wave approach direction and negative value represents southward direction);
- The *significant* swell wave height can reach H_s = 1.8m at the northern spit of the Entrance due to SSE(157.5°TN) swells and H_s = 1.5m along the northern part of North Entrance Beach due to E(90°TN) swells;
- The direction of approach of wave energy along North Entrance Beach would mostly favour northward longshore sediment transport for the swell waves while a southward sediment transport would be generated at the northern spit of the Entrance.



DATE 25/10/2010	COORDINATE SYSTEM MGA 94 Zone56	
PROJECT NO. 3001053	PROJECT TITLE	Longshore Sediment Transport modelling study for the Entrance and Entrance North
FIG NO. 4.1	FIGURE TITLE	Locality Map and SWAN Grids
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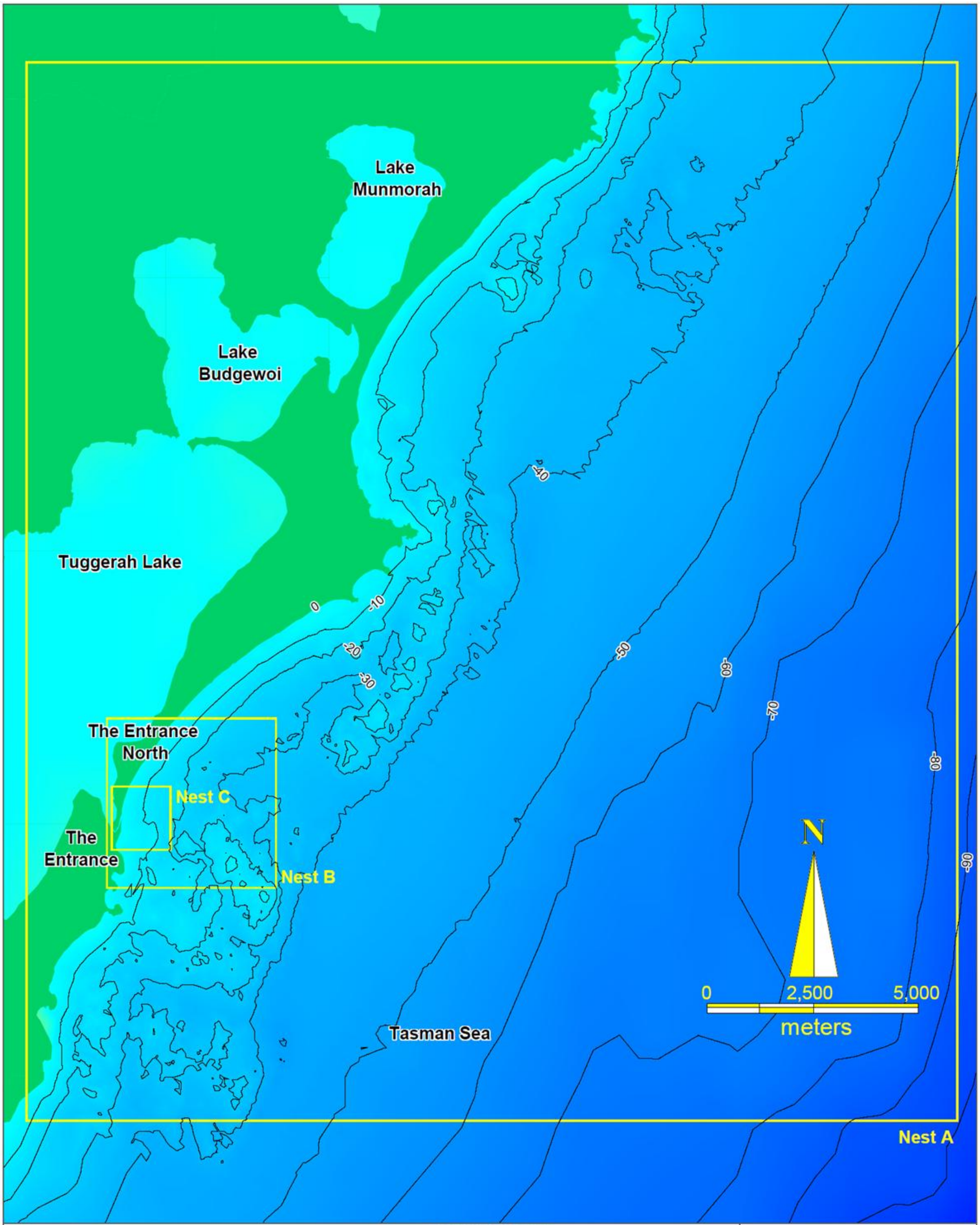

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PROJECT NO. 3001053	PROJECT TITLE	Longshore Sediment Transport modelling study for the Entrance and Entrance North	
FIG NO. 4.2	FIGURE TITLE	Locality Map and SWAN Grids (Zoom)	SMEC
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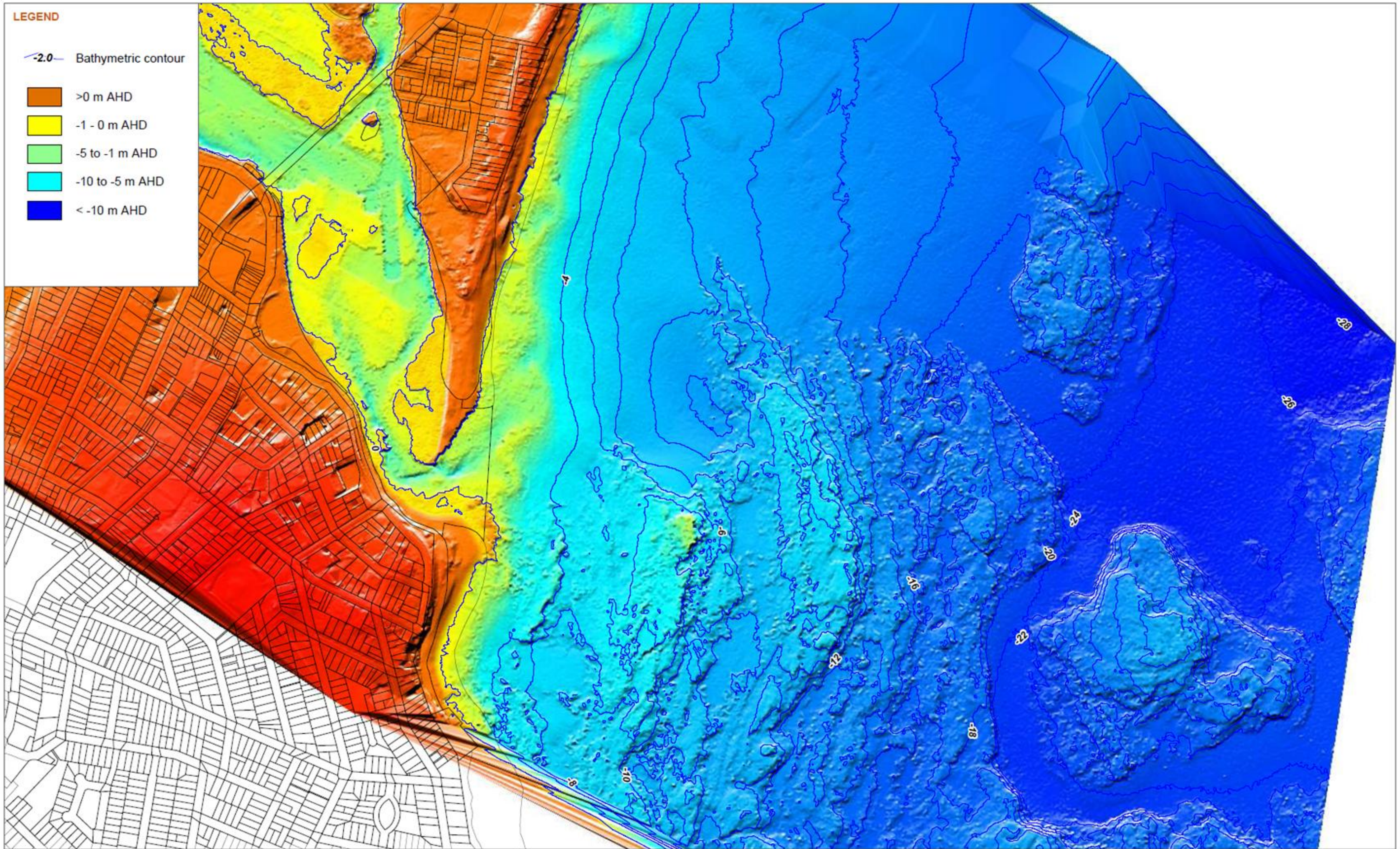


DATE 10/02/2011	COORDINATE SYSTEM MGA 94 Zone 56	FIG NO. 4.3	FIGURE TITLE Detailed LADS bathymetric data
PROJECT NO. 3001053	PROJECT TITLE Longshore Sediment Transport Modelling Study for The Entrance and The Entrance North	CREATED BY C. Adamantidis	LOCATION I:\projects\31461 - Wyong CZMP\2010 Sediment transport and Entrance stability analysis\Data\GIS\The Entrance.WOR

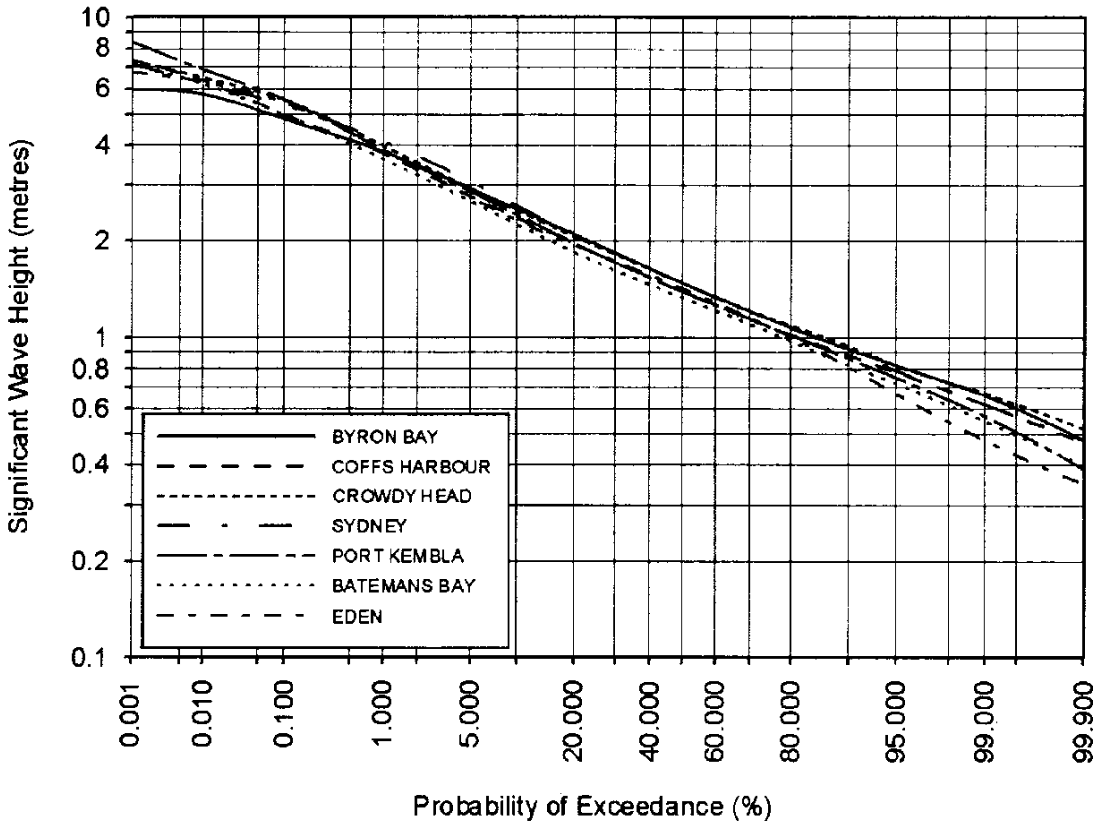


Figure 4.4 – Significant wave height exceedance for NSW coast (Lord & Kulmar, 2000)

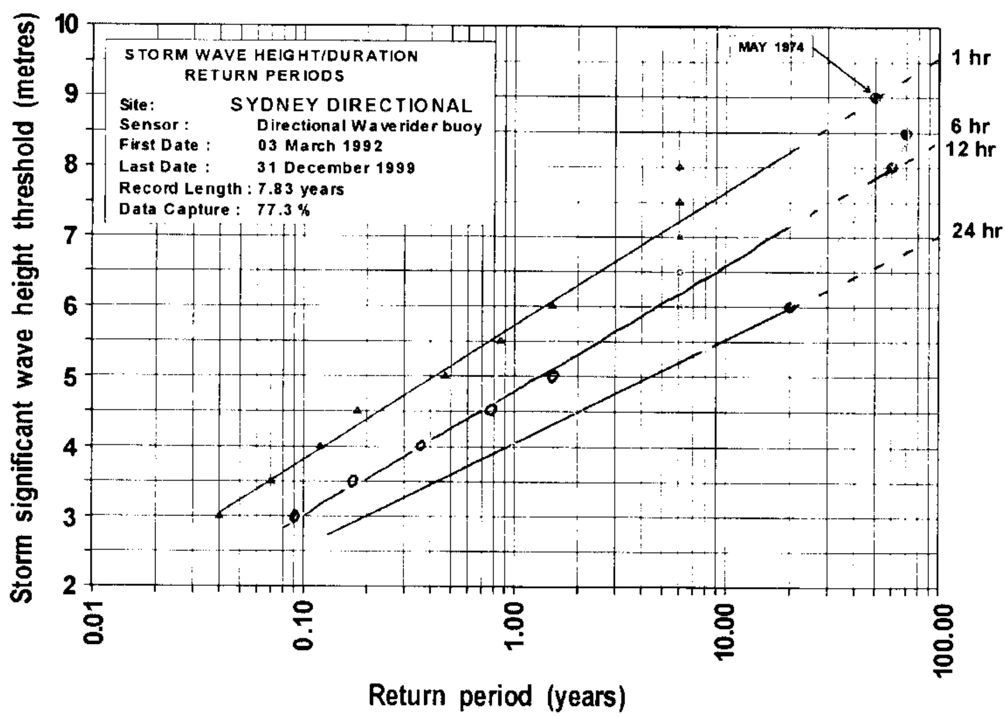
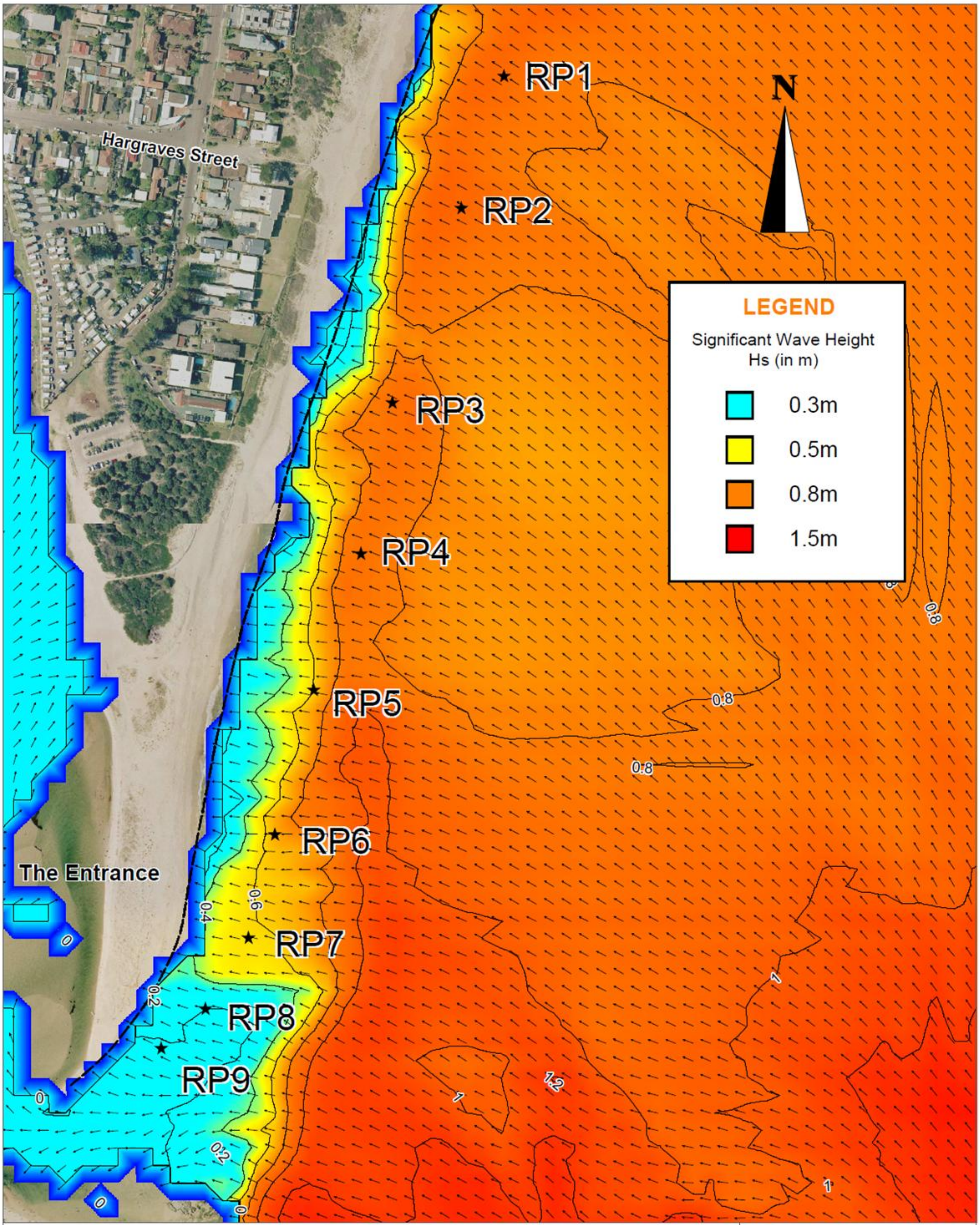


Figure 4.5 – Storm wave height duration recurrence (Lord & Kulmar, 2000)



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PROJECT NO. 3001053	PROJECT TITLE	Longshore Sediment Transport Modelling Study for The Entrance and The Entrance North	
FIG NO. 4.6	FIGURE TITLE	Location of Measurement Reference Point of the predominant wave approach angle for swell waves Hs = 1m; T = 10s; offshore wave direction = SSE	
CREATED BY A. XIAO	LOCATION	I:\projects\31461 Wyong CZMP\009DATA\data\MapInfo\Workspaces	

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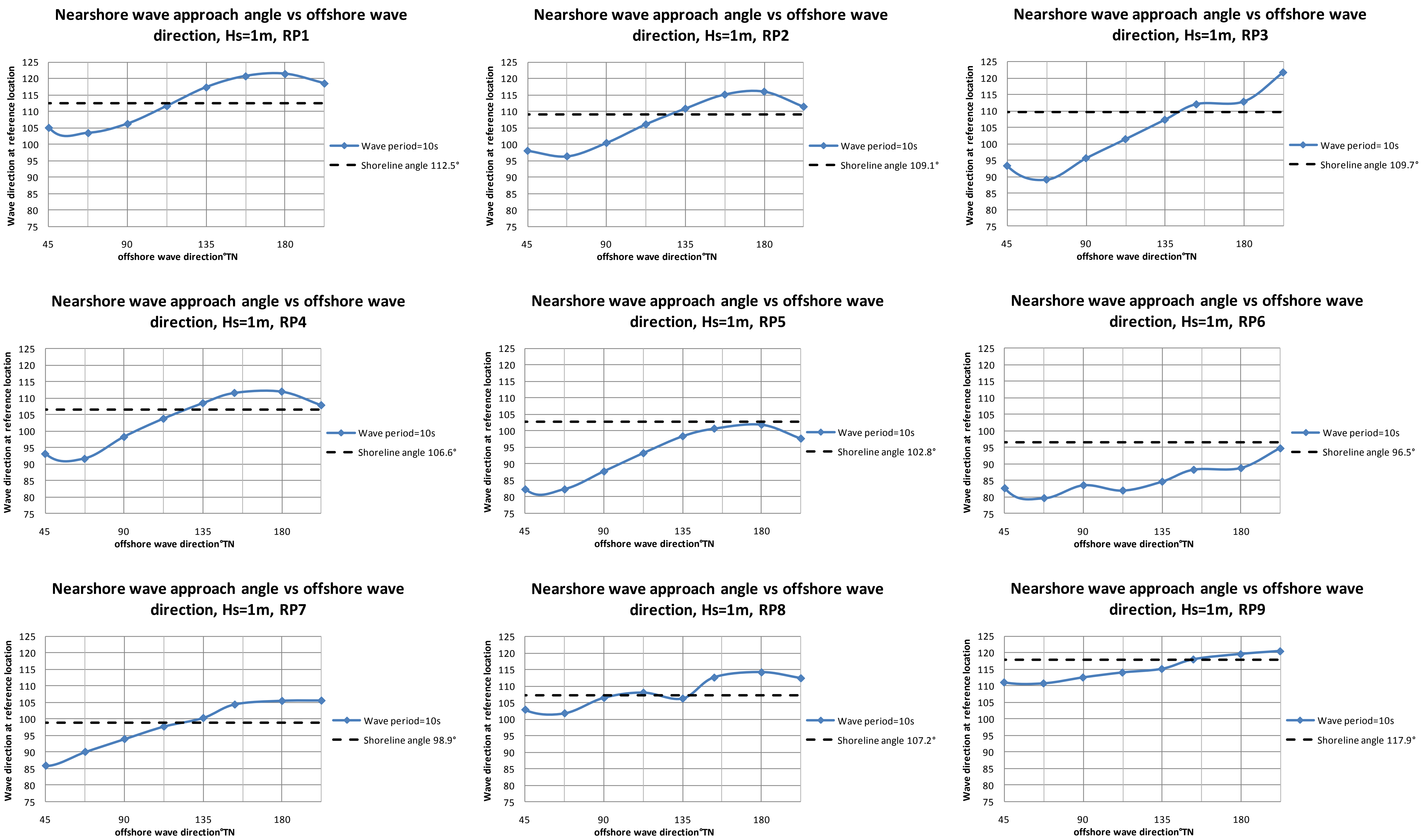


Figure 4.7 – Nearshore swell wave approach angle vs. offshore wave direction, Reference Point 1-9

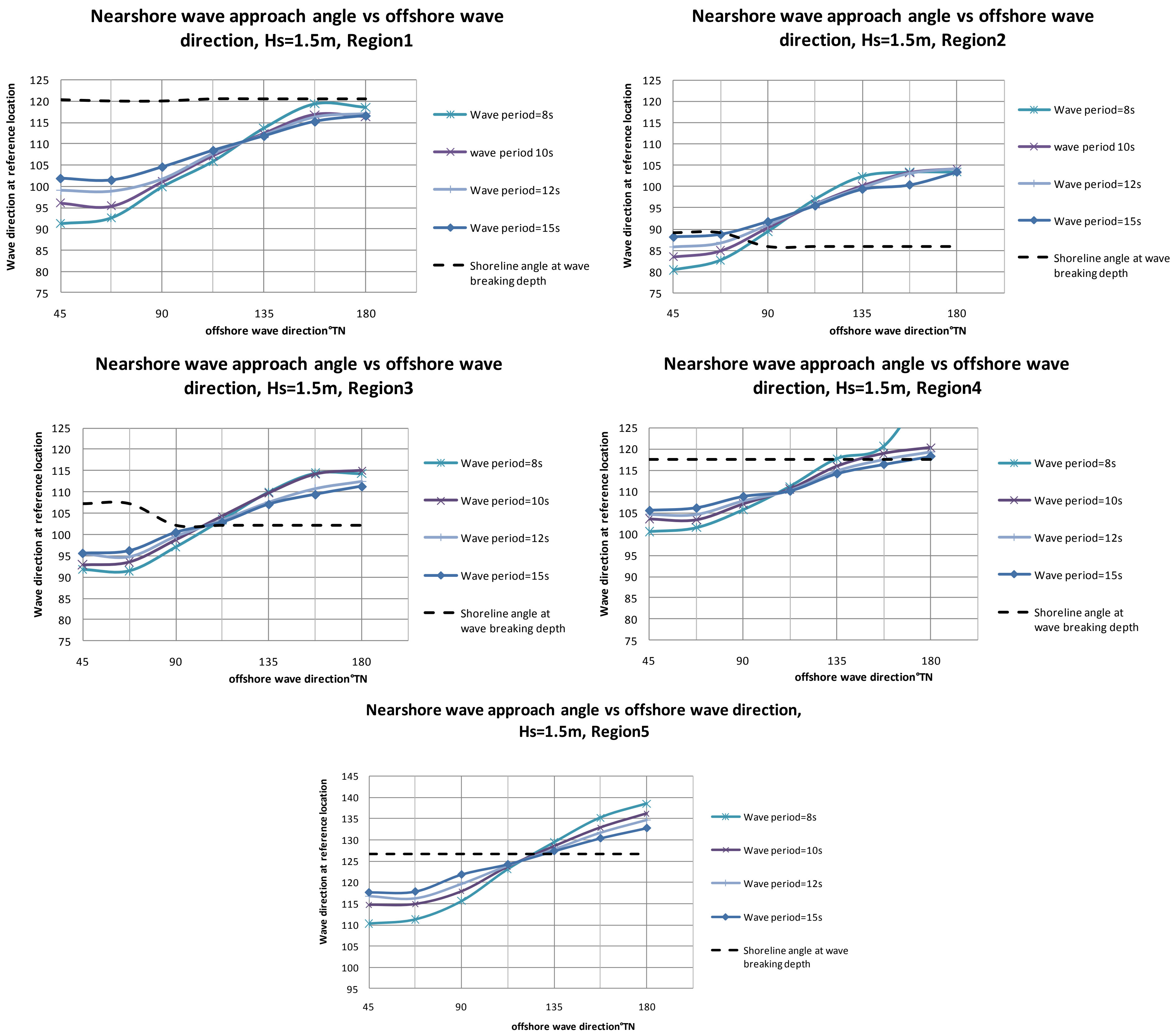
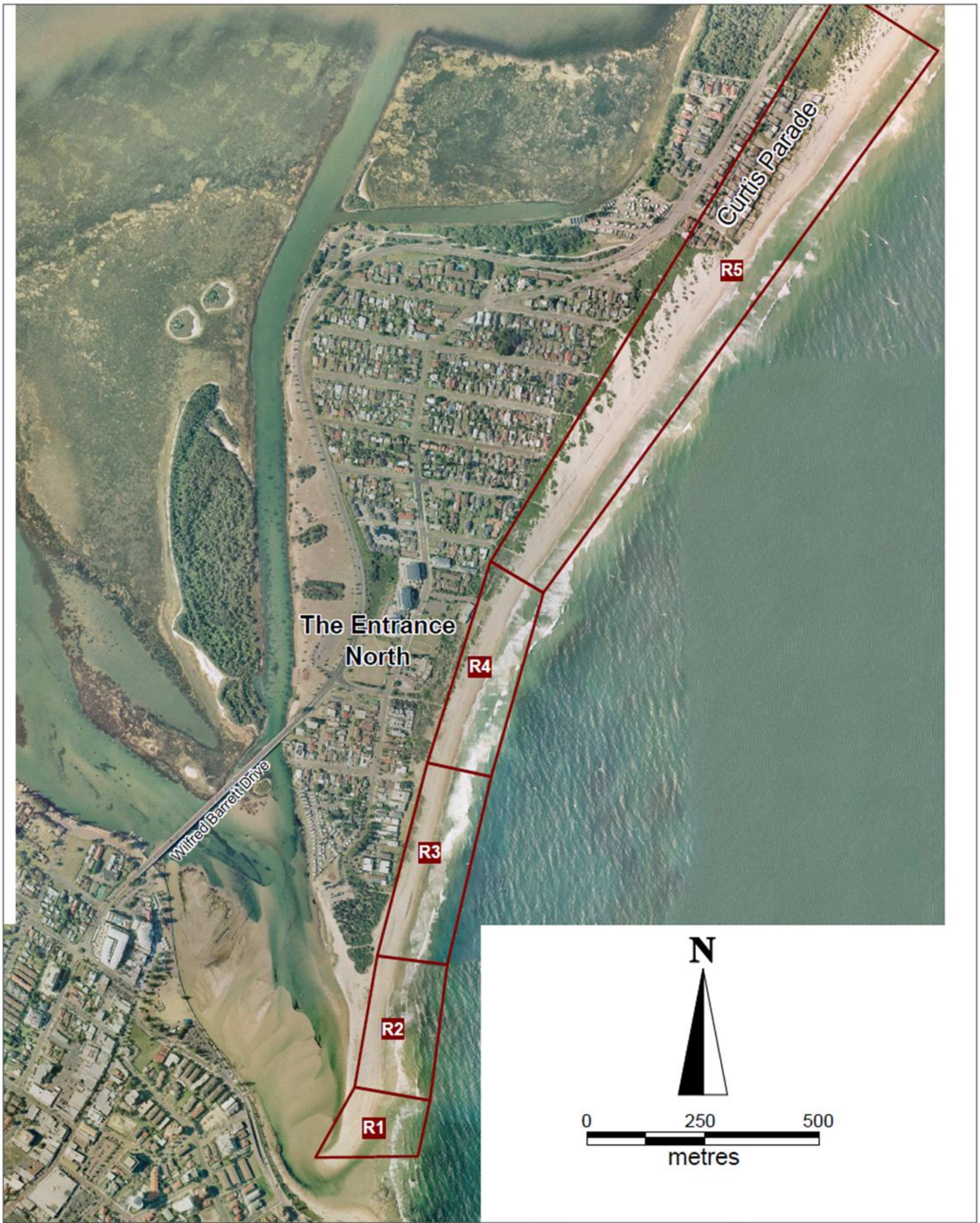


Figure 4.8 – Nearshore swell wave approach angle vs. offshore wave direction, Regions 1 to 5



DATE 16/12/2010

COORDINATE SYSTEM
MGA 94 Zone56

PROJECT NO. 3001053 PROJECT TITLE Longshore Sediment Transport Modelling Study for The Entrance and The Entrance North

FIG NO. 4.9 FIGURE TITLE Area division along the North Entrance Beach for sediment budget analysis

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5 LONGSHORE SEDIMENT TRANSPORT

The sediment pathways and magnitudes play a key role in tidal inlet opening and stabilisation. Wave-induced longshore currents carry sediment from the erosion of the updrift coast to downstream of the tidal inlet, transiting by the tidal channel. Over long time scales, the total amount of sand stored in the tidal inlet would attain a reasonably constant volume if the inlet is in equilibrium. The estimation of longshore sediment transport at the inlet and adjacent beaches can help us to evaluate how an inlet evolves in its natural configuration.

Using the understanding of the coastal processes and the SWAN numerical model from Section 4.1, a ***potential*** net longshore sediment transport rate has been estimated for the site. ***Potential*** net longshore sediment transport refers to the amount of sediment that would be transported along the shoreline by wave action over a given period of time, assuming that there is an infinite supply of sand available on the updrift side, and ignoring the effects of currents, coastal structures, bedrock in the surf zone and onshore-offshore transport processes. The net transport rate refers to the sum of the sediment transport for each possible wave condition and duration, summed over a chosen time period.

5.1 Derivation Of Sediment Transport Rate by *CERC*

The Coastal Engineering Research Center (CERC) suggests various methods of deriving gross longshore sediment transport rates for a site, including using the known transport rate at a nearby site, measured sediment volume changes between two bathymetric surveys of the site, or use of the CERC formula (Shore Protection Manual, 1984) for potential sediment transport. The CERC formula assumes that the longshore sediment transport rate depends on the longshore component of energy flux in the surf zone.

The CERC formula is given by:

$$Q = \frac{K}{(\rho_s - \rho)ga'} P_{ls} \qquad (5.1)$$

where

- Q = Longshore sediment transport rate
- K = dimensionless empirical coefficient, related to sediment grain size
- ρ_s = sediment density
- ρ = water density
- g = acceleration due to gravity
- a = solids fraction of the in-situ sediment deposit (1 – porosity).

and the longshore component of energy flux in the surf zone is given by:

$$P_{ls} = \frac{\rho g}{16} H_{sb}^2 C_{gb} \sin(2\theta_b) \qquad (5.2)$$

where

- H_{sb} = nearshore breaking height of the significant wave
- C_{gb} = wave group speed at breaking, and
- θ_b = angle breaking wave crest makes with the shoreline.

In shallow water,

$$C_{gb} = \sqrt{g d_b} \qquad (5.3)$$

where

d_b = depth of wave breaking, which is assumed to be related to the wave breaking height as $H_b = 0.78 d_b$.

The values for the parameters in the CERC formula are given below:

K = dimensionless empirical coefficient, related to sediment grain size. Sediment sampling was undertaken at the Entrance North along the spit and the sieve analysis is illustrated in Figure 5.1. The median grain size of sediment (D_{50}) in the surf zone at The Entrance North is 0.35 mm. From Coastal Engineering Manual (2003), an empirically based value for K is around 0.62, based on the median grain size (refer Figure 5.2).

ρ_s = sediment density = 2650 kg/m^3

ρ = water density = 1025 kg/m^3 for seawater

g = acceleration due to gravity = 9.81 m^2/s

a = solids fraction of the in-situ sediment deposit (1 – porosity). Porosity of a typical beach berm is around 40%, so a = 0.6;

H_{sb} = nearshore breaking height of the significant wave – from the analysis in Section 4.2.2;

C_{gb} = wave group speed at breaking, which varies with the wave height in accordance with Equation 5.3;

θ_b = angle breaking wave crest makes with the shoreline, which is -38.5° to +27.5°(positive value represents northward wave approach direction and negative value represents southward direction).

The CERC formula provides an estimate of the instantaneous (gross) sediment transport, ignoring the effects of currents and onshore-offshore processes. The above parameters were used in conjunction with long-term statistics on swell wave direction to derive longshore sediment transport rates for North Entrance Beach. It should be noted that the longshore sediment transport rates derived using the CERC formulation provide at best an order-of-magnitude estimate of the sediment transport, as there is considerable scatter in reported estimates of the dimensionless K value (refer Figure 5.1), and as the formulation does not take the effect of wave period into account in the calculations.

Table 5.1 shows the annual *potential* net longshore sediment transport induced by offshore swell waves at reference locations along North Entrance Beach under typical conditions (detailed calculations shown in *Appendix A-1*). The estimates are based on analysis of wave statistics for wave direction, significant wave height and period for Sydney provided in Tables 5.2 and 5.3. The swell–generated longshore sediment transport has been weighted for each direction between NE and SSW (45° - 202.5°TN), three significant wave heights (0.5m, 1.5m and 2.5m) and four wave periods (8s, 10s, 12s and 15s) using the wave occurrence statistics shown in Table 5.2 and 5.3. The above conditions are representative of around 95% of all recorded wave directions and periods on the Central Coast of NSW.

The wave height used for sediment transport estimation was 0.5m for the “0.00→0.99” significant wave height, 1.5m for the “1.00→1.99” significant wave height and 2.5m for the “2.00→2.99” significant wave height. The three typical significant wave heights used in the calculation cover 94.8% of wave height occurrences. The frequency of occurrence for wave periods of 8s, 10s, 12s and 15s are 33.5%, 30%, 32.5% and 4% respectively which cover approximately 100% of wave period occurrence in NSW. For example, the sediment transport generated by a SSE swell wave direction with a wave period of 8s and significant wave height of 1.5m was weighted using a coefficient of $\frac{18.20}{94.8} \times 33.5\%$ from Table 5.2 and 5.3. Weighted potential sediment transport rates for all combinations of wave period, direction and height were added to give an estimated potential net annual sediment transport rate at each representative reference location along the beach. Sediment Transport reference locations are shown in Figure 4.9. It should be noted that the estimates are indicative only based on average statistics (as well as uncertainties inherent in the sediment transport formulae) and that net sediment transport rates would vary significantly from year-to-year.

The *potential* longshore sediment transport rates at Region 3 (R3), Region 4 (R4) and Region 5 (R5) are mainly driven by the swell waves from SSE (157.5°TN) and ENE (67.5°TN), resulting in overall northerly sediment transport with a local southerly reversal of littoral drift moving sands along the northern entrance sand spit back to the entrance. The CERC equation predicted northward *potential* longshore sediment transport of up to 4 M m^3/yr for R2, 1.1 M m^3/yr for R3 and 0.4 M m^3/yr for R5, with reduced longshore transport magnitude further north. However, long term beach recession was generally observed to increase northward along the beach, from photogrammetric data analysis in the Wyong Coastal Hazard Study (SMEC, 2010). The increased long term recession further north along the beach may be due to offshore sand transport during storms or aeolian transport into the dune system, as longshore transport rates are relatively low along the northern parts of the beach.

The ***net*** actual sediment transport rate would be a lot smaller than ***potential*** sediment transport, as this estimate does not take into account the availability of sediment for transport, the input of sediment to the system from other sources such as sand from occasional wind-blown sand transport and tidal sand outflow from the channel of the entrance. While the ***net*** sediment transport rate at the site is not known precisely, it is evident that the main potential is for sediment transport from south to north along the northern beach away from the tidal inlet and gradually reverses direction from north to south entering the tidal inlet.

Table 5.1 – Estimated potential longshore sediment transport using CERC (1984) formula in typical conditions

Longshore Sediment Transport ('000 m^3/yr)	T=8s	T=10s	T=12s	T=15s	Total '000 m^3/yr
R1	-425	-580	-689	-76	1770 S
R2	877	1028	1163	110	3178 N
R3	227	358	200	20	805 N
R4	30	-81	-117	-20	188 S
R5	136	57	48	-4	236 N

**Positive value represents northward transport and negative value southward transport.*

Table 5.2 – Sydney wave height occurrence by direction to December 2004 (Kulmar et al., 2005)

Start Date: 03-Mar-1992 **End Date:** 31-Dec-2004 **Record:** 12.84 years **No. Records:** 86,595 **Capture:** 82.7%

Hsig (metres)	Wave Direction (° True North)									TOTAL
	NNE	NE	ENE	EAST	ESE	SE	SSE	SOUTH	SSW	
0.00 → 0.99	0.02	0.43	1.27	1.71	1.87	3.20	5.75	1.96	0.08	16.48
1.00 → 1.99	0.06	2.34	6.44	7.53	6.39	9.74	18.20	9.91	0.41	61.13
2.00 → 2.99		0.35	1.08	1.46	1.52	2.35	5.27	5.03	0.13	17.19
3.00 → 3.99		0.01	0.11	0.29	0.24	0.51	1.29	1.39	0.04	3.89
4.00 → 4.99			0.03	0.08	0.08	0.15	0.31	0.33		0.98
5.00 → 5.99				0.02	0.02	0.05	0.10	0.09		0.27
6.00 → 6.99							0.02	0.01		0.04
7.00 → 7.99							0.01			0.01
TOTAL	0.08	3.13	8.93	11.09	10.12	16.00	30.96	18.73	0.66	100.00

Table 5.3 Wave Period Occurrence for all stations to December 2004 (Kulmar et al., 2005)

TP1 (sec)	Byron Bay	Coffs Harbour	Crowdy Head	Sydney	Port Kembla	Batemans Bay	Eden
2 → 3.99	0.404	0.429	0.301	0.353	0.924	0.401	0.260
4 → 5.99	5.492	5.879	5.201	5.702	6.035	6.955	7.569
6 → 7.99	16.005	15.475	15.289	15.492	17.017	20.330	19.309
8 → 9.99	34.185	33.744	32.731	24.037	31.913	30.271	31.325
10 → 11.99	27.168	28.026	27.833	36.302	25.600	25.785	24.320
12 → 13.99	14.742	14.399	15.853	14.160	15.871	14.733	15.127
14 → 15.99	1.796	1.824	2.382	3.415	2.307	1.341	1.865
16 → 17.99	0.199	0.215	0.387	0.469	0.310	0.176	0.208
18 → 19.99	0.011	0.010	0.023	0.069	0.023	0.007	0.016
Average TP1	9.57	9.57	9.71	9.83	9.57	9.36	9.41
Start Date	14-Oct-1976	26-May-1976	10-Oct-1985	03-Mar-1992	07-Feb-1974	27-May-1986	08-Feb-1978
Record (years)	28.23	28.62	19.24	12.84	30.91	18.61	26.91
No. Records	142,000	164,021	145,059	86,595	171,794	148,537	152,809
Capture (%)	71.5	84.6	86.0	82.7	83.5	91.0	80.6

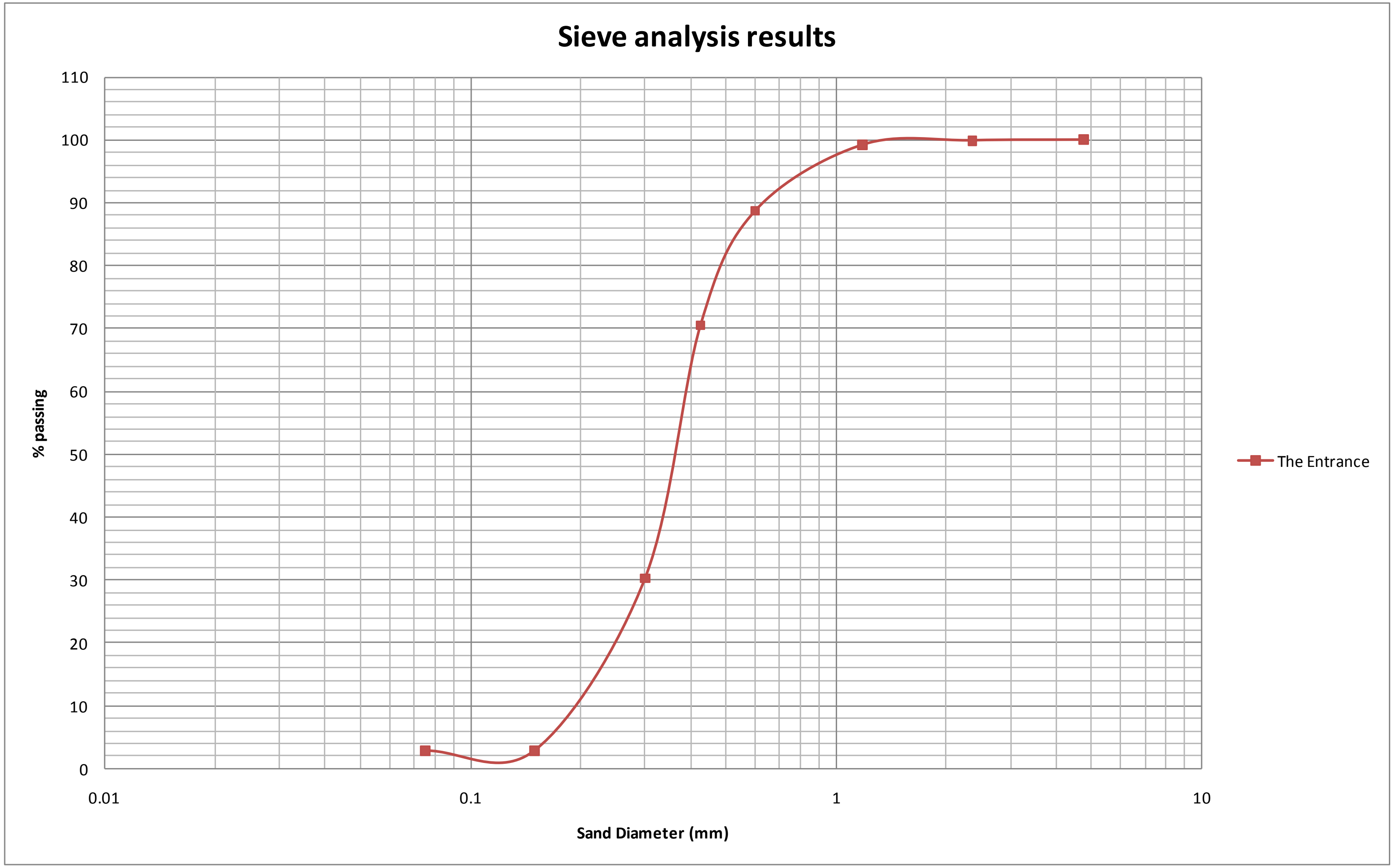

Figure 5.1 – Results of the Sieve Analysis for the Entrance North

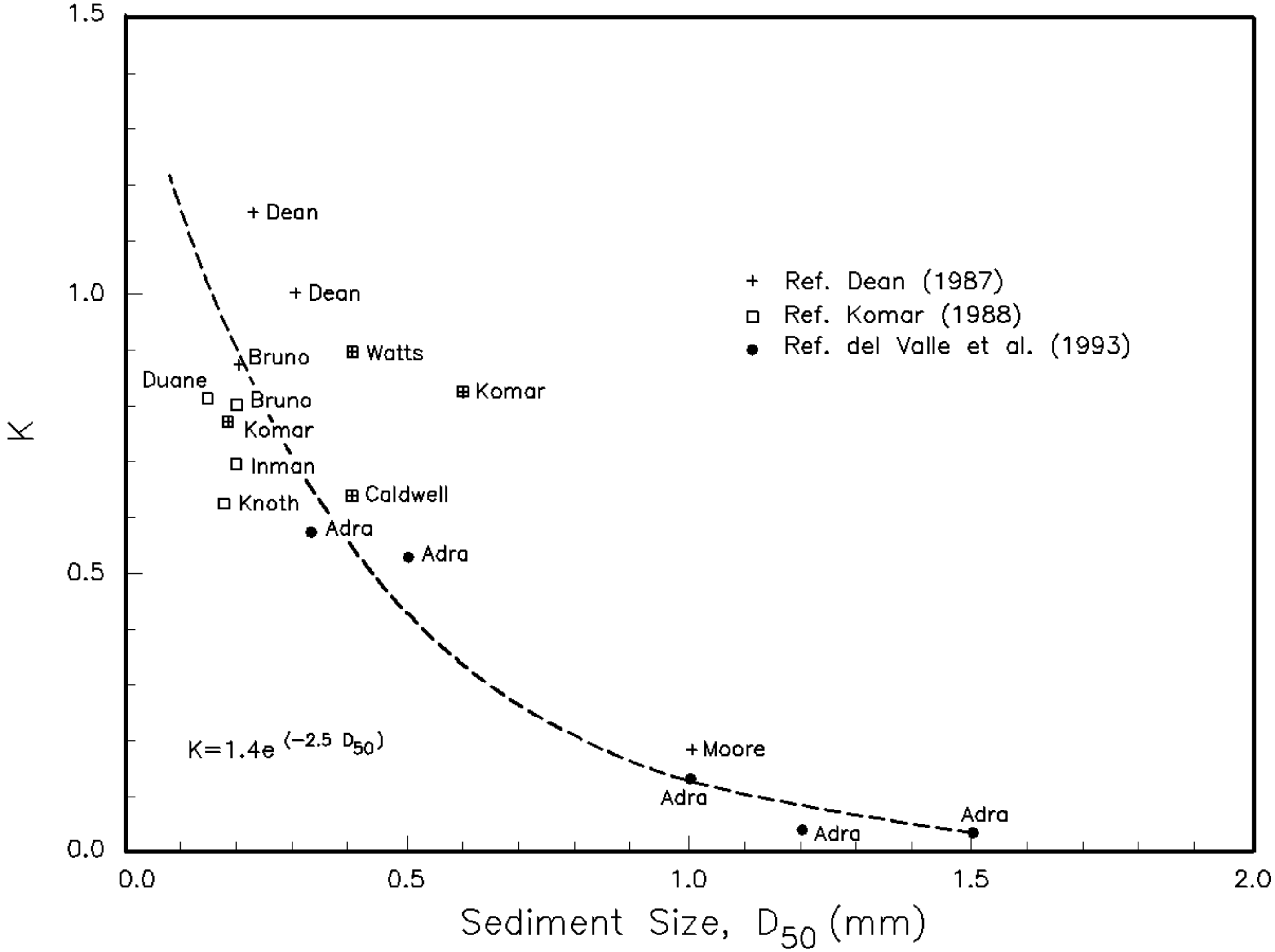

Figure 5.2 – Determination of value of K parameter in CERC sediment transport formula (from Coastal Engineering Manual, 2003)

5.2 Derivation Of Sediment Transport Rate by *Kamphuis*

For comparison purposes, the sediment transport rate was also evaluated using the Kamphuis (1991) expression. This expression is based on an extensive series of hydraulic model tests, and depends on breaking wave height, wave period, grain size, nearshore beach slope and nearshore wave approach angle. The expression is given by:

$$Q_k = (6.4 \times 10^4) H_{sb}^2 T_{op}^{1.5} m_b^{0.75} D^{-0.25} \sin(2\alpha_b)^{0.6}$$

where

Q_k = sediment transport rate, m^3/year

H_{sb} = breaking wave height

T_{op} = wave period (10s for swell waves)

m_b = nearshore beach gradient (i.e. 1:10 as measured in the beach survey)

D = sediment grain size (i.e. 0.25mm according to the sand samples taken along the beach)

α_b = angle breaking wave crest makes with the shoreline, which is ranging from -20.5° to +12°for the different swell wave directions.

Using these parameters, the sediment transport rate as calculated by the Kamphuis expression is provided in Table 5.4 (detailed calculations shown in *Appendix A-2*).

Table 5.4 – Nett Sediment Transport at North Entrance, Kamphuis expression

Longshore Sediment Transport ('000 m³/yr)	T=8s	T=10s	T=12s	T=15s	Total '000 m³/yr
R1	-403	-851	-1311	-206	2771 S
R2	683	1083	1634	229	3631 N
R3	235	460	372	56	1123 N
R4	59	-67	-201	-58	267 S
R5	160	132	160	2	454 N

**Positive value represents northward transport and negative value southward transport.*

The Kamphuis (1991) method gave similar results to the CERC method, with the main potential for sediment transport from south to north along the North Entrance Beach and a reversal of the transport direction from north to south entering the tidal inlet. It is noted that the Kamphuis equation takes into account wave period, a factor that influences wave breaking which is not a parameter used by the CERC equation. The potential sediment transport rates at the Entrance and North Entrance Beach calculated by the Kamphuis equation are a little higher than the values calculated by the CERC equation.

5.3 Conceptual Sediment Transport Model

A conceptual sediment transport model for The Entrance and North Entrance Beach based on the results of the previous calculation is illustrated in Figure 5.3 and Figure 5.4. Along North Entrance Beach, the swell generates a predominantly northward sediment transport, strongly along the coastline in Region 2 between the Entrance northern spit and Karagi Park, but much less further north from Region 3 to Region 5 (refer Figure 4.9 for the locations of the regions). Southward sediment transport entering the inlet is observed at the Entrance and along the Entrance northern spit. A tide-induced sediment circulation between the upstream entrance shoals, entrance sand bar and the entrance spit was identified by earlier studies (PBP 1994). Sand carried out by the ebb tide through the entrance channel deposits on the entrance sand bar area, whereby it becomes available for onshore transport back onto the beach. Flood tide and breaking waves carry the sands from the entrance bar both southward back to the entrance shoals and northward along the coast, with some being brought onshore by wave action. The northward transport in Region 2 may be limited due to limited amount of sand available for transport, but it is likely that some sand is being transported onshore by wave action. The estimated magnitudes and pathways of detailed sediment transport within the five regions along the Entrance North are shown in Figure 5.4.

Cross-shore sediment movement occurs mostly during storm events. Tide-induced sediment transport involves the entrance bar, entrance sand spit and the upstream sand shoals. The action of breaking waves and flood tide currents carries sand onshore, towards the entrance channel, and deposits it on the upstream sand shoals. During ebb tide, sand is removed from the entrance channel and northern and southern channels, transported back through the entrance throat and deposited on the entrance sand bar. In this sand circulation, more sand is transported onto the upstream entrance shoals and gradually builds up the upstream sand shoals.

5.4 Potential impact of training wall at the Entrance

A potential option for management of the entrance area is to construct a training wall at the northern side of the entrance channel. The impacts of such a training wall on the entrance dynamics and sediment transport are discussed below, with reference to the conceptual coastal process model of the area.

5.4.1 Entrance Bar

A training wall at the northern side of the entrance could result in the widening and deepening of the entrance channel and significant scour of the existing entrance bar. The sand circulation between the entrance sand bar, upstream shoals and the entrance channel shown in Figure 5.4 would be cut off by the training wall, as southerly sediment transport into the entrance channel would be blocked, and the ebb tide would continue to scour upstream shoals through the substantial opening entrance throat. The creation of a strong ebb tide jet would build up a new entrance sand bar further offshore. Wave action would be unable to move this offshore sand back onto the beach as readily as it does under existing conditions, and the nearshore wave climate at the southern section of North Entrance Beach would be altered due to changes in nearshore bathymetry, which could cause changes in sediment transport patterns and possible erosion of the entrance spit.

5.4.2 Shoaling

The existing entrance sand shoals would erode due to a permanent loss of sand from littoral drift along northern entrance spit back to the entrance obstructed by the northern training wall. Sand moving onshore by flooding tide and breaking waves would tend to be trapped by the training wall and the ebb tide would continue to scour the upstream sand shoals, transporting sand through the entrance throat onto the new sand bars. Hence the sand deposited onto the upstream shoals would be greatly reduced. However, increased tidal currents would tend to bring sediment further into the estuary and extend the flood tide delta upstream.

5.4.3 Erosion and Sedimentation

The construction of northern training wall perpendicular to the beach would interrupt the local southerly reversal of littoral drift back onto the entrance upstream shoals. The sand captured against this wall would accumulate so as to form a fillet of sand. If the training wall were to be constructed for the purpose of keeping the entrance channel open, the northern training wall would need to be of a sufficient length such that the naturally occurring equilibrium plan alignment of the beach in this fillet results in no sand being able to be swept by waves around its end (and into the mouth of the entrance) during periods of southerly sand transport. This sand is no longer available to be moved onshore from the entrance sand bar due to the scour of the entrance sand bar. This would exacerbate the North Entrance beach erosion due to lack of sand supply to feed northward longshore sediment transport. There would be massive sand relocation from the upstream shoals to the margins of adjacent beaches.

5.4.4 Tuggerah Lake

Continued scour of the entrance channel would result in an increasing trend in the tidal range and tidal prism of the Tuggerah Lake. The entrance channel would evolve toward an equilibrium following entrance training, and allow ocean swell to propagate through the entrance. Scour in the entrance channel as a result of increasing tidal flow could threaten the foundations of the road bridge resulting in expensive remedial works to the bridge abutments. The Wilfred Barrett Drive would be exposed to sediment scour of the bridge piers by swift tidal currents. The ecological environment within Tuggerah Lake would be influenced greatly by the rate at which water in the lake is exchanged with oceanic waters through the entrance, as well as changes to the natural tidal regime, changing the natural assemblages of vegetation communities in the area.

5.4.5 Flooding

The gradually removal of upstream shoals would have an adverse effect on entrance stability. An extreme flood event could split the main channel of the entrance into two with one channel along the southern bank and one along the sand spit. A training wall in front of the northern entrance spit would therefore need to extend upstream along the entrance channel toward the bridge so as to prevent breakthrough of the entrance spit in a large flood event.

5.5 Historic Sediment Transport

The existing wave climate was compared to the shoreline angle observed from the historic aerial photographs to determine a general trend in the sediment transport and observed the location of the null point over time. A similar pattern to the existing circulation was noted with a southward sediment transport at the entrance and a northward sediment movement further north. The difference in the pattern occurs in 1941 when the sand spit was closed and some northward sediment movement was observed at the southern end of the entrance.

The null point was found to migrate between Hargraves Street and the northern end of the unvegetated sand spit. This range of migration was similar to that reported in Worley Parsons (2010) and illustrated in Figure 5.5.

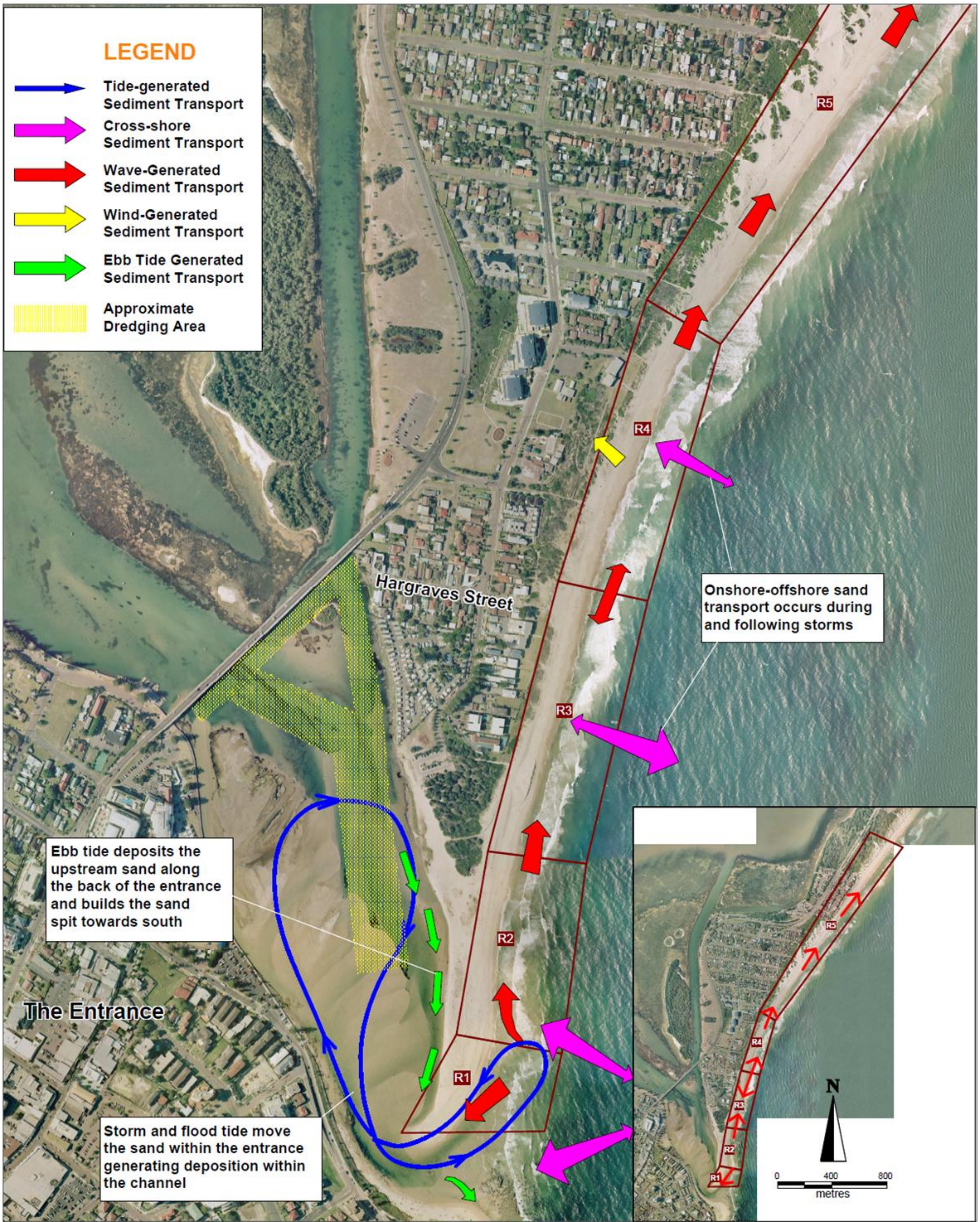

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FIG NO. 5.3	FIGURE TITLE	Conceptual Sediment Transport Model for North Entrance Beach	
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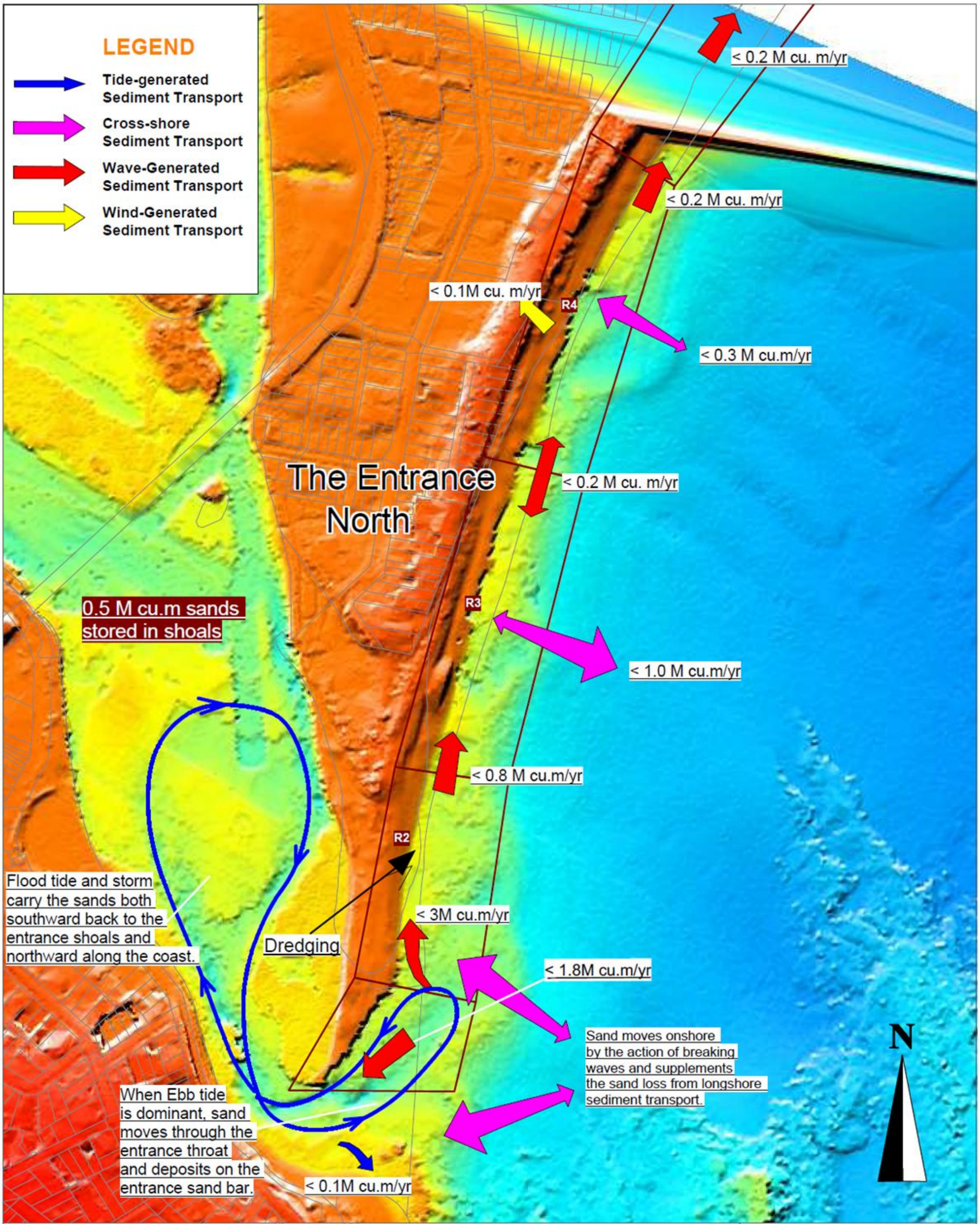

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PROJECT NO. 3001053	PROJECT TITLE	Longshore Sediment Transport modelling study for the Entrance and Entrance North	
FIG NO. 5.4	FIGURE TITLE	Longshore/offshore sediment transport along the Entrance North Beach and tide-induced sand circulation between the entrance sand bar and upstream sand shoals	SMEC
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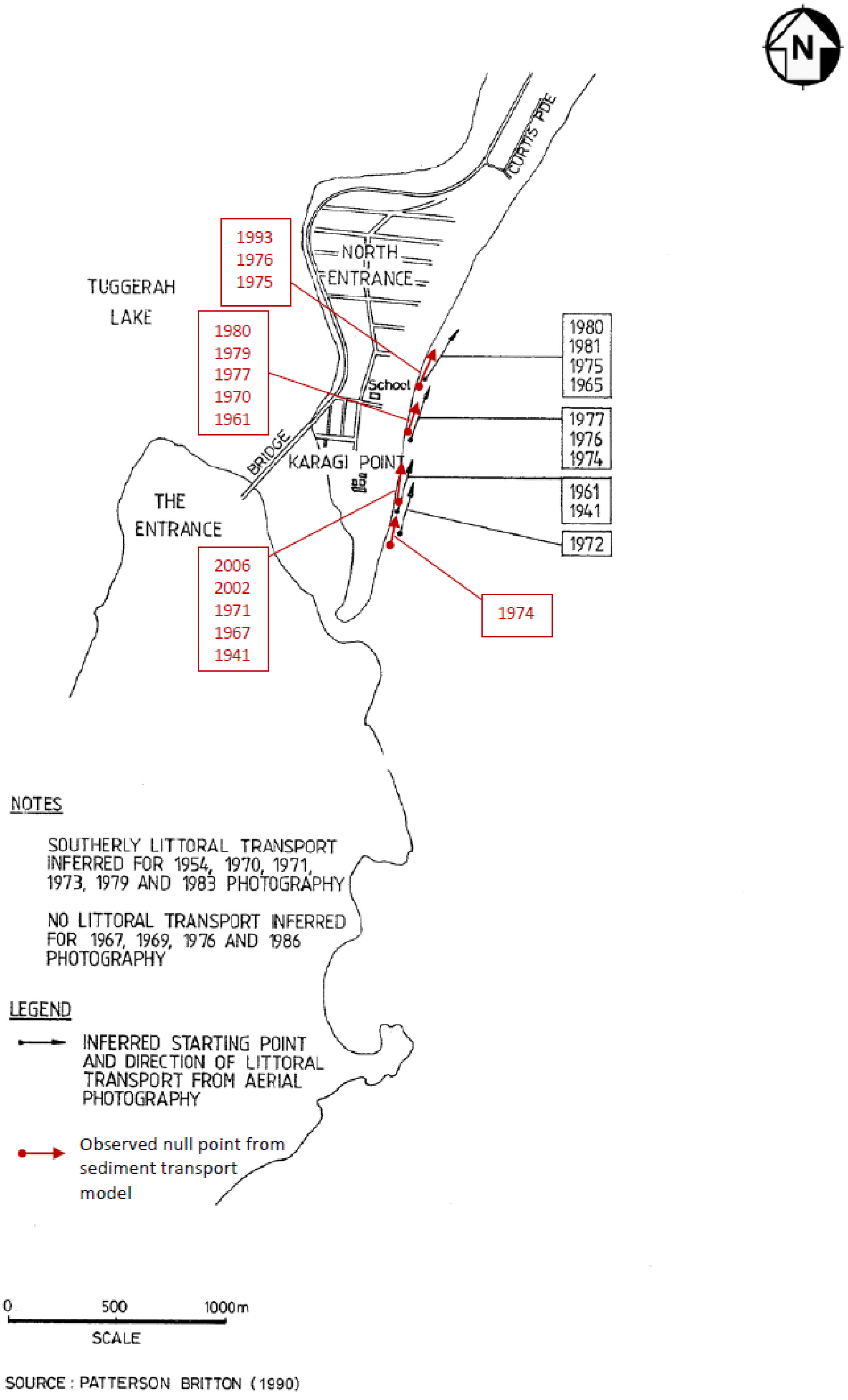

Figure 5.5 Locations of null point observed from sediment transport model compared with Worley Parsons (2008).

6 ENTRANCE STABILITY ANALYSIS

The cross-sectional stability of a tidal inlet has been first analysed by Escoffier in 1940. Escoffier's theory analysed the permanency of the stability of the entrance depending on its size and the maximum current speed at the entrance. The relationship between cross-sectional area and maximum velocity is illustrated in Figure 6.1. When the maximum velocity is equal to the equilibrium velocity, the cross-sectional area is in equilibrium and the entrance is stable. When the maximum velocity is lower than the equilibrium velocity, the current is not strong enough to move the sediments carried into the inlet by littoral drift and the sediments will deposited into the entrance reducing the cross-sectional area. When the maximum velocity is higher than the equilibrium velocity, the sediment transport capacity of the inlet currents will be larger than the volume of sediment carried into the inlet entrance by littoral drift and the entrance will therefore erode and the cross-sectional area will increase. From this and Figure 6.1, it can be observed that:

- if the cross-sectional area A is lower than A1 (A<A1), the sediments will deposit into the entrance and the entrance will tend to close over time;
- if A1 < A < Ae, the entrance will erode until A = Ae;
- if A > Ae, the sediments will be deposited into the inlet entrance and the entrance cross-sectional area will reduce until A = Ae;
- if A = A1, the equilibrium is unstable. If there is any storm depositing or removing some sediment from the entrance, the entrance would either close or widen to reach the equilibrium area Ae; and
- if A = Ae, the equilibrium is stable. If a storm deposits or removes some sediments from the entrance it will recover to reach A = Ae.

Hence, the entrance is stable for A > A1.

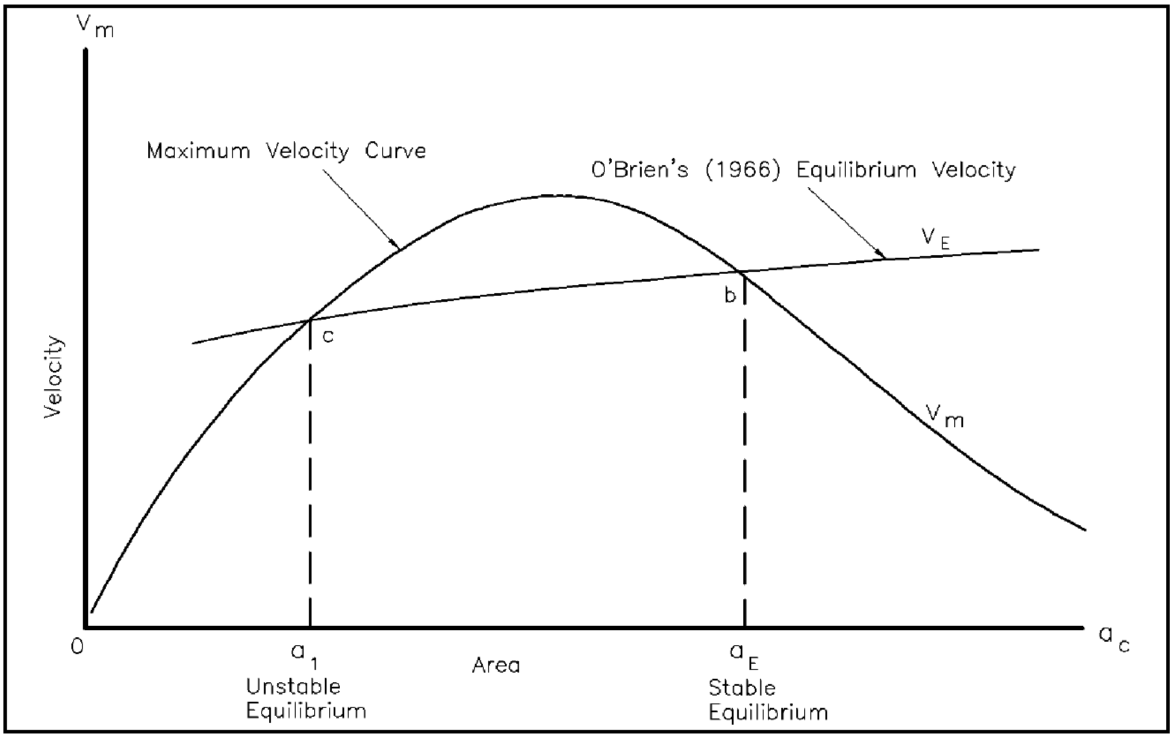

Figure 6.1 – Escoffier (1940) curve, maximum and equilibrium velocities versus inlet cross-sectional area (C.E.M., Chap. II-6)

However, the equilibrium cross-sectional area may be subject to long term changes. O'Briens (1966) determined a relationship between cross-sectional area and tidal prism. Assuming a maximum velocity $u_i = \hat{u}_i \sin(wt)$ with w the angular frequency of the tide and t the time, it follows:

$$\Omega_i = \frac{A_i \hat{u}_i T}{\pi}$$

with	Ω_i	=	Tidal Prism of the estuary
	A_i	=	Cross-sectional area of the inlet entrance
	T	=	Tidal period

This formula is usually presented as:

$$A = C\Omega^n$$

with C and n free parameters. These parameters can be obtained by analysing the correlation between the tidal prism and the cross-sectional area of several estuaries located within the same region. This correlation has been undertaken along Australia's East Coast by BMT WBM (2008) as shown on the graph in Figure 6.2.

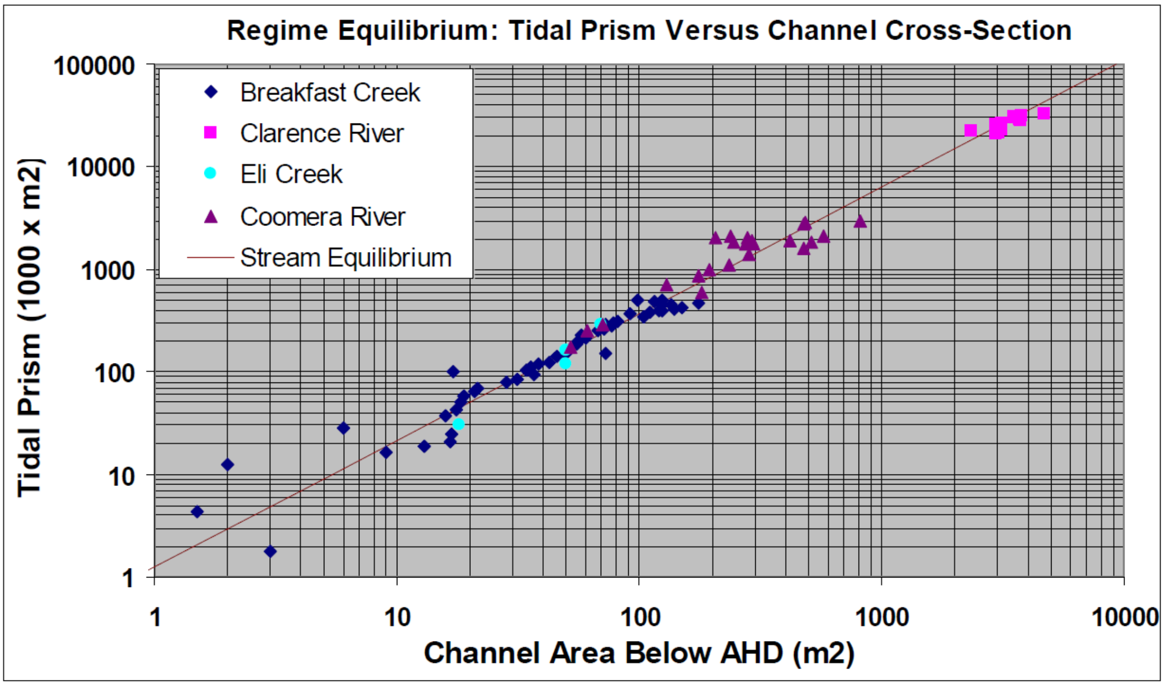

Figure 6.2 – Regime equilibrium relationship for tidal estuaries along Australia's East Coast (BMT WBM, 2008)

From this graph, the relationship derived was identified as:

$$A = 3.1 \text{ x } 10^{-3}\Omega^{0.81}$$

This cross-sectional area-tidal prism relationship has been used for Tuggerah Lake at The Entrance.

The dimensions of the lake entrance were observed using the historic aerial photographs and available bathymetric soundings. It was found that the channel entrance width was varying between around 20 and 100m, its length ranges between 90 and 450m and its depth was assumed to range between 0 and 2m.

The water level response of Tuggerah Lake was calculated using a difference method from the predicted ocean tide level calculated by the software WXTide 32 over a year. An example of the results of the calculation for the entrance channel characteristics as measured using the LADS data (i.e. width=40m, depth=0.85m and length=250m) are provided in Figure 6.3. These results were validated by checking against the real-time tidal data recorded at Toukley by MHL available on their website at the time of writing this report showing a lake level of around 0.2 and a negligible tidal range.

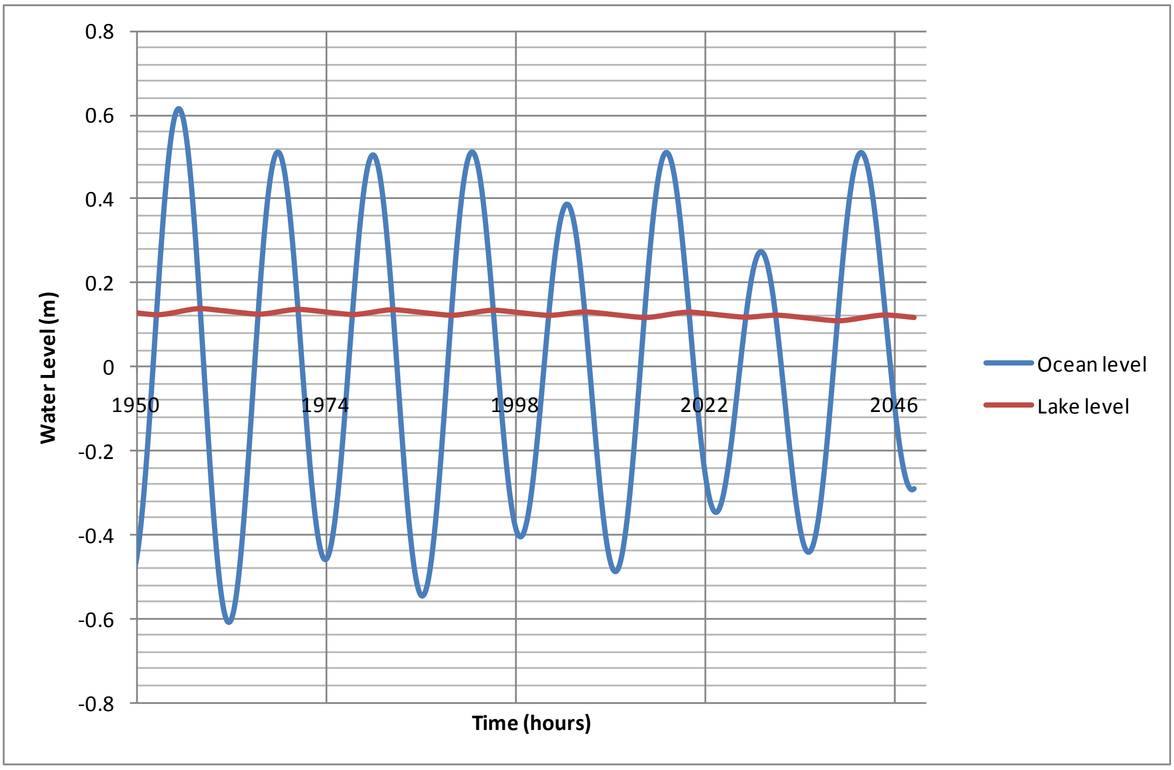

Figure 6.3 – Results of the water level response of Tuggerah Lake using a difference method

A sensitivity analysis was undertaken using the various channel dimension measured from the aerial photographs. The average lake level increases when the entrance is shallower and the tidal range increases when the entrance is wider. The length of the channel slightly reduces the tidal range and increases the water level. The water level in the lake does not exceed 0.15m and the tidal range is around 0.20m. However, these values assume the tidal impact only and do not take into account the rainfall and fluctuations in atmospheric pressure that may increase or decrease them. This is of the same order as the results of MHL (2010) illustrated in Figure 6.4 and confirm the 0.2-0.3m tidal range found by Worley Parsons (2010).

Given the very low tidal range within the lake and therefore the low tidal prism, as well as the various dimensions of the channel entrance, the current velocities will be low and this would result in sand deposition within the entrance over time. Therefore the lake entrance tends to reduce and would eventually close if the dredging is stopped. Flood events may increase the flow at the entrance and generate erosion that would widen the entrance temporarily.

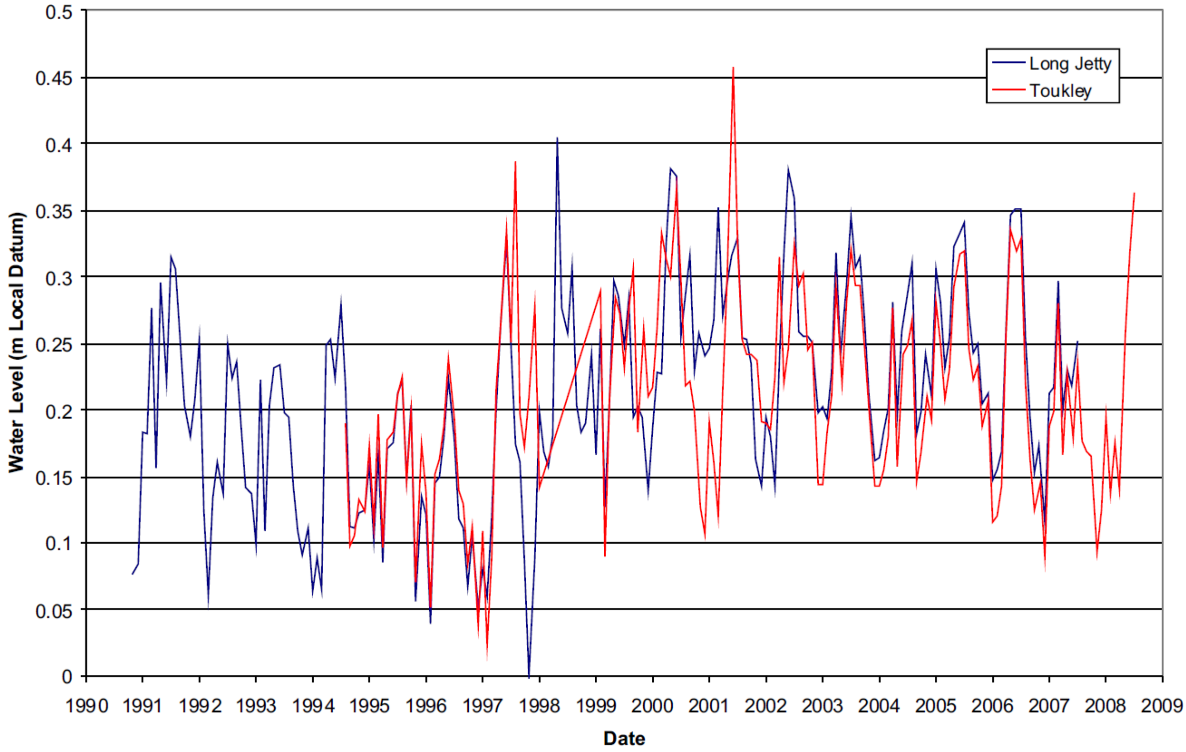

Figure 6.4 – Monthly averaged water level at Toukley and Long Jetty, Tuggerah Lake

7 CONCLUSION

Existing information, documents and data regarding Tuggerah Lake entrance were analysed to create a SWAN model and determine the local wave climate.

Resulting longshore sediment transport rates were calculated. It was found that a main southward movement is observed at the entrance of the lake and a northward movement starts further north from the entrance. The null point where there is a change in direction of sediment transport may vary over time and was observed to be located near the southern end of the vegetated area directly north of the sand spit. If sand dredged from the entrance is placed south of this location, it will make its way back into the entrance; conversely, if the sand is placed north of this location, it would move northward along North Entrance Beach but may subsequently be lost to the littoral system due to offshore transport during storms. . A conceptual sediment transport model of the entrance area and adjacent North Entrance Beach was compiled.

Inlet stability calculations were carried out based on bathymetric data and observation of historical aerial photography. The entrance was found to be unstable due to the narrow entrance width reducing the tidal range and prism. Therefore, it would tend to accrete and close without regular dredging. Only a flood would erode and widen the entrance.

This investigation largely confirms the observations made by Worley Parsons and PBP in earlier investigations. Further information that could confirm the basic coastal process understanding developed in this report could include:

- Calibration of the tidal model against long-term measured water level time series, velocities and channel bathymetry;
- Physical measurement of sediment movement through tracer studies and field data collection at the entrance to confirm the inferred tidal circulation model; and
- Development of a coupled 3D hydrodynamic and sediment transport model to test various management scenarios.

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APPENDICES

A-1 Estimated potential longshore sediment transport using CERC (1984) formula in typical conditions

Longshore Sediment Transport ('000 m³/yr m³/yr)	**R1**			
	T=8s (Occurrence of 34%)	**T=10s** (Occurrence of 30%)	**T=12s** (Occurrence of 32%)	**T=15s** (Occurrence of 4%)
Hs=0.5m (Occurrence of 17%)	-14	-21	-17	-17
Hs=1.5m (Occurrence of 61%)	-807	-1111	-1289	-1127
Hs=2.5m (Occurrence of 17%)	-445	-789	-829	-781
94.8% occurrence of Hs	-1267	-1921	-2134	-1926
100% occurrence of Ts	-425	-580	-689	-76
			Sum	1770 S

Longshore Sediment Transport ('000 m³/yr m³/yr)	**R2**			
	T=8s (Occurrence of 34%)	**T=10s** (Occurrence of 30%)	**T=12s** (Occurrence of 32%)	**T=15s** (Occurrence of 4%)
Hs=0.5m (Occurrence of 17%)	-8	-16	-12	-13
Hs=1.5m (Occurrence of 61%)	902	1317	1493	1127
Hs=2.5m (Occurrence of 17%)	1720	2105	2119	1658
94.8% occurrence of Hs	2613	3406	3600	2773
100% occurrence of Ts	877	1028	1163	110
			sum	3178 N

Longshore Sediment Transport ('000 m³/yr m³/yr)	**R3**			
	T=8s (Occurrence of 34%)	**T=10s** (Occurrence of 30%)	**T=12s** (Occurrence of 32%)	**T=15s** (Occurrence of 4%)
Hs=0.5m (Occurrence of 17%)	-3	-7	-5	-6
Hs=1.5m	64	417	-13	74

Longshore Sediment Transport	R3			
(Occurrence of 61%)				
Hs=2.5m (Occurrence of 17%)	615	778	636	433
94.8% occurrence of Hs	677	1188	618	501
100% occurrence of Ts	227	358	200	20
			sum	805 N

Longshore Sediment Transport ('000 m³/yr m³/yr)	R4			
	T=8s (Occurrence of 34%)	T=10s (Occurrence of 30%)	T=12s (Occurrence of 32%)	T=15s (Occurrence of 4%)
Hs=0.5m (Occurrence of 17%)	-1	-3	-5	-6
Hs=1.5m (Occurrence of 61%)	-79	-210	-295	-334
Hs=2.5m (Occurrence of 17%)	168	-54	-62	-174
94.8% occurrence of Hs	88	-267	-361	-514
100% occurrence of Ts	30	-81	-117	-20
			sum	188 S

Longshore Sediment Transport ('000 m³/yr m³/yr)	R5			
	T=8s (Occurrence of 34%)	T=10s (Occurrence of 30%)	T=12s (Occurrence of 32%)	T=15s (Occurrence of 4%)
Hs=0.5m (Occurrence of 17%)	3	2	1	-0.5
Hs=1.5m (Occurrence of 61%)	98	32	-0.5	-54
Hs=2.5m (Occurrence of 17%)	304	155	147	-47
94.8% occurrence of Hs	405	188	147	102
100% occurrence of Ts	136	57	48	-4
			sum	236 N

**Positive value represents northward transport and negative value southward transport.*

A-2 *Estimated potential longshore sediment transport using Kamphuis expression in typical conditions*

Longshore Sediment Transport ('000 m^3/yr m^3/yr)	R1			
	T=8s (Occurrence of 34%)	T=10s (Occurrence of 30%)	T=12s (Occurrence of 32%)	T=15s (Occurrence of 4%)
Hs=0.5m (Occurrence of 17%)	-29	-55	-61	-88
Hs=1.5m (Occurrence of 61%)	-915	-1731	-2556	-3235
Hs=2.5m (Occurrence of 17%)	-257	-1035	-1441	-1884
94.8% occurrence of Hs	-1200	-2822	-4058	-5207
100% occurrence of Ts	-403	-851	-1311	-206
			sum	2771 S

Longshore Sediment Transport ('000 m^3/yr m^3/yr)	R2			
	T=8s (Occurrence of 34%)	T=10s (Occurrence of 30%)	T=12s (Occurrence of 32%)	T=15s (Occurrence of 4%)
Hs=0.5m (Occurrence of 17%)	-19	-44	-46	-68
Hs=1.5m (Occurrence of 61%)	923	1729	2543	2874
Hs=2.5m (Occurrence of 17%)	1129	1904	2573	2984
94.8% occurrence of Hs	2033	3588	5065	5790
100% occurrence of Ts	682	1083	1637	229
			sum	3631 N

Longshore Sediment Transport ('000 m^3/yr m^3/yr)	R3			
	T=8s (Occurrence of 34%)	T=10s (Occurrence of 30%)	T=12s (Occurrence of 32%)	T=15s (Occurrence of 4%)
Hs=0.5m (Occurrence of 17%)	-4	-17	-22	-36
Hs=1.5m (Occurrence of 61%)	189	670	172	431
Hs=2.5m	516	871	1000	1027

Longshore Sediment Transport	R3			
(Occurrence of 17%)				
94.8% occurrence of Hs	700	1524	1150	1423
100% occurrence of Ts	235	460	372	56
			sum	1123 N

Longshore Sediment Transport ('000 m³/yr m³/yr)	R4			
	T=8s (Occurrence of 34%)	T=10s (Occurrence of 30%)	T=12s (Occurrence of 32%)	T=15s (Occurrence of 4%)
Hs=0.5m (Occurrence of 17%)	-0.5	--8	-19	-35
Hs=1.5m (Occurrence of 61%)	-54	-296	-654	-1160
Hs=2.5m (Occurrence of 17%)	229	81	51	-261
94.8% occurrence of Hs	174	-223	-622	-1455
100% occurrence of Ts	59	-67	-201	-58
			sum	267 S

Longshore Sediment Transport ('000 m³/yr m³/yr)	R5			
	T=8s (Occurrence of 34%)	T=10s (Occurrence of 30%)	T=12s (Occurrence of 32%)	T=15s (Occurrence of 4%)
Hs=0.5m (Occurrence of 17%)	7	7	8	3
Hs=1.5m (Occurrence of 61%)	164	143	125	-23
Hs=2.5m (Occurrence of 17%)	305	287	363	69
94.8% occurrence of Hs	476	437	496	50
100% occurrence of Ts	160	132	160	2
			sum	454 N

**Positive value represents northward transport and negative value southward transport.*

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