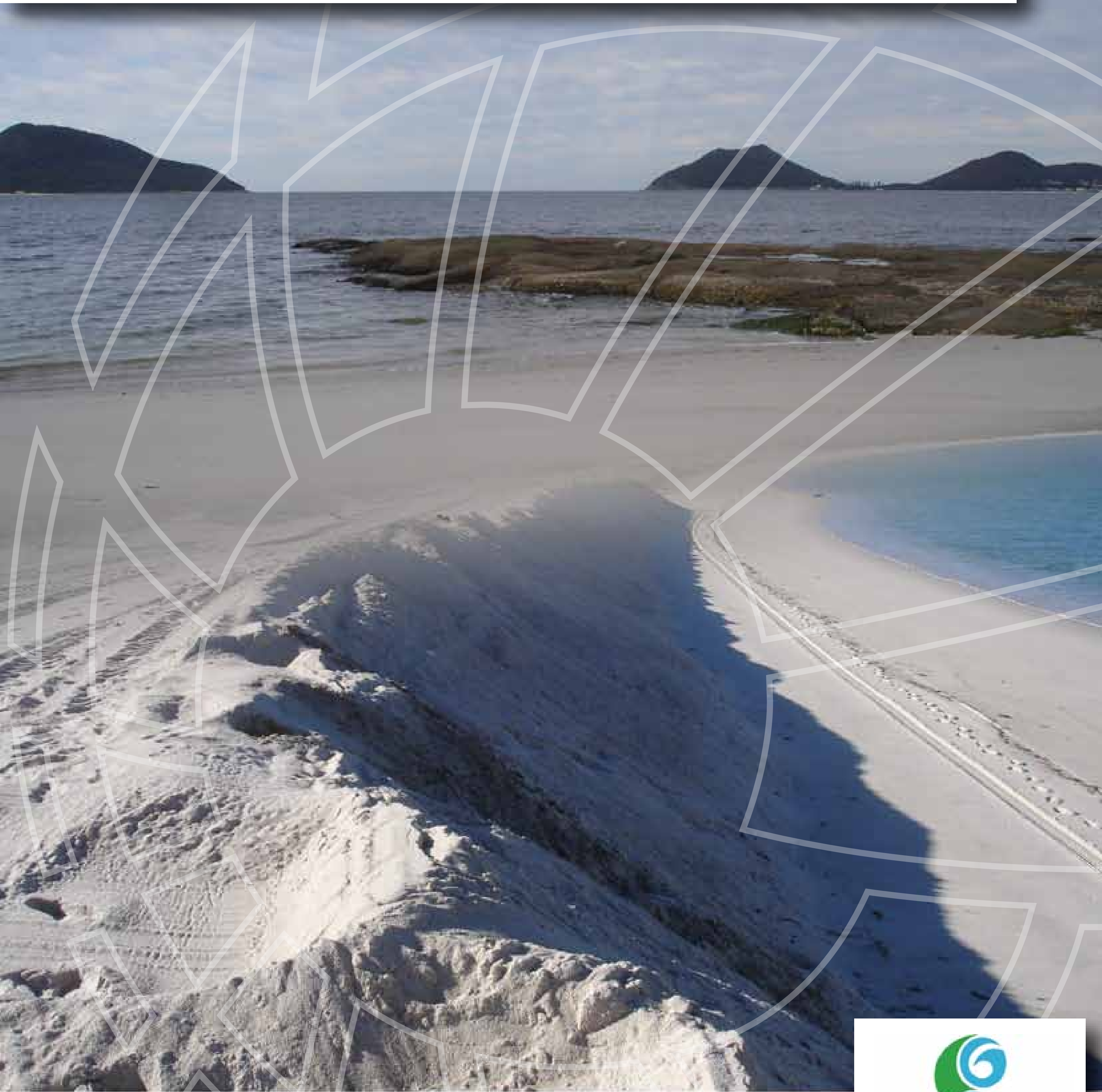
“Where will our knowledge take you?”

Jimmys Beach Sand Nourishment Assessment

Final Report November 2012



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Jimmys Beach Sand Nourishment Assessment

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Title :	Jimmys Beach Sand Nourishment Assessment
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Synopsis :	This document provides a technical review of past coastal processes assessments of Jimmys Beach, which is complemented by new numerical analysis of longshore sediment transport, as well as hydrodynamic and sediment dynamic modelling to provide an updated investigation of impacts of sediment transport and accumulation. Based on these findings, recommendations are provided for sourcing and placement of nourishment sand to manage on-going erosion and recession along the shoreline.

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EXECUTIVE SUMMARY

History of Erosion and Nourishment at Jimmys Beach

Jimmys Beach has a long history of erosion that pre-dates the residential development established during the 1970s. There are about 150 houses located along the Winda Woppa peninsula. Jimmys Beach is a current 'hot spot' for coastal erosion in NSW, and it is prone to further shoreline recession due to future sea level rise (potentially impacting directly on all existing properties on the peninsula).

Prompted by a major erosion event in 1983, emergency sand nourishment of Jimmys Beach was first carried out in 1984, which then continued about every 3 years up to 1998. Following a 10 year gap wherein only emergency works were carried out, major beach nourishment recommenced in 2008 and has been continuing annually since then.

Processes Causing Beach Erosion and Sand Accumulation

The coastal sediment processes along Jimmys Beach are very complex. Sand eroded from the main erosion zone (along The Boulevard between Kururma Cres and Germalia St) may be transported westward, eastward and offshore, depending on the prevailing meteorological conditions (including wind and swell patterns). Further investigations, including field testing, are required to confirm pathways for eroded sediment.

Erosion may be exaggerated immediately after placement of large volumes of sand onto the beach face, because the beach profile is essentially not in a natural shape. Smaller and more frequent nourishment campaigns are therefore considered to be more effective at Jimmys Beach.

The on-going extension of the Winda Woppa spit into the Lower Myall River Eastern Channel is not specifically related to recent sand nourishment on Jimmys Beach. Similarly, the Yacaaba sandwave is also not specifically related to sand nourishment, as its formation pre-dates the most recent nourishment and indeed a similar large sandwave on the Yacaaba isthmus has been noted in historical boating charts between 1850 and 1910.

Options for Sand Sourcing

The most suitable sources for sand for on-going nourishment are the terrestrial sand reserves at the Winda Woppa sand spit and the Yacaaba sandwave. There is considerably more sand available at the Winda Woppa sand spit, so this location is preferred.

Sourcing of sand via a dredger (e.g. within the Eastern Channel or at the Yacaaba sandwave) is considered to be a relatively ineffective and costly alternative compared to land-based excavation of terrestrial sand.

Options for Sand Transport and Placement

In the short-term, sand can continue to be trucked from Winda Woppa sand spit and end-dumped directly onto the beach, which is then reprofiled to suit. Trucking would need to be mindful of impacts on the local community and damage to public roadways. Trucking from the Yacaaba Sandwave would be more problematic than Winda Woppa as the route along the eastern shoreline is more environmentally sensitive and is actively used by the community for walking, fishing, 4WD-ing etc.

A more permanent nourishment program would consist of a hopper at the sand source which mixes the material with seawater and pumps it directly to the erosion hotspot. Depending on the rate of discharge, small settlement ponds may be required on the beach to prevent excessive turbidity plumes in the adjacent Marine Park and seagrass meadows.

Recommended Nourishment Program

Trial Nourishment

It is recommended that a trial program of manual loading and trucking from the Winda Woppa sand spit is implemented, with operations occurring at least 4 times per year (of about 5,000m^3 each, which is about half the volume moved during June 2012 emergency nourishment works). The trial period would allow for refinement of operations and also confirmation that Winda Woppa is the most appropriate sand source.

Long-term Program

If trucking is not viable for the long-term, then significant capital investment will be required to reduce the on-going operational costs. On-demand pumping of sand is more cost effective, so a hopper (or possibly a Sand Shifter, subject to further investigations) should be pursued.

Any future nourishment program that differs from the existing approval conditions (comprising dredging from the Yacaaba sandwave) will need to be assessed for impacts and all relevant consents obtained.

On-going Monitoring and Investigations

A trial nourishment program will enable further monitoring and investigations to be carried out to support and validate proposed long-term solutions for Jimmys Beach. This would include detailed beach profile surveys, a sediment tracer study, and further numerical analysis on beach response to erosion and long term recession (including potential for sea level rise impacts).

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PART A – BEACH NOURISHMENT FEASIBILITY ASSESSMENT

1 INTRODUCTION

1.1 Jimmys Beach Locality

Jimmys Beach is located on the northern foreshore of Port Stephens immediately west of the northern entrance headland, known as Yacaaba Headland. Yacaaba Headland is connected to the mainland via a narrow sandy isthmus, with the eastern portion of Jimmys Beach on the estuary side, and the southern end of Bennetts Beach (Hawks Nest Beach) on the ocean side of the isthmus. A locality map of Jimmys Beach is presented in Figure 1-1.

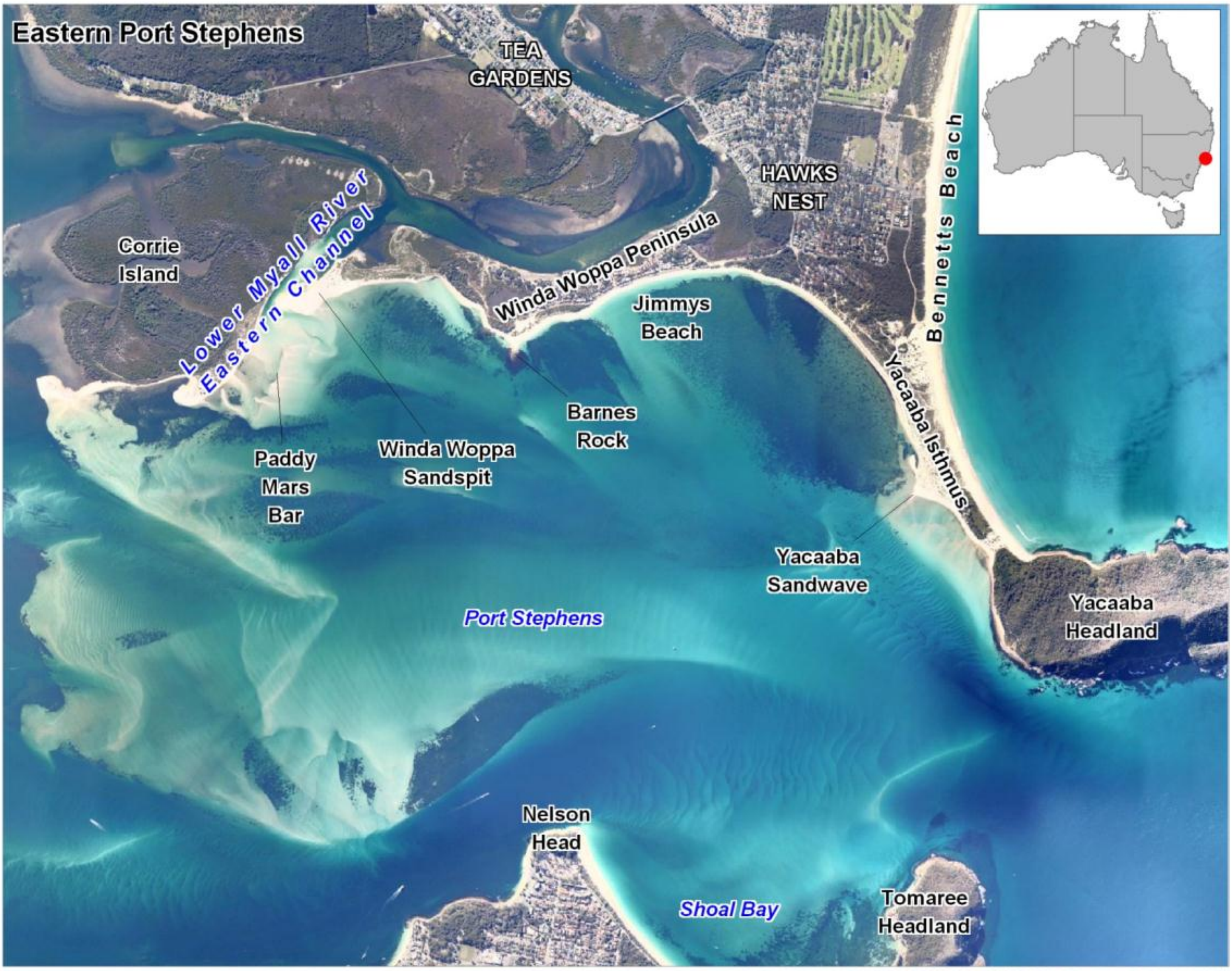
From Yacaaba Headland, Jimmys Beach extends westward along the Winda Woppa peninsula. The distance between Yacaaba Headland and Barnes Rock, at the western end of the beach, is approximately 4km. Jimmys Beach has a well documented history of erosion, and is regarded as one of NSW's erosion hotspots. The main assets at risk at Jimmys Beach include a public roadway, and residential development that was established during the 1970s (approximately 150 houses have been built on the peninsula). Modelling by SMEC (in prep.) suggests that all of these properties are at risk of being lost to erosion within a 100 year timeframe, when considering both storms and sea level rise impacts.

Winda Woppa peninsula extends west of Barnes Rock for a distance of approximately 1.5km, terminating at the eastern channel of the Lower Myall River entrance. The eastern channel is a highly dynamic environment where sediment is reworked readily under the influence of waves, tides and flood currents. The dynamism of the eastern channel and its growing propensity for closure has prompted concerns from the local community regarding navigability and reduced flushing potential within the Lower Myall River. A task group has been established by the State Government to advise on the issues associated with erosion of Jimmys Beach and the on-going sedimentation of the Lower Myall River entrance. This report has been prepared on behalf of Great Lakes Council and the NSW State Government to assist the task group in recommending appropriate future management measures for Jimmys Beach and the Lower Myall River.

1.2 Erosion of Jimmys Beach

The issue of erosion at Jimmys Beach has been studied extensively since the early 1980s. Prompted by a major erosion event in 1983, emergency sand nourishment of Jimmys Beach was first carried out in 1984 and 1985, whilst at the same time a detailed scientific study (PWD, 1987) and a management options study (GLSC & PWD, 1985) were undertaken. The outcomes from these studies lead to further sand nourishment (1988, 1992, 1995, 1998) before a second major coastal processes study was commissioned (MHL, 2000), which outlined a more long-term solution to the on-going erosion.

In addition to these management-oriented studies, beach profiles of Jimmys Beach have been monitored at various times over the past 20 years to determine the effectiveness of the nourishment works and to establish the fate of the nourished material (Watson, 1997, 1999, 2000). Research studies of coastal processes along Jimmys Beach have also been conducted by the University of Sydney's School of Geosciences (Cholinski, 2004; Vila-Concejo *et al*., 2007, 2009, 2010, 2011; Jiang *et al*., 2011).



Title:

Study Locality

Figure: **1-1**

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BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Approx. Scale

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1.3 Yacaaba Sandwave

Of particular interest to researchers has been the 'sandwave' that is intermittently present adjacent to the Yacaaba isthmus (refer Figure 1-2). Since the 1980s, the sandwave has progressively increased in volume, while compared to surveys in from the 1960s, the isthmus has also widened through accretion along the shoreline on the western (Port Stephens) side. Historical mapping, including surveys that extend back to the late 18th century (as documented in PWD, 1987) show that a sandwave on the Yacaaba isthmus is actually a transient feature, which was generally observed from about 1850 to 1910, then largely absent between 1920 and 1980.

Figure 1-2 The Yacaaba isthmus, shoreline sandwave and shallow nearshore shoals, c. 1997 (photo courtesy Aust. Dept. of Defence)

1.4 Record of Beach Nourishment

Table 1-1 outlines the major nourishment campaigns that have occurred on Jimmys Beach. It is expected that other unrecorded emergency nourishment works have also been carried out over the past 30 years or so, particularly immediately after severe storm events that have caused large storm bite along Jimmys Beach. The vast majority of nourishment has been placed on the shoreline beside The Boulevard between Kururma Crescent and Guya Street (refer Figure 1-1).

Table 1-1 Record of Jimmys Beach Nourishment Campaigns (adapted from MHL, 2000)

Year	Nourishment Volume (m^3)	Source
1967		Artificial beach widening, by lowering backbeach dunes and pushing sand seaward, during residential development of Winda Woppa peninsula.
1984	43,000	Corrie Channel(1) (initiated as interim emergency works following large storms and erosion in 1983)
1985	20,000	Corrie Channel(1)
1988	80,000	Corrie Channel(1)
1992	47,000	Corrie Channel(1)
1995	69,000(2)	Corrie Channel(1)
1998	100,000	Corrie Channel(1)
1999 - 2007	?	Several rounds of emergency works, typically 3,000 – 8,000m^3/yr, taken from Deadmans sand dune
Oct 2008	51,500	Yacaaba sandwave
Aug 2009	32,500	Yacaaba sandwave
Nov-Dec 2010	23,000	Yacaaba sandwave
June 2011	5,000	Deadmans sand dune (emergency works)
June 2012	9,000	Deadmans sand dune (emergency works)
	480,000+ m^3	*TOTAL TO DATE (recorded)*

(1) In the context of MHL (2000), Corrie Channel is the Eastern Channel of the Lower Myall River
(2) (a volume of 80,000m^3 is reported in Watson, 2000)

It is anticipated that the substantial and irregular nourishment of only a portion of the Jimmys Beach shoreline places the beach morphology into a temporary imbalanced state. Fine scale coastal processes are expected to rework a proportion of this material under the influence of currents and wave-induced sediment entrainment.

1.5 Summary of Coastal and Sediment Transport Processes

As indicated above, coastal dynamics and longshore sediment transport processes have been investigated previously by numerous authors. As part of this study, a detailed review of these previously investigations has been undertaken, which has been complemented with numerical hydrodynamic modelling, wave propagation modelling and longshore transport calculations, as well as interpretation of historical and current ortho-rectified aerial photographs and Marine LiDAR survey. This supporting technical review and assessment is documented in Part B of this report.

The review confirms that sediment dynamics along Jimmys Beach is complex – indeed it is likely to be much more complex that previously realised. The area between Kururma Crescent and Germalia St received the highest swell wave energy, and is the most susceptible to erosion. Sand lost from this section of the shoreline has the potential to be reworked offshore, as well as both westward and eastward along the shoreline.

In the context of this beach nourishment investigation, there are no firm conclusions regarding the fate of sand eroded from the beach, and thus an adaptive and pragmatic approach should be taken for sourcing of beach nourishment to ensure long-term sustainability of sand resources.

The investigations also conclude that nourishment should involve smaller and more frequent campaigns to avoid out-of-equilibrium beach alignments that promote rapid erosion to return to a more natural alignment. Based on historical rates of erosion and accretion, the ideal nourishment strategy would involve placement of approximately 10,000m^3 of sand onto the main erosion zone of Jimmys Beach every 6 months

1.6 Scope of Works

Part A of this report focuses on providing relevant information on the engineering feasibility and practical options for sourcing sand, transporting sand, and placing sand as part of a program of future on-going nourishment at Jimmys Beach. An assessment of options is carried out taking into consideration the environmental, social and economic implications of the more feasible nourishment alternatives. Part A concludes with recommendations on which options are considered most practical and cost-effective given our improved understanding of sediment transport processes along the beach.

Part B of this report provides a desktop technical review and analysis of information for the purposes of determining coastal sediment processes that potentially affect the long-term suitability of sand nourishment options at Jimmys Beach. No fieldwork was carried out to support the findings of the desktop review. A series of further investigations and monitoring is recommended as part of the on-going nourishment program (refer Section 4.4) to confirm the assumed coastal processes that have underpinned the overall nourishment feasibility assessment.

2 METHODS OF BEACH NOURISHMENT

This chapter was prepared with a significant contribution from BMT JFA, specialist dredging consultants.

The available methods for undertaking beach nourishment can be broadly divided into three categories:

- Land Based Plant (Excavate and Truck);
- Floating Plant (Dredge) and hydraulic transport; and
- Land based / Fixed Hydraulic (Pump).

The key aspects of these options are described in the following sub-sections below.

2.1 Land Based Plant

Beach renourishment operations are often undertaken using only conventional land based earthmoving equipment. The general methodology for these types of beach nourishment operations is:

- Excavate sand from beach and stockpile for drainage;
- Load sand into trucks and transport to nourishment area; and
- Spread sand over beach 'nourishing' the area as required.

This type of operation would typically consist of an excavator (possibly a longreach) excavating sand and then stockpiling of this material temporarily on the beach. A front end loader may be used to transport this material to a suitable temporary stockpile area to allow the sand to dry out if it is sourced from the intertidal or sub-aqueous profile of the beach. The front end loader would then transfer the stockpiled material into haulage trucks. The haulage trucks then transport the material to the renourishment site. Other machinery (e.g. another front end loader) is then generally required to level and profile the material dumped by the haulage trucks so that this material can be formed into the preferred beach profile.

It should be noted that the haulage operations can be undertaken using road licensed trucks or off-road plant (e.g. 4WD, rubber tyre / balloon tyre dump trucks). The main determinants of this haulage operation selection are:

- The distance between the material source and the nourishment site;
- The existing infrastructure between the sites;
- The degree to which these beaches and infrastructure is used by the public; and
- The ability of licensed trucks to access the beach without getting bogged.

Should road trucks be favoured as the preferred haulage option, temporary tracks on the beach may need to be created to facilitate beach access. Road trucks, however, have the potential to damage roads, depending on the initial condition of the roads, the number of loads moved and the degree of articulation of the trucks on the road. Should off-road trucks be used along the beach, careful consideration needs to be given the migratory birds and the limitations in access due to sea conditions (tides, wave run-up etc).

The main *advantages* of using this Land Based Plant methodology to undertake beach nourishment operations are as follows:

- Offers a very quick response time (i.e. plant can be easily and promptly mobilised and demobilised when required, although off-road trucks may be harder to source than normal road trucks). This results in these type of renourishment operations being most suitable when undertaking ‘emergency’ works in response to severe erosion event;
- Mobilisation/demobilisation operations are relatively economical, compared to mobilising specialised plant, particularly to remote locations (possibly with the exception of off-road trucks);
- Less weather/seastate dependent compared to other operations (assuming the excavator can readily access the sand supply from land), although access along the beach for off-road trucks may be limited to the state of the tide; and
- Can be cost competitive for small projects.

The main *disadvantages* of using this Land Based Plant methodology to undertake beach nourishment operations are as follows;

- This method can only be applied in situations where the replenishment material can be accessed from land. This is because the plant can only operate in shallow water or close to the shore. Furthermore, trafficability of the beach may limit plant type and access;
- Can be unpopular with the general public (particularly through developed areas). This is because these operations can:
  - Result in high truck/plant traffic volumes that restricts/disrupts beach access;
  - Cause unacceptable noise levels (the noise from the heavy plant and trucks may mean operations may be limited to ‘normal’ working hours if near residential properties);
  - Exhaust diesel emissions from the heavy truck/plant operating on a beach is perceived as unsightly; and
  - Result in an increased chance of sand being lost, accidents occurring and damage occurring on public roads.

  For these reasons generally the use of the Land Based Plant methodology may not be favoured by the local community for ongoing recurrent works;
- Production can be low when compared to alternative pumping methods, at about 75m^3/hr; and
- Determining an appropriate production based method of payment can be difficult with wrack and sand mixture.

This nourishment option has been favoured in remote nearshore transport applications. Such previous projects to utilise this method include:

- Lancelin, Western Australia (~ 10,000m^3/yr);
- Collaroy-Narrabeen, New South Wales (~50,000m^3 every 3 years or so); and

- Geraldton, Western Australia (~ 12,000m^3/yr).

Photographs showing working examples of this Land Based Plant methodology in operation are shown in Figure 2-1.

Figure 2-1 Land Based Plant methodology being used to excavate and haul material in Lancelin, Western Australia

2.2 Floating Plant

There are two basic types of floating plant suitable for beach nourishment works, a Cutter Suction Dredger (CSD) or a Trailing Suction Hopper Dredger (TSHD). The selection is generally dependent on the sand source location and the proximity to the renourishment location.

2.2.1 Cutter Suction Dredger

A small Cutter Suction Dredger (CSD) is an effective and efficient method to source sand from the sea floor. As such this method has been used at many of the small ports and beach renourishment projects across Australia. The general methodology for these types of beach nourishment operations is:

- The CSD and associated equipment is transported to site (usually by road for this scale of work);
- CSD is placed in the water and is connected up to a delivery pipeline leading to the disposal site. This pipeline can be floating, submerged, along the shore or any other combination;
- The cutter head and suction mouth is lowered to the seabed;
- The cutter head is rotated and is directly linked to the suction intake which with support of associated machinery, pumps the materials through the pipeline to the disposal site; and
- Anchors connected to the CSD and spuds on the CSD are adjusted allowing the cutter head to operate at the work face to continually recover materials.

The suction pipe on a small CSD is generally of the order of 250/350 mm diameter, and is capable of accommodating the occasional debris / rocks in the sandflow up to a maximum size in of the order of 100-150mm. Production rates for fine sand are higher than coarser material, providing that it is not too compact with a high fines content. Typical production rates for small CSDs are about 100m^3/hr. Small CSDs can work in water depths of up to approximately 13m.

As small CSDs are generally just motorised barges with specialist equipment on board, they do not handle rough sea conditions, and generally need to unhitch and take shelter during storms.

The main *advantages* of using a CSD methodology to undertake beach nourishment operations are as follows:

- Operations are mobile enabling multiple work areas to be established. Likewise the dredger can be easily moved around the working areas;
- The dredgers can easily extract materials on the seabed that conventional land based plant would not be able to access effectively;
- Reduces the need for heavy land based equipment to operate on the beaches areas that can be readily accessed and used by the public;
- This work is generally conducted by a Contractor that is experienced in regularly undertaking similar sourcing and nourishment operations. This allows them to offer additional skills and expertise in completing the works; and
- Allows the potential for more risk to be transferred on the Contractor through a lump sum or similar contract arrangement. This is because the Contractor has more control and thus is in a better position to manage the risk aspects such as production rates, turbidity, material suitability etc.

The main *disadvantages* of using CSD methodology to undertake beach nourishment operations are as follows:

- Dredgers (especially small CSDs) are susceptible to local wave climate and thus are reliant on suitable wave and swell conditions. The actual limitations are dependent on the specifications and in particular the size of the dredger;
- Dredgers have the potential to create turbidity plumes at the dredge head, depending on the proportion of fine material within the sediment being dredged;
- The mobilisation and de-mobilisation costs can be high. This is especially the case for CSD's that are not "road transportable";
- A competitive quote is heavily dependent on there being a choice of suitable dredgers available at the time required. The fluctuating availability of dredgers and thus costs associated with undertaking these works can make it difficult to plan and accurately budget for the works; and
- Is considered to have the higher unit operating costs compared to alternative pumping methods where low quantities are involved.

This nourishment option has been favoured when the sand source has been in small boat harbours and river entrances that cannot be easily accessed by conventional Land Based Plant. Such operations have allowed both beach nourishment and maintenance dredging operations to be undertaken simultaneously. Such previous projects to utilise this methodology include;

- Tweed River, Northern NSW (about 30,000 – 100,000m^3 per campaign);
- Swansea Channel, Lake Macquarie, NSW (about 30,000 – 50,000m^3 per campaign);
- Jimmys Beach, NSW (refer Table 1-1);

- Kalbarri, Western Australia;
- Carnarvon, Western Australia; and
- Onslow, Western Australia.

Photographs showing working examples of this Floating Plant methodology in operation are shown in Figure 2-2. Great Lakes Council (pers comm David Bortfeld) estimates that 30,000m^3 can be dredged in a single campaign for a cost of around $700,000, with no long term liabilities other and the contract costs for delivery.

Figure 2-2 Floating Plant methodology being used to dredge material with a small CSD and being discharged directly onto the beach north of the Murchison River mouth, Kalbarri, Western Australia.

2.2.2 Trailing Suction Hopper Dredger

A Trailing Suction Hopper Dredge (TSHD) provides a versatile method that sources sand from the sea floor. A TSHD is a self propelled powered vessel that can deliver production rates of up to about 700m^3/hr. The general methodology for these types of beach nourishment operations is:

- The TSHD is sailed to site with any associated required support equipment transported to site (usually by road);
- TSHD sails to the area where the material is to be removed;
- One or more suction pipes (pick-up arms) are lowered to the seabed;
- Suction is provided by a pump which sucks a material from the seabed through the draghead (lower end of suction pipe) into a hopper within the hull;
- The TSHD then discharges the material from the hopper to the disposal site. These discharge operations may occur through either:
  - Split hull or bottom door opening over a subaqueous disposal site;
  - Pumping out the material through a pipeline direct to an onshore or offshore the disposal site (ship must be stationary); or

- o 'Rainbowing' the material directly onto a beach/shoreline by pumping it through a nozzle directly over the bow of the vessel.

In these operations, the loading process sees the hopper being progressively filled and the excess water and finer particles of material flowing out of the hopper into the surrounding water causing turbidity. The extent of turbidity is a function of the material type being dredged. Discharge of sand slurry directly on the beach (through pumping or rainbowing) would also potentially cause turbidity within the nearshore zone, especially if the sand mix contains organics. It is expected that the beach would need to be configured into a series of small settling ponds, separated by bunding, in order to reduce turbidity in the adjacent Marine Park zone. This has been adopted previously and meets EPA and Marine Park requirements for turbidity.

TSHDs are not as readily available as small CSDs, and their mobilisation/demobilisation costs can be prohibitively high depending on the balance between the distance the dredge has to sail to mobilise to the dredge site and the actual size of the job. As such, they tend to be used for large-scale offshore dredging operations.

For Jimmys Beach nourishment, the proposed relatively low quantities and the availability of sand from shallow nearshore areas (which are mostly out of reach of a TSHD) means that a TSHD is not considered an appropriate piece of plant.

2.3 Hydraulic

There are several systems available for beach nourishment works that are primarily hydraulic in nature. For simplicity these have been divided into the two categories being the onshore pumping unit and offshore pumping unit.

2.3.1 Onshore Pumping Unit

Onshore pumping units have been considered as those which generally require support machinery in the way of conventional earthmoving equipment to source the material. The onshore pumping units generally consist of an integrated slurry pump and hopper unit. The general methodology for these types of beach nourishment operations is:

- Conventional earthmoving equipment is used to excavate the renourishment material from the source location and feed excavated material into a hopper on the unit;
- The hopper is generally fitted with a screen/shredder that then removes debris, oversize rocks and seagrass wrack from the sand or reduces these to manageable sizes;
- The unit mixes the sand with water (from a separate water supply pump) to form a slurry; and
- The slurry is pumped through a pipeline (with booster pumps if required) to the renourishment site.

It should be noted that the units can be either tracked or fixed in place (located either above ground or mostly buried) and have production rates of about 75m^3/hr.

Tracked hopper units such as the *Slurrytrak* (CGC Dredging) enable it to traverse the beach under its own power to the location where excavation of material is being undertaken (see Figure 2-3). While the mobility of the hopper means it can track across rough or boggy terrain where regular trucking plant would be limited and be repositioned to minimise distance to the source material, it is most efficient when continual movement of the hopper is minimised.

Alternatively, the hopper unit may be fixed in one place only (and moved by other equipment, e.g. cranes, if required). Due to such requirements, it is more conventional to transport the material to the fixed hopper unit using earthmoving equipment, such as dozers, front end loaders and trucks (depending on distance to be transported). Fixed units may be connected to mains power, which would provide considerable operational cost savings.

Hopper-based onshore pumping units are most suited when working adjacent to a continuous sand trapping structure (e.g. groyne) or where there is a large stockpile of material on the shoreline.

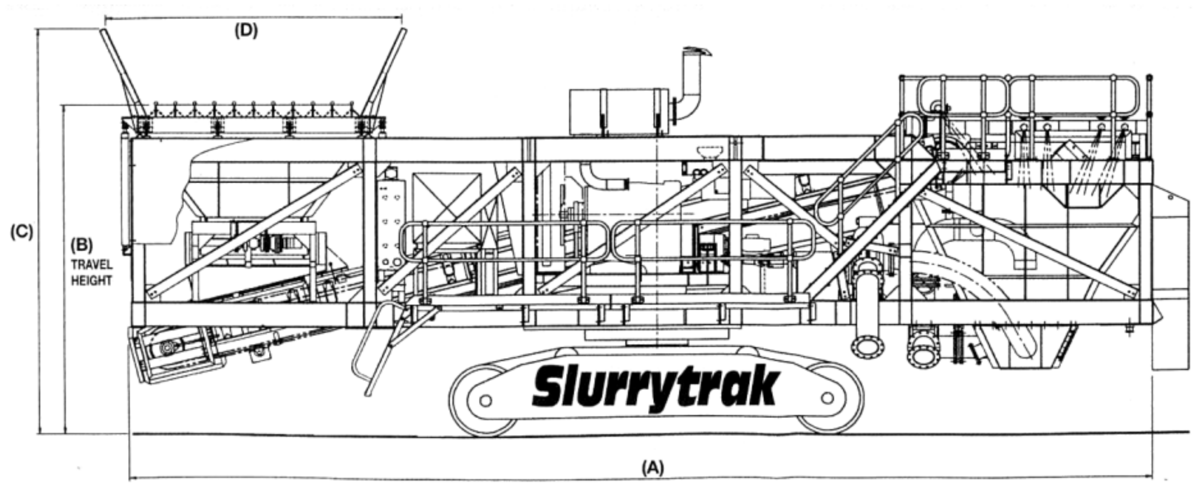


Figure 2-3 ***Slurrytrak*, a tracked mobile pumping unit (Source: CGC Dredging)**

The main *advantages* of using on-shore pumping units to undertake beach nourishment operations are as follows:

- Favoured when there is a large obstruction prevent trucking (e.g. harbour, inlet, public amenity, environmental constraints) but allows a pipe to more easily be directly discharged to this location;
- Traditional earthmoving equipment can be used to source the sand and fill the hopper;
- The screen/shredder activity of the hopper reduces the chances of blockages occurring in the system; and
- Equipment can be moved to where the greatest volumes of sand are available, and not necessarily limited to natural processes to bring sand to the exaction / removal site.

The main *disadvantages* of using on-shore pumping units to undertake beach nourishment operations are as follows:

- This method can only be applied in situations where the replenishment material can be accessed from land. This is because land based plant is still required to supply material to the hopper;
- Both the hopper and the earth moving equipment supplying the hopper (excavator) generates noise and disrupts to beach users at the material sourcing location; and

- As debris and seagrass wrack is separated from the sand to be bypassed, consideration must be given to methods to manage the collection and accumulation of these substances.

Specific examples of such previous projects to utilise this mobile pumping unit methodology include:

- Dawesville, Western Australia (see Figure 2-6) (~ 100,000m^3/yr);
- Mandurah, Western Australia (~ 100,000m^3/yr); and
- Port Geographe, Western Australia.

Figure 2-4 A tracked mobile pumping unit operating in Dawesville, Western Australia.

2.3.2 Offshore Pumping Unit

For the purposes of this assessment and for comparative purposes, offshore pumping units have been considered as those which do not require conventional earthmoving equipment to source the material. The two common types of offshore pumping units are Jet Pumps and Sand Shifters.

2.3.2.1 Jet Pumps

Jet pumps are hydraulically powered pumps with no moving parts at the sand source that rely on the exchange of momentum to do work. A stream of high-velocity clear water from a supply pump is forced through the nozzle. On exiting the nozzle, the high-velocity jet entrains the surrounding fluid and forces the mixture through the mixing chamber into the diffuser, where velocities slow and pressure energy is recovered. This movement of the fluid into the diffuser creates a negative pressure, inducing flow into the suction opening. When the suction opening is buried in the sand, a slurry of sand and water is drawn into the jet pump.

Jet pumps frequently include fluidisers that inject clear water into the seabed to create a slurry of sand. These fluidisers may allow more efficient operation of the jet pump by making it easier for the slurry to be drawn into the jet pump suction inlet. The fluidisers also allow for easier deployment and removal of jet pump from the seabed. A typical jet pump arrangement is shown in Figure 2-5.

Jet pumps are typically used to form a crater(s) in the seabed that intercepts the littoral drift. Jet pumps should readily be available to be lowered, raised and retrieved as required for maintenance. Proven modes of jet pump operation have generally seen the jet pump being attached to an existing supporting fixed marine structure such as a jetty. Being attached to such a structure has allowed the jet pump pipelines to be less susceptible to damage by wave action and has also allowed material collection to occur in deeper water. Should no supporting fixed marine structure be in place, a crane (or similar) operating from shore is required to collect material from the nearshore region. Such alternative nearshore operations can contribute a significant cost to the scheme, particularly if located in active wave climates when the jet pump is more susceptible to damage.

Various fixed jet pumping units have been used both nationally and internationally. Examples of jet pumps include:

- Nerang River, Queensland (~500,000m^3/yr);
- Tweed River, New South Wales (~500,000m^3/yr); and
- Oceanside Harbour, California, USA.

For Jimmys Beach nourishment, there is no existing fixture marine infrastructure, and it is not proposed to construct any purpose-built structures. As such, offshore jet pumps are not considered an appropriate approach.

Figure 2-5 Typical jet pump configuration (Source: Slurry Systems Marine)

2.3.2.2 Sand Shifter

The Sand Shifter is a proprietary system developed by Slurry Systems Marine Pty Ltd. The Sand Shifter unit is a single structure that acts as an offshore sand recovery and transport system (see Figure 2-6). The unit is based on a fluidising principle that allows sand to be recovered from below the seabed. The fluidising system on the Sand Shifter comprises of a fluidising pipe below an inverted channel and barrier that both traps and creates a sand-water slurry. The principle is that the slurry is less dense than the surrounding material and so is displaced by this surrounding material and is forced up into the inverted channel. Once contained in the inverted channel the slurry is then pumped along a pipeline to the disposal site (with additional booster pumps onshore as required).

Figure 2-6 Typical Sand Shifter unit configuration (Source: Slurry Systems Marine)

As the sand shifter removes sand from the recovery location, it becomes self burying and can be buried up to 8m deep. As this burying occurs a basin, or ‘crater’, forms around the buried unit, thereby attracting sand deposition under the influence of waves and tidal current, which increases the efficiency of the unit.

Generally the Sand Shifter units are installed in a configuration parallel to the shore because the onshore-offshore sediment transport through wave and storm action is generally considered greater than the longshore sediment transport. It is believed that sand transport volumes in the order of approximately 20,000m^3/annum would be within this unit’s typical operating range, and is similar to the operations at the Noosa River, Qld.

One consideration that needs to be taken into account with the Sand Shifter, is that the fluidising jets and other components of the unit are prone to marine growth, potentially causing blockages. Thus the unit may need to be recovered on a periodic basis for maintenance, which may require access by a crane or similar.

The main *advantages* of using a Sand Shifter to undertake beach nourishment operations are as follows:

- System is well suited to material collection close to the shoreline (Sand Shifter) where it can be easily maintained;
- If the sand material to be sourced is suitable (fine grained, clean sand material with minimal presence of contaminants such as seagrass wrack, wooden debris etc.), then it will have relatively low running ongoing costs;
- It is often a favoured option by the public. This is because operations are quiet, sourcing the material does not cause turbidity and has a minimal disruption to beach users as there is no requirement to close sections of beach;
- The systems are capable of operating under the majority of wave and swell conditions;
- Nourishment operations can be undertaken on a regular basis throughout the year. This prevents a large build up of sand at the source site and reduces the likelihood of 'emergency' renourishment works being required;
- Nourishment operations can be scheduled to occur only at night to minimise the visual impact of these operations at the disposal site; and
- Operations can be automated with limited operator input.

The main *disadvantages* of using a Sand Shifter to undertake beach nourishment operations are as follows:

- Can become blocked and can be very costly to remove blockage. This is most likely in areas that are subject to large amounts of seagrass wrack, wooden debris etc. It is expected that overall maintenance costs would be much higher if blockage was regular;
- A relatively high capital cost;
- Operations result in a crater being formed at the source location – potentially impacting beach amenity and possibly safety; and
- The production is dependent on the natural sediment transport to bring sand to the unit (i.e. production cannot quickly and easily be increased significantly).

Photographs showing a working example of a sand shifter unit in operation are shown in Figure 2-7.

Figure 2-7 Sand shifter unit sourcing materials from the shore (left) with the associated onshore booster pumps and pipework (right) operating in Noosa , Queensland. (Source: Slurry Systems Marine)

Specific examples of previous projects to utilise the Sand Shifter methodology include:

- Noosa, Queensland (~20,000m^3/yr); and
- Port of Portland, Victoria.

2.4 Application of Methodology to Jimmys Beach

2.4.1 Selection Criteria

In considering the most appropriate method for beach renourishment at Jimmys Beach, the following key selection criteria for the system was considered:

- Needs to deliver a smaller quantity of sand to Jimmys Beach on a more regular basis. From historical analysis, the ideal nourishment program would likely involve approximately 10,000m^3 placed on Jimmys Beach every 6 months (20,000m^3/annum);
- Needs to minimise any potential detrimental impacts to the environment;
- Should minimise impacts to public infrastructure, including roads;
- Should minimise disruption and impacts to public amenity and beach access;
- Should be a cost effective solution, such that it has relatively easy maintenance and low ongoing operational costs;
- Should be able to respond and undertake works following storm events when ‘emergency’ renourishment works may be required;
- Should be robust and reliable such that it is not be susceptible to malfunctions, blockages or downtime due adverse weather / seastate conditions;
- Should be as autonomous as possible, reducing the requirements for human management and operator input as best as possible; and
- Should ideally have the flexibility to source material and deliver material from more than one location.

2.4.2 Material Collection

The two sand material sourcing options available are the accretion areas of the Myall River Entrance and the Yacaaba sandwave. It is understood that from a sedimentary perspective both source sites are equally suitable as renourishment material for Jimmys Beach, and both locations have been used in the past to source nourishment material (i.e. Lower Myall River in the 1980s and 1990s; Yacaaba sandwave 2007 – 2011).

The Myall River is known to be very dynamic with high velocity tidal flows (and hence high sediment mobility). High sediment mobility makes material sourcing using offshore pumping units more effective. Yacaaba sandwave is also quite dynamic as it is influenced by the effect of ocean swell waves entering Port Stephens.

It is not clear how much seagrass wrack or wooden debris exists at either of the Myall River Entrance and Yacaaba sandwave. Extensive beds of seagrass are located in close proximity to both the Myall River Entrance and Yacaaba sandwave. Meanwhile, flooding in the Myall River is expected to deliver debris and organic material from the extensive Myall Lakes system, with high flows lasting for many weeks to months following a flood event.

It is unlikely that rocks or bedrock are located in the Myall River Entrance, however, rocks have been reported at relatively shallow depths beneath the Yacaaba sandwave by previous dredging contractors. The depth and extent of this rocky section at Yacaaba is unknown.

Both source locations are in relatively protected locations. For more recent dredging campaigns, dredgers have cut a shelter into the northern side of the Yacaaba sandwave, offering protection against the effects of waves and sea-state.

Dredging carried out in the 1980s and 1990s was undertaken in the Myall River Entrance by CSD. Initially the dredging campaigns attracted quite a few tenderers, however, the dredging contractors found conditions difficult (e.g. excessive downtime due to exposure to wind and waves, pipeline blockage due to some large aggregate). There were also some difficulties in attaining an accurate measure of material moved, given the dynamism of the borrow site and the constant reprofiling by beach processes upon placement. As tenderers became more familiar with the site, the number of competitive quotes for works dropped, and overall tender prices increased.

CSD has a relatively high set-up cost compared to its operational cost. Therefore, the most efficient use of a CSD is for relatively large scale bulk dredging operations. This is somewhat opposite of the requirements of Jimmys Beach, as bulk nourishment in the past has tended to be lost relatively quickly, thus effectively wasting considerable effort and cost associated with CSD operations. The only other alternative for CSD is to place bulk material into temporary stockpiles instead of directly onto the beach, which is then re-transported and placed on the beach on demand. This scenario is limited at Jimmys Beach due to the absence of any areas that can accommodate large volumes of sand (e.g. Deadman's dune has limited capacity in the order of 20-30,000m^3, which is sufficient for 3-4 years of emergency nourishment only). Double-handing of the material is also an added expense.

2.4.3 Material Delivery

In delivering the sand materials it is noted that there are primarily two main ways that the material can be delivered to Jimmys Beach:

- Trucking (Land Based Plant); and
- Pumping (Hydraulic).

2.4.3.1 Trucking

Should the materials be trucked to Jimmys Beach, other land based plant (e.g. another front end loader) would be required for the levelling and profiling of the material after it has been dumped by the haulage trucks. The movement of this plant means significant public disruption also occurs at the renourishment site. Indeed all forms of placement (land-based, hydraulic) would significantly limit public usage of the renourishment area during operations.

It is noted that the adjacent public roads in the areas are limited and are generally trafficked by local residents only. This means any trucking and haulage activities would also affected local residents (unless hauling directly along the beach via off-road trucks). Trucking of material for emergency nourishment works have generally deteriorated the local roads, necessitating repairs. Any plan for regular trucking operations would need to consider investment in road improvements as well as on-going repairs.

Off-road trucks would eliminate the impact on road. Rubber tyre trucks have been used for nourishment on Shoal Bay beach, however, their operation was constrained by the state of the tide and could only be used at low tide. Any trucking along Jimmys Beach from Yacaaba sandwave would also be constrained by JAMBA and CAMBA agreements (which would limit operations during migration periods, e.g. little tern / pied oystercatcher nesting during summer months), high public usage of the beach (especially during school holidays), commercial fishing from the shore, and threatened vegetation issues.

Trucking along the western Winda Woppa spit is likely to have fewer constraints, however, a dedicated haul road would need to be constructed, which may involve some loss of vegetation. Also, there is a short section of beach that is suffering on-going and rapid erosion. It is anticipated that protection of the haul road in this location would be required (or realignment of the haul road on a regular basis – approx. annually through this ~200m section).

2.4.3.2 Pumping

Pumping activities would eliminate any need to truck the materials and thus would generally be considered the preferred option by the community.

It is understood that there currently exists a 12 inch (~300mm) pipeline between Jimmys Beach and the Yacaaba sandwave. This pipe size is consistent with the pipe sizes generally used for pumping for renourishment operations. Should this pipeline be in a reasonable condition, it could represent a good asset that would reduce capital expenditure for any future planed pumping operation between these two sites.

Pumping provides a more autonomous means to deliver the material to Jimmys Beach, compared to trucking which is much more labour intensive. However, trucking would be considered slightly more reliable than pumping, due to the risks of potential blockages and pump breakdowns.

It is noted that the Yacaaba sandwave is approximately 2.7km away from Jimmys Beach which is approximately 600m greater than the distance between the Myall River Entrance and Jimmys Beach. In this regard the Myall River Entrance offers a slightly reduced transport distance to Jimmys Beach which is advantageous for both trucking and pumping operations. Both sites would likely require a booster pump mid-way along the pipeline route, which adds to the cost.

2.4.4 Financial Constraints on Nourishment Options

Smaller scale emergency nourishment works (with sand sourced from Deadmans sand dune) have historically been undertaken and funded by Great Lakes Council, at a cost of about $70,000 - $80,000 per annum. Larger scale operations are dependent on external funding (typically from the NSW Government), as the costs far exceed the financial capacity of Council for such works. More recent larger scale works involving dredging have been in the order of $600,000 – $700,000 per campaign, and have removed some 30-50,000m^3 (giving a cost rate of $15 – 20/m^3).

Whilst Council can forward plan for some financial investment in operations (in the order of historical annual costs), contributions from the NSW Government are uncertain, as the relevant state-wide programs are reviewed annually and funding is distributed to different projects on a state-wide prioritised and competitive basis. The availability of external funding therefore does not necessarily accord with the timing of the needs for nourishment of Jimmys Beach.

The ideal funding model for on-going management of Jimmys Beach would be to have a system that has low operational costs that are within the annual budget of Council (with no NSW Government contribution). Council could then plan internally how their funding is to be sourced (e.g. through local resident contributions or levies).

Operations would ideally also be undertaken by Council staff directly, as it would avoid the need to be profitable (as is the case for a third party contractor). Council has a range of earthmoving equipment and a works crew that is capable of supporting such operations (but not a fleet of trucks, especially off-road trucks).

2.4.5 Other Constraints/Considerations on Nourishment Options

2.4.5.1 Temporary Stockpiling of Sand

As noted above, the suitability of CSD could be improved if larger scale dredging works also involve the stockpiling of sand for subsequent use in between episodic dredging campaigns. Deadmans sand dune has been used recently as a stockpile for dredging works, largely to replace sand removed from the dunes for emergency works throughout the early 2000s. Deadmans dune has limited capacity (in the order of 20-30,000m^3) before impacting on surrounding vegetation and access.

An area at the western end of The Boulevard has been used for stockpiling of sand in the past, however, this site is under private ownership and therefore is not viable for future operations.

The western end of Winda Woppa spit has the potential to accommodate considerable stockpiling of sand. However, as there are already vast quantities of in-situ sand available at this location, there would be no significant benefit in removing sand from elsewhere (e.g. within the river channel) only to place it there temporarily when compared to direct excavation of in-situ sand from this land source.

It is noted that stockpiling is not considered particularly efficient as it results in double-handling of the materials. This rehandling of the materials makes the renourishment operations more expensive (in the order of \$4/m^3 if subsequently transported by road trucks to the nourishment site). Notwithstanding this, it is appreciated that such re-handling costs are favoured and cheaper than regularly remobilising either Floating Plant or the entire Land Based Plant spread. Thus it is considered stockpiling would not be ideal for routine operations, but may still have merit for 'emergency' situations.

2.4.5.2 Nourishment Trigger

In the absence of a regular program of nourishment, Jimmys Beach has been nourished with an informal trigger for undertaking 'emergency works' when The Boulevard roadway is at imminent risk of impact. For the most recent emergency works, a significant threat to The Boulevard lasted for a couple of days, with the rate of erosion exceeding the rate of beach nourishment (despite some 100 – 120 truck loads per day being dumped on the beach). The threat to the road was compounded by the fact that there was not a good reserve of sand protecting the asset at the commencement of the erosion event.

It is considered that future management of Jimmys Beach will need to include various triggers for top-up nourishment that may be in addition to a regular program of nourishment works. These triggers would most likely relate to a set distance of an erosion face from the road, with the trigger distance to incorporate a 'minimum' buffer for erosion as well as consideration of how quickly additional emergency works can be mobilized (or the regular nourishment program simply fast-tracked). It is recognised that management of Jimmys Beach since 1990 has included a provision for a trigger-initiated response (nominally 15 metres from the road), however, the timing of the storms, contract administration, funding availability and dredger availability have all compromised the ability to respond timely to the trigger.

2.5 Overview of Practical / Feasible Options

Table 2-1 provides a summary of nourishment options for sourcing from both the Yacaaba sandwave and the Lower Myall River Eastern Channel entrance. The main nourishment options considered in the context of Jimmys Beach are:

- Land-based excavation and trucking;
- Land-based excavation and custom-built fixed in place hopper, for hydraulic (slurry) transport;
- Cutter Suction Dredger; and
- Sand Shifter.

Other nourishment options as discussed in the preceding Sections of this Chapter are considered to be largely unsuited for application at Jimmys Beach.

The high-level consideration of environmental and logistical constraints and other issues has suggested a number of nourishment options are feasible for extraction from both the Yacaaba sandwave and the Lower Myall River, while other options may also be feasible provided that some specific constraints or issues can be resolved or mitigated (refer Table 2-1). Overall, land-based excavation and hydraulic transport using a fixed hopper arrangement is considered feasible for both sites, as is excavation and trucking from the Lower Myall River entrance spit. Land based excavation and trucking from Yacaaba sandwave may also be feasible subject to timing and environmental issues, while a Sand Shifter in the Lower Myall River entrance may also be feasible providing it can be recovered occasionally for maintenance.

CSD at Yacaaba sandwave may be feasible, but it would be working with relatively small volumes (even with top-up of Deadmans dune stockpile), so it may be cost prohibitive as a continuing solution. CSD in Lower Myall River is not considered feasible as there would be no tangible advantage in stockpiling sand on the Winda Woppa spit (because there is already enough sand there to excavate and truck to Jimmys Beach).

The next chapter explores the cost-benefits of these options more closely, along with the likely impacts of the works in the context of wider hydrodynamic and sediment dynamic processes of the outer Port Stephens area.

Table 2-1 Summary of Feasibility of Nourishment Options for Sourcing from both Yacaaba and Myall River entrance

Nourishment Option	Constraints / issues for Yacaaba sandwave sourcing	Constraints / issues for Lower Myall River entrance sourcing
Land-based excavation and trucking	Issues for vehicle transportation along beach due to threatened species, vegetation and loss of amenity (e.g. high usage during school holidays, commercial fishing access etc) Would need to be 4WD – rubber tyre trucks (limited availability, but used before for Shoal Bay nourishment), and would also be limited in operating times by tides. Could potentially use scraper haulage along beach, again subject to availability and tide state. Could plan ahead for works to coincide with low tides during daylight hours. <u>Overall: feasible but may be compromised</u> (by potential limited availability of suitable trucks or scraper, and restricted window of operations due to tide and other environmental constraints)	Would need to be 4WD – rubber tyre trucks (limited availability, but used before for Shoal Bay nourishment) and would have some amenity issues if transport along the beach, and would also be limited in operating times by tides (could be planned ahead to optimize tides). Alternatively, could create suitable access and construct haul road through vegetated Winda Woppa Spit, including around erosion zone. This 200m long section may need on-going repair/realignment every 12 months or so to remain trafficable. Trucks on public roads would damage road surface, which would require on-going repairs (at extra cost). <u>Overall: feasible</u>
Land-based excavation and custom-built fixed in place hopper, for hydraulic (slurry) transport	Could use existing 12 inch pipeline from Yacaaba to Jimmys. Would need to be sure that extracted material will be replaced over time, as limited in-situ supply available for land-based excavation (about 50,000m^3). Hopper would need to be protected/secured during non-operating times. Power would need to be connected to the hopper (diesel could be used as an interim measure, but operating costs would be much higher). Would need a booster pump (preferably with power). Large capital outlay for fixed in place infrastructure would limit flexibility of system for alternating the source of sand. <u>Overall: feasible</u>	Would need to lay a delivery pipeline. Know that about 10,000m^3 pa is accreted on spit due to on-going erosion of western shore, so on-going supply should be met relatively easily. Nonetheless, there is significant in-situ capacity (>100,000m^3) comprising the entire Winda Woppa spit, which can be extracted if necessary. Hopper would need to be protected/secured during non-operating times. Power would need to be connected to the hopper (diesel could be used as an interim measure, but operating costs would be much higher). Would need a booster pump (preferably with power). Large capital outlay for fixed in place infrastructure would limit flexibility of system for alternating the source of sand. <u>Overall: feasible</u>
Cutter Suction Dredger	Could use existing 12 inch pipe if dredger is big enough. Limited availability of units, which may increase costs. Could be problematic with large aggregate and seagrass wrack. Would ideally move large quantities per campaign due to high set-up costs compared to operation costs.	Limited availability of units, which may increase costs. Potentially inclement wave conditions and blockage due to seagrass wrack could cause excessive down-time. Could remove material from protected location behind existing spit, and therefore not in the open channel. Would ideally move large quantities per campaign due to high set-up

Nourishment Option	Constraints / issues for Yacaaba sandwave sourcing	Constraints / issues for Lower Myall River entrance sourcing
	Placement of a large nourishment volume onto Jimmys Beach will likely result in rapid and significant beach reprofiling, and subsequent loss of a high proportion of nourishment material. Would need booster pump. Could pump into temporary storage sites, but available site (i.e. Deadmans) has limited capacity and sand would still need to be transported at a later time (at extra cost). Episodic high costs can't be funded by Council, so reliant upon on-going funding sources from NSW Government. <u>Overall: feasible, but may be compromised</u> (either through availability of on-going funding, ability to stockpile, or rapid loss of over-nourishment)	costs compared to operation costs. Placement of a large nourishment volume onto Jimmys Beach will likely result in rapid and significant beach reprofiling, and subsequent loss of a high proportion of nourishment material. Would need booster pump and laying of pipe. Could pump into temporary storage site on Winda Woppa Spit, but it would still need to be transported at a later time (as there is plenty of sand already on-site on Winda Woppa spit, there is no real advantage of stockpiling at this location). Episodic high costs can't be funded by Council, so reliant upon on-going funding sources from Government. <u>Overall: not feasible</u>
Sand Shifter	Likely to be insufficient sediment dynamics to infill 'crater' in between pumping events, unless positioned more offshore in swell affected part of sandwave. Would need a booster pump (preferable with power), but may be able to use existing pipe. Power would need to be connected to the Sand Shifter unit (diesel could be used as an interim measure, but operating costs would be higher). Difficult to reposition into another location. May need to be recovered occasionally for maintenance and removal of marine growth build-up, which would be difficult due to site access and remoteness. As it involves subaqueous removal, there is potential risk for off-site impacts of changed hydrodynamics and sediment processes. <u>Overall: not feasible</u>	Would be most suited if located within the channel at the end of the spit, where sediment dynamics are greatest, and positioned transverse to the dominant tidal and wave driven currents. Subaerial sand from the spit could be pushed into the crater in the channel using land-based equipment if the crater does not infilled naturally in time for next pumping event. Would need a booster pump (preferable with power) and new pipework. Power would need to be connected to the Sand Shifter (diesel could be used as an interim measure, but operating costs would be higher). Difficult to reposition into another location. May need to be recovered occasionally for maintenance and removal of marine growth build-up, which would be difficult due to site access and remoteness. As it involves subaqueous removal, there is potential risk for off-site impacts of changed hydrodynamics and sediment processes. <u>Overall: feasible but may be compromised</u> (by the potential for blockage and the ability of the equipment to be readily recovered on a periodic basis)

3 ASSESSMENT OF FEASIBLE NOURISHMENT OPTIONS

3.1 Nourishment Options for Consideration

Potentially feasible nourishment options being considered further are summarized in Table 3-1.

Table 3-1 Potentially feasible options for further consideration

Option Ref.	Source	Description
YSS-1*	Yacaaba sandwave	Land-based excavation and trucking along the beach
YSS-2	Yacaaba sandwave	Land-based excavation and hydraulic pumping using a fixed hopper
YSS-3*	Yacaaba sandwave	Cutter Suction Dredger (CSD) with top-up of Deadmans dune. Subsequent emergency works sourcing from Deadmans.
LMR-1	Lower Myall River entrance	Land-based excavation from Winda Woppa spit and trucking along haul road and streets
LMR-2	Lower Myall River entrance	Land-based excavation from Winda Woppa spit and hydraulic pumping using a fixed hopper
LMR-3*	Lower Myall River entrance	Sand Shifter located in channel at end of spit. Sand Shifter operations would more likely be an on-going process (with small quantities pumped every week or fortnight as part of an automated process rather than larger quantities on a 6 monthly basis). Note this would not increase depth or physical condition of the Eastern Channel.

** These options may have limitations in implementation due to logistical or functional constraints, as highlighted in Table 2-1.*

3.2 Cost Estimates

A detailed breakdown of the costs as well as the key assumptions in deriving these cost estimates is presented in Appendix C. A summary of these derived costs is presented in Table 3-2.

Cost estimates have been calculated on the assumption that Council would need to outsource all elements of the works with the exception of project management. Costs have also been calculated with a 30% contingency at this stage, however, costs do not include any initial or on-going environmental assessments, surveys, investigations or works designs.

With the exception of Option YSS-3 (CSD), costs are based on set-up and transfer of 10,000m^3 of sand every 6 months. For Option YSS-3, it was assumed that the CSD would dredge 30,000m^3 of sand every 18 months, with 10,000m^3 placed directly onto Jimmys Beach and the remaining 20,000m^3 placed in Deadmans dune. The subsequent transfer of this volume to Jimmys Beach by road haulage was therefore also included in the cost of this option. For the Sand Shifter option (LMR-3), actual operations would most likely involve pumping of a much smaller volume of sand on a much more regular basis (say weekly or fortnightly). This would minimise the extent of the 'crater' left behind by extraction, allowing for more rapid readjustment/filling by regular tides and waves.

Table 3-2 Summary of the cost estimates for various methods of undertaking beach nourishment

	Nourishment Option					
Description	**YSS-1* (land-based)**	**YSS-2 # (hopper)**	**YSS-3* (CSD)**	**LMR-1 (land-based)**	**LMR-2 # (hopper)**	**LMR-3** (SandShifter)**
Capital Cost	$0	$1,690,000	$0	$3,900	$1,690,000	$1,755,000
Annual Recurrent Cost	$364,500	$182,500	$665,900	$387,900	$182,500	$104,000
Total over 5 years	***$1,822,600***	***$2,602,600***	***$3,329,733***	***$1,943,500***	***$2,602,600***	***$2,275,000***
Total over 10 years	***$3,645,200***	***$3,515,200***	***$6,659,467***	***$3,883,100***	***$3,515,200***	***$2,795,000***
Total over 20 years	***$7,290,400***	***$5,340,400***	***$13,318,933***	***$7,762,300***	***$5,340,400***	***$3,835,000***

** These options may have limitations in implementation due to logistical or functional constraints, as highlighted in Table 2-1.*

*** In addition to logistical or functional constraints on suitability, the costs adopted for the Sand Shifter assume no on-going need for recovery and maintenance due to blockage or damage to equipment. Should recovery of subaqueous equipment be required on a regular basis, it is expected that these costs would be substantially higher.*

 # overall costs for use of a hopper (at Yacaaba or Lower Myall River) can be reduced to less than the Sand Shifter costs if the excavation, loading and spreading of sand using standard earthmoving equipment is undertaken by Council staff as in-kind contribution.

Overall it was found that the prices for the various options vary significantly with the Land Based Plant (Options YSS-1 and LMR-1) representing the likely cheapest options when amortised over 5 years. The annual recurrent costs for these options, however, have been calculated at more than $350,000 (Year 2012 dollars), which is likely to exceed the affordability of Council. When spread over the number of properties on Winda Woppa spit, it represents an annual cost (contribution) of more than $3,000 per property, which exceeds their entire rates revenue. Land-based operations from Yacaaba (Option YSS-1) are slightly cheaper than operations from the Lower Myall River spit (Option LMR-1) due to the expected on-going repairs/re-alignment of the haul road and expected on-going repairs to the bitumen streets. However, the Yacaaba option would potentially be compromised due to environmental and amenity constraints, as well as the on-going availability of off-road trucks, which may make the Lower Myall River option more feasible and cost effective.

When amortised over 10 years or more, the options that involve significant capital cost but lower operational costs become more cost competitive. Overall, the Sand Shifter (Option LMR-3) was the cheapest option (but recognising the potential for cost blow-out if the equipment needs to be recovered regularly – refer Table 2-1). This option also has the lowest annual operational cost at

$104,000, which is considered much more affordable for Council, and within the range of historical expenditure on emergency nourishment works on Jimmys Beach.

Given the uncertainty around the operational costs for the Sand Shifter, the best (uncompromised) options would involve the use of a hopper arrangement (i.e. YSS-2 and LMR-2 – both considered feasible, with Yacaaba having slightly lower costs if the existing pipeline can be utilised). The on-going operational cost for the hopper options is about $180,000 per annum. It is noted that this cost includes land-based excavation, loading and spreading of sand. If these tasks could be undertaken by Council staff utilising Council equipment (as in-kind contribution), the annual costs would reduce to about $100,000, making these options the most economic solutions.

The most expensive option is the periodic deployment of a CSD (YSS-3), and is more than three times more expensive that the cheapest option (LMR-3) over a 20 year period. Interestingly, CSD has been the option adopted for nourishment historically, with costs in the order of $600,000 - $700,000 per campaign. From the cost comparison shown in Table 3-2, it can be seen that a one-off capital investment of magnitude only about 2.5 the value of recent dredging campaigns would potentially deliver a lasting and cost-effective solution to nourishment.

It should be noted that the costs discussed above are indicative estimates only. Should more exact costs be required, then these would need to be determined undertaking further investigation of the preferred option.

3.3 Sediment Dynamic Modelling of Options

This section of the report details the refinement of the coastal hydrodynamic and morphodynamic numerical model that was developed previously (refer BMT WBM, 2011). The model is capable of simulating tidal hydrodynamics, waves, sediment transport and geomorphology for the Port Stephens / Myall Lakes estuary and in particular the region of interest for this report, being the Jimmys Beach shoreline. The primary application of the model, for this study, was to investigate sand dredging and the associated morphological impacts to provide further understanding of sediment transport pathways. The two locations chosen for sand extraction included the Lower Myall River Entrance Spit and the Yacaaba sandwave (refer Figure 1-1).

3.3.1 Model refinement

The modelling component includes a hydrodynamic model, a morphological component and a wave model, which are all integrated. The original integrated models were set-up and calibrated as documented in BMT WBM (2011). Following this, minor changes were made to the model to include updated nearshore bathymetry (based on 2011 Marine LiDAR data) and increased grid resolution along Jimmys Beach shoreline. The revised integrated models were validated to tidal velocities. Temperature and salinity were not modelled and therefore not considered within the re-calibration. Re-validation of tidal flows in the Myall River was also not included, as the focus of this study was on Jimmys Beach (which is tidal and wave dominated).

3.3.2 Scenario descriptions

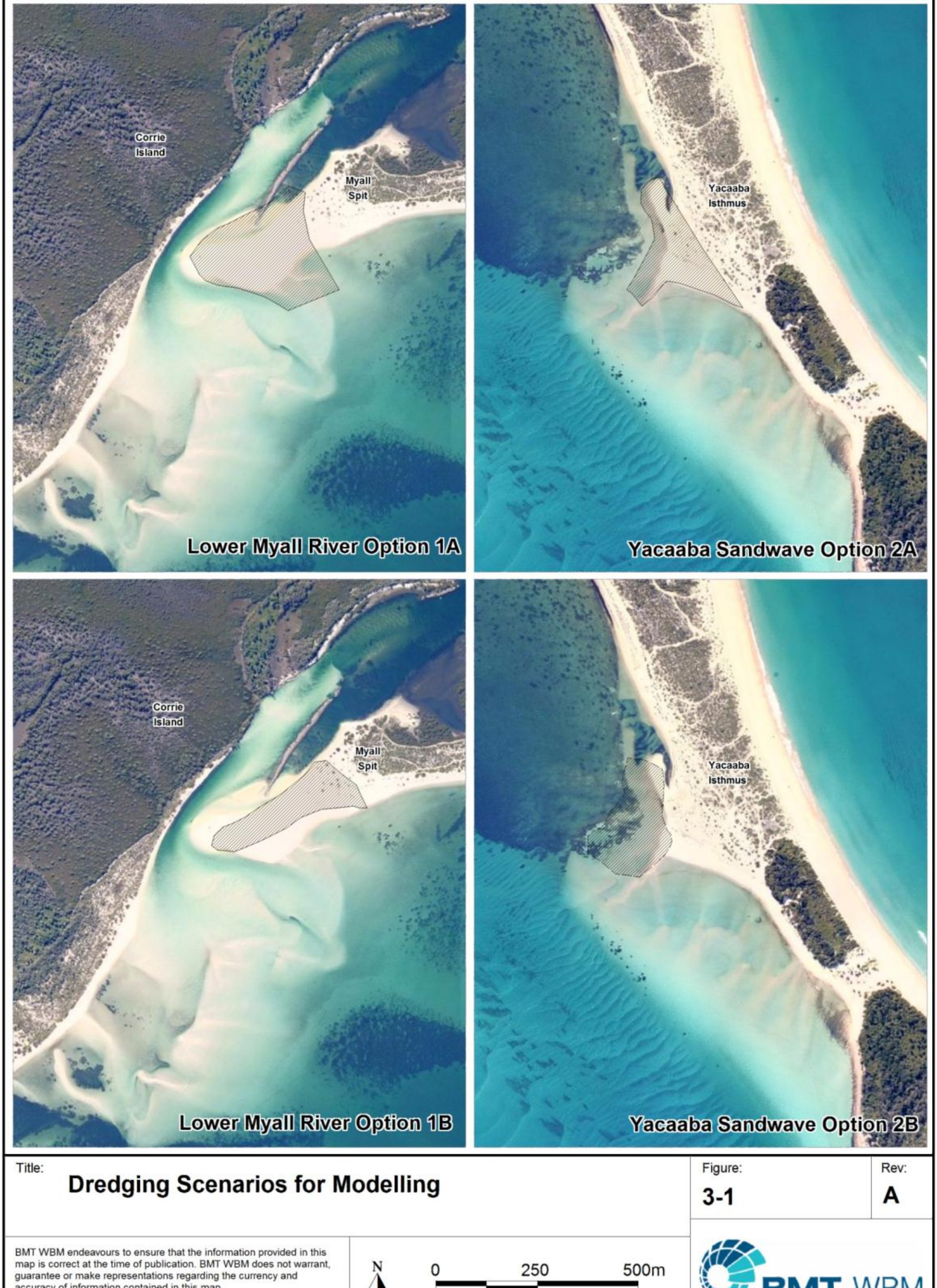
A review of ocean swell wave climate using historical wave data measured at Sydney revealed large SE swell wave events occurred between March-April 2005 (refer BMT WBM 2011). This period was therefore chosen as boundary conditions for the model to represent a 'stormy period'.

Two source sites were identified for the removal of sands to nourish Jimmys Beach, namely the Lower Myall River entrance shoal and the sandwave at Yacaaba isthmus. Within these two locations, two separate options were considered, one focusing on removal of shallow sands (mostly subaerial) and the other focusing on removal of subaqueous sands (see Figure 3-1). Optimisation of dredging profiles and configurations would be the subject of detailed design. A summary of the dredging scenarios is given in Table 3-3.

Table 3-3 Dredging scenarios for Modelling

Reference	Description	Volume (m^3)
Option 1A	Removal of sands from Lower Myall River entrance sand spit, shallow surface sands only, resulting in a flat profile of approximately -0.5m AHD	~ 51,000
Option 1B	Removal of sands from Lower Myall River entrance sand spit, sub surface and channel sands only	~84,000
Option 2A	Removal of sands from Yacaaba sandwave, shallow surface and beach/dune sands only	~40,000
Option 2B	Removal of sands from Yacaaba sandwave, subaqueous sediments only, limited to the northern side of the sandwave (as per recent dredging campaigns)	~48,000

The impacts on sediment transport were assessed on a daily/weekly timescale. The timescale was considered reasonable under the assumption that any changes to the morphology were likely to occur shortly after extraction, as the bed profile attempts to reach a steady state under the applied tidal flows and wave conditions.



Title: **Dredging Scenarios for Modelling**	Figure: **3-1**	Rev: **A**

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3.3.3 Results

3.3.3.1 Lower Myall River Entrance

The options considered for removal sand from the Lower Myall River entrance sand spit roughly accord with the options assessed previously by BMT WBM (2011). The outcomes of that assessment indicated that 'opening up' of the Eastern Channel through dredging of the entrance sand spit would increase tidal flows through the channel.

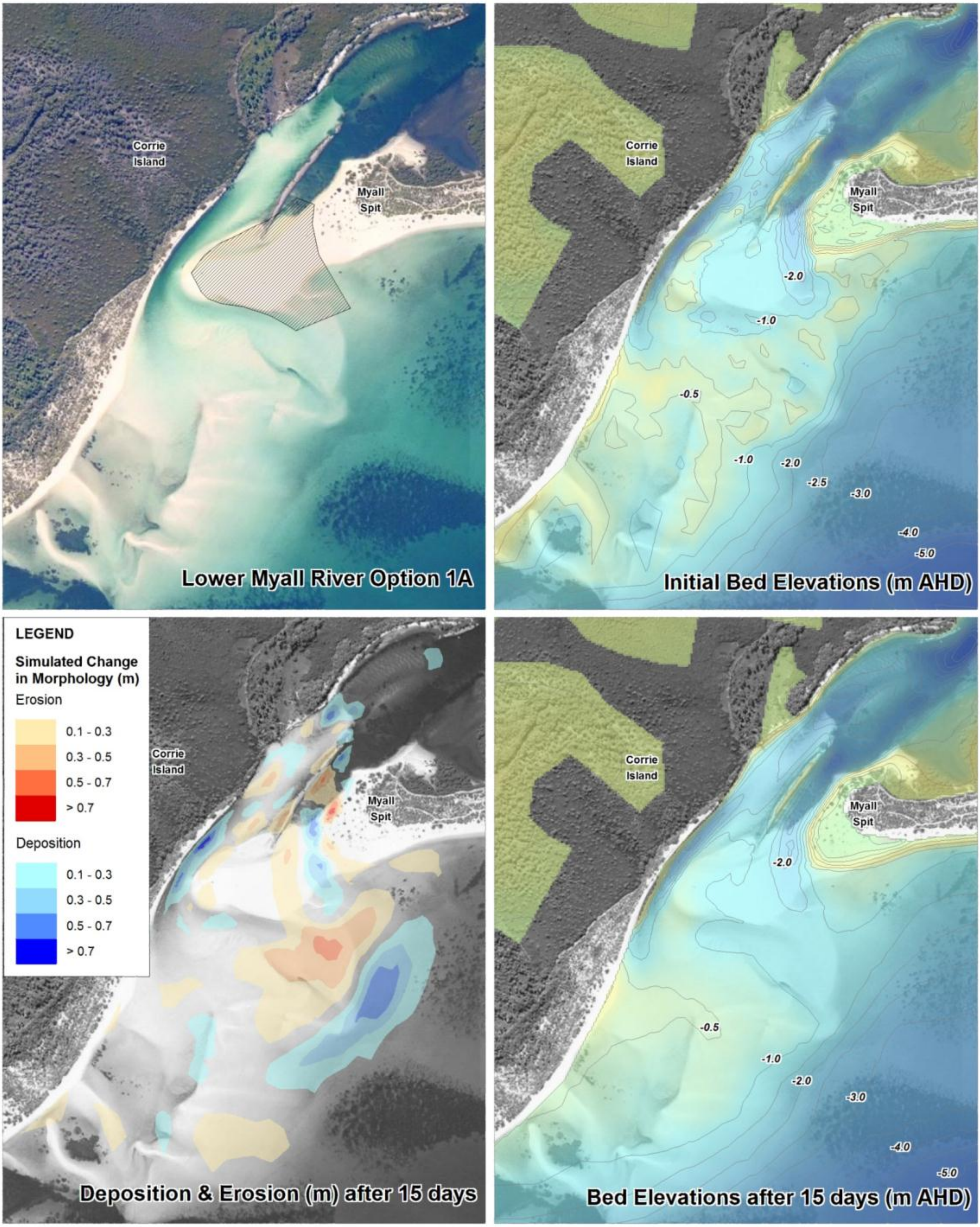
The high tidal currents flowing through the entrance channel following sand extraction is expected to have relatively rapid flow-on effects to seabed morphology. Figure 3-2 shows the predicted response of local bathymetry around the Lower Myall River entrance channel for Option 1A, which involves removal of the subaerial sand spit down to a level of approximately -0.5m AHD. The results suggest that tidal flows over the shallow dredged area during mid-high tides will scour some sands on the ebb tide, primarily depositing this material on the sea-side of the ebb-tide entrance delta area. Preferential flow over this section of the entrance will also result in some minor infilling of deeper pockets within the entrance delta area that had previously been 'self scouring' during high flows as a result of localised constrictions.

Figure 3-3 shows the predicted response of morphology to the more extensive extraction associated with Option 1B. For this scenario, the majority of the entrance sand spit was removed, and a new channel created connected to the deeper relict channel on the eastern side of the rock wall. For this option, there was some reworking of sediments predicted around the new channel and the adjacent edge of the ebb-tide entrance delta. In essence, the morphology changes involved a general smoothing of the localised bathymetry, with scoured sands again deposited on the sea-side of the ebb-tide entrance delta.

3.3.3.2 Yacaaba sandwave

Figure 3-4 shows the predicted morphological response to Option 2A, involving the mostly subaerial extraction of sand to a depth of about -0.5m AHD. This depth approximately corresponds with the level of the shallow sand shoals that dominate this area. The results of the morphological modelling indicate that the distal edge of the shoal will continue to be reworked, with sand primarily being directed shoreward and northward. It is considered that swell waves during the 'stormy' period used for the modelling are the primary drivers for sediment transport. These results are consistent with the conceptual coastal processes model described in Section 6.3.4, which hypothesised that sediment deposits on the edge of the shoal are reworked onshore (and onto the sandwave) by swell-dominated currents.

Figure 3-5 shows the predicted morphological changes for Option 2B, involving more extensive subaqueous dredging along the northern side of the sandwave (as per recent dredging campaigns). The results show virtually identical erosion and accretion patterns to Option 2A despite significant difference in the planform shape and morphology of the sandwave. These results suggest that the sediment reworking process at the edge of the sand shoal is independent of the sandwave. Removing this 'independent' morphological change, the sand extraction from Yacaaba sandwave for both Option 2A and 2B will have very little impact on sediment transport across the local seabed. This is entirely consistent with the slow rate of infilling of the existing dredging hole located on the northern side of the Yacaaba sandwave.



Title:	Figure:	Rev:
Lower Myall River Option 1A: Simulated Changes to Seabed Morphology	**3-2**	**A**

N

0 250 500m

Approx. Scale

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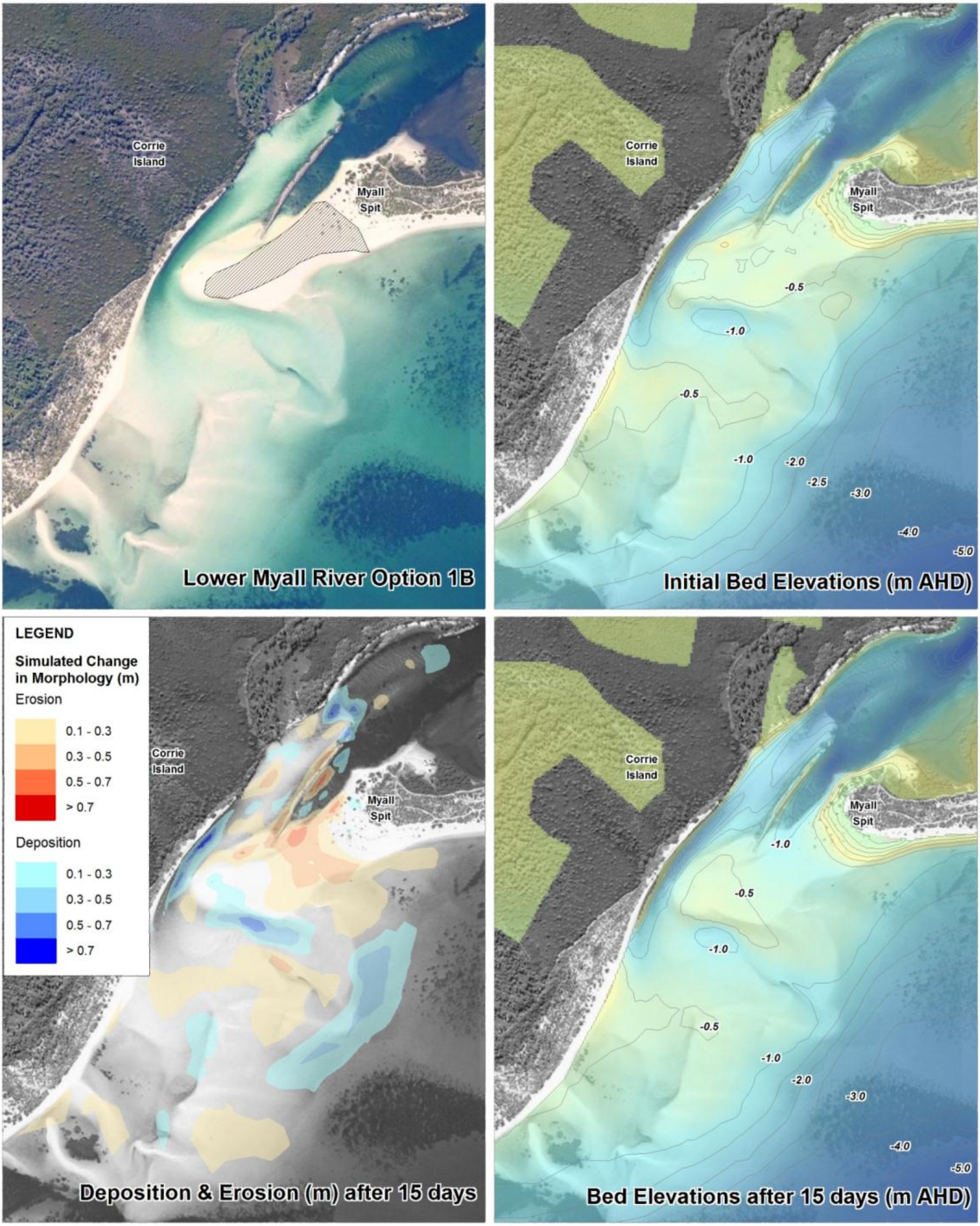

Title:

Lower Myall River Option 1B:
Simulated Changes to Seabed Morphology

Figure: 3-3

Rev: A

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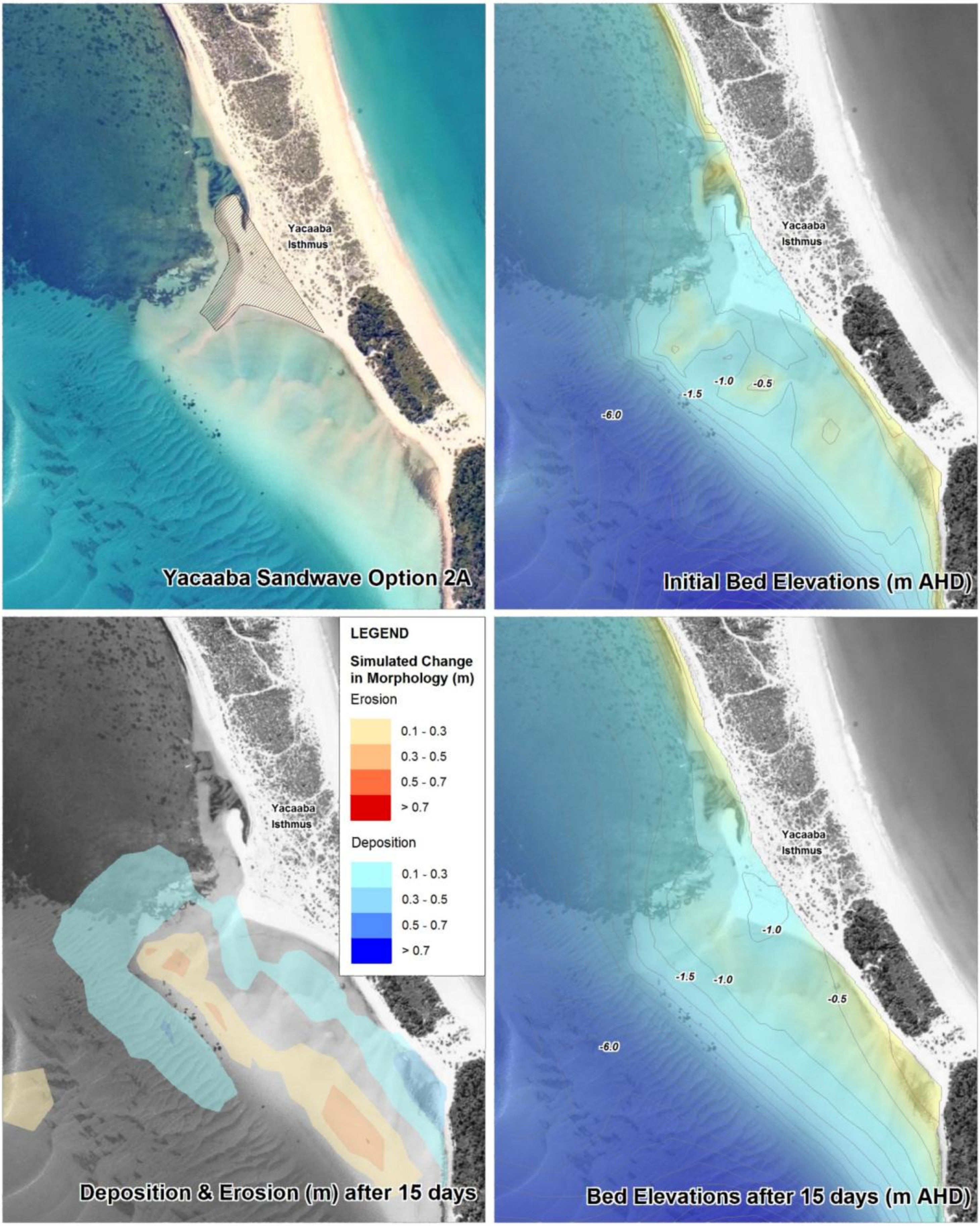

Title: **Yacaaba Sandwave Option 2A: Simulated Changes to Seabed Morphology**	Figure: **3-4**	Rev: **A**

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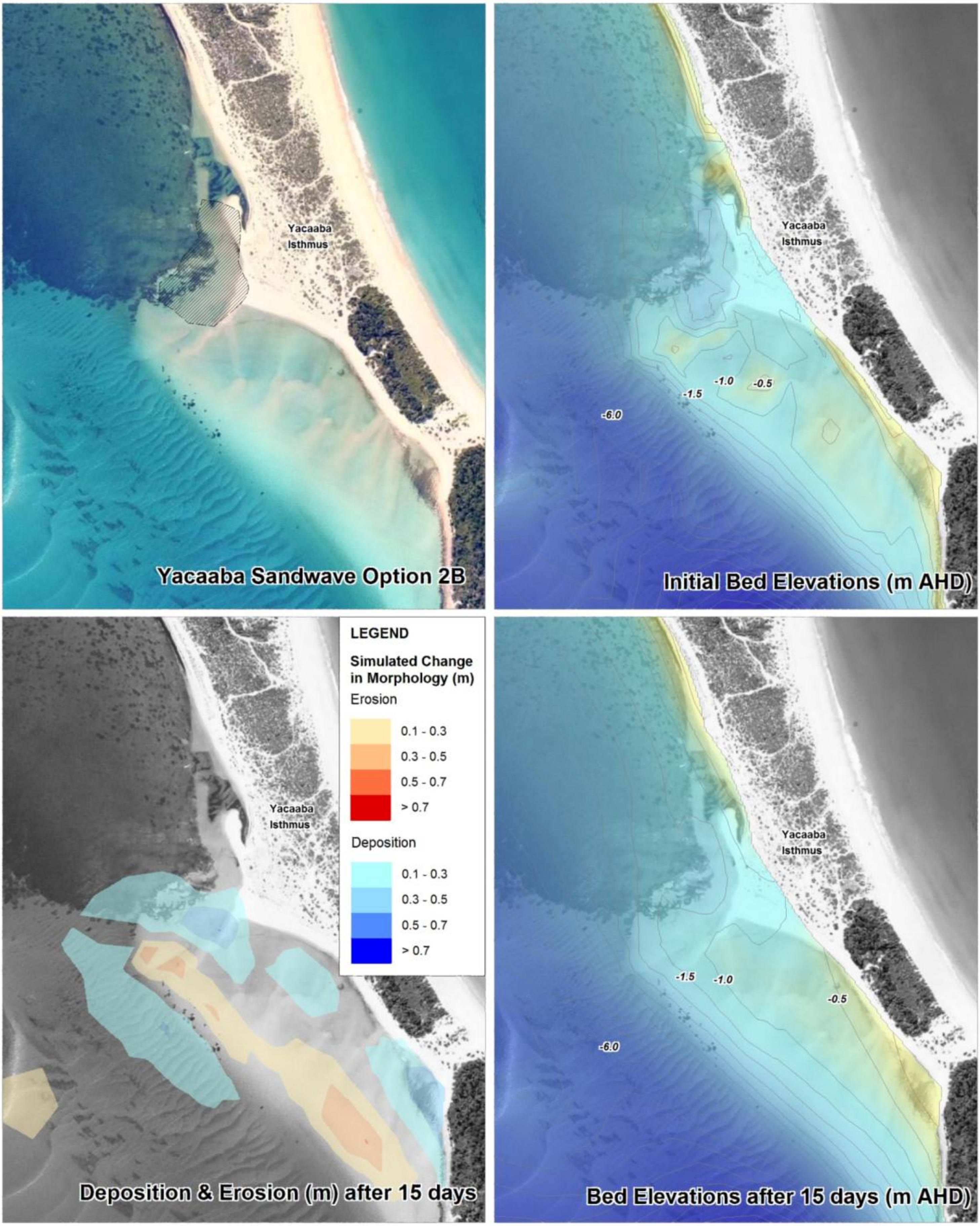

Title:
Yacaaba Sandwave Option 2B: Simulated Changes to Seabed Morphology

Figure: 3-5

Rev: A

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It is considered that infilling of the dredge hole will be governed more by longshore transport of sediment moving around the sandwave under the influence of incident swell wave, and spilling into the dredge hole from the south (as observed by the northerly oriented recurved spits at the edge of the dredge hole seen in the air photos and observed on-site).

3.4 Potential Impacts Associated with Sediment Accumulation

The hydrodynamic and sediment dynamic modelling carried out for this assessment was not used to specifically predict and quantify the fate of nourishment sand placed on the beach. This is because the sediment transport processes are largely shoreline processes, and are not directly integrated into the coastal and estuary model.

Two nourishment sourcing options have been considered as part of this study, these being extraction from the Yacaaba sandwave and the Lower Myall River sand spit. There is a small difference in extraction location at the Lower Myall River between land-based and water-based operations, with the land-based options extracting sand from the sub-aerial sand spit and the water-based options extracting sub-aqueous sand from within the tidal channel.

As discussed in Section 6.3:

- Erosion of sand on Jimmys Beach will not affect accumulation of sand at the Yacaaba sandwave;
- Accumulation of sand within the Lower Myall River entrance channel will continue to occur (at a rate similar to historic levels) irrespective of whether Jimmys Beach is nourished or not; and
- The majority of sand eroded from Jimmys Beach is migrated offshore due to cross-shore processes.

For the reasons listed above, it is considered that on-going nourishment will not have a significant and detrimental impact on sediment accumulation within Port Stephens or around the foreshores of Jimmys Beach embayment.

3.5 On-going Accumulation in the Lower Myall River Entrance

The terminus for the sand directed westward along the shoreline is the entrance shoals of the Lower Myall River Eastern Channel. As discussed previously, sand accumulation within this vicinity of the entrance has led to the extension of the Winda Woppa sand spit by some 800 metres since 1950 (at a volume of some 300 – 400,000m^3). Importantly, air photos show that the sand spit extended some 500 metres (with a volume of about 150,000m^3) before nourishment commenced. Despite an extra 360,000m^3 of sand placed on Jimmys Beach between 1980 and 2006, the rate of accumulation has not changed significantly, meaning that the beach nourishment activities have not exacerbated the shoaling. Nourishment of Jimmys Beach is therefore not providing an additional source of sand for accumulation within the entrance, but rather, replaces sand that would otherwise have be sourced from erosion and recession of the beach profile.

On this premise, the impact of further on-going nourishment of Jimmys Beach on accretion within the Eastern Channel would be minimal. The bigger issue relates to sourcing of the sand. If nourishment sand is drawn from the Winda Woppa sand spit and entrance channel at a rate of approximately 20,000m^3 per year, it can be assumed that a proportion (say around 25% or 5,000m^3/yr) would be reworked back to the source location, meaning that the erosion of the western foreshore would meet the remaining longshore sediment transport demand of about 7,000m^3/yr. Thus, there would be about 20,000m^3/yr extracted and about 12,000m^3/yr deposited along the Winda Woppa sand spit, giving a net depletion of about 8,000m^3/yr. This does not necessarily translate to a removal of 8,000m^3/yr from the Eastern Channel, as the extraction may occur from the subaerial sand spit. Indeed some 50,000 – 100,000 m^3 of sand would need to be removed from the Eastern Channel in order to restore pre-2001 flushing conditions through the channel (BMT WBM, 2011).

It is important to recognise that the trend of shoaling within the Eastern Channel is punctuated periodically by flood events from the river, which tends to scour the channel and rework sands onto the broad inter-tidal shoals of Paddy Mars Bar. This is highlighted by recent changes in the shoal following sustained periods of high flow within the river (refer Figure 3-6). Nonetheless, any overall accretionary trend in the entrance increases the possibility of the eastern channel becoming completely blocked (particularly under the influence of extreme storm events similar to that which was responsible for the destruction of Myall Point in the 1920s).

May 2010 June 2011

Figure 3-6 Changes in Lower Myall River entrance shoals due to river flooding

3.6 Evaluation of Nourishment Options

Nourishment options for Jimmys Beach have been evaluated giving consideration to social, environmental and financial factors (i.e. a triple bottom line review). The evaluation has been carried out at a high-level, meaning that factors have been reviewed and assessed in a cursory and qualitative manner. It is considered that a more detailed assessment of potential impacts would be undertaken as part of a formal Environmental Impact Statement (EIS) or similar that would support the necessary development/licence applications for such a project.

The Social and Environmental Factors have been evaluated to determine an overall impact rating for the six feasible nourishment options described in Table 3-1. This impact rating was then considered in combination with the Financial Factors to give an overall preferential ranking for the potential options.

The Social Factors considered in the evaluation include:

- Disturbance to beach users (recreational and commercial): this captures the potential impact on general users of Jimmys Beach, including the residents and visiting public that utilise the beach for recreation (including walking, swimming, wind-surfing, fishing, 4WDing – including 4WD access to Bennetts Beach), as well as the commercial users such as professional fisherman that net from the beach.
- Disturbance to street/road users and residents: this captures the potential impact of reduced amenity due to increased heavy traffic (i.e. trucks and earthmoving equipment) on the local streets. It is recognised that the on-going emergency works practice of trucking sand to Jimmys Beach has had significant disturbance on residents as well as physical damage to the road infrastructure. The most recent works (June 2012) involved some 1,100 truck loads over a week and a half.
- Visual amenity impacts: Tea Gardens and Hawks Nest are prime destinations for holidays, while many of the residences on Wind Woppa spit overlook Jimmys Beach and the embayment. Heavy machinery on the beach and/or in the water would detract from the visual appeal of the area.

Works are proposed on a periodic basis (approximately six monthly), with the required 10,000m^3 (equiv. 15,000 tonnes) moved and placed over an approximate 4 week period (assuming pumping rates in the order of 100m^3/hr of solids, or trucking rates of about 750-1000 tonnes/day). Therefore it is considered that the social impacts of the proposed works would be relatively minor, with works timed to minimise impacts on users (e.g. not to be carried out during school holidays, public holidays, weekends, key fishing periods etc).

The Environmental Factors considered in the evaluation include:

- Disturbance to threatened species / key habitats: this includes impacts on vegetation as well as fauna. It is noted that Jimmys Beach is a nesting area for some protected migratory birds, such as Little Tern, as well as the threatened Pied Oystercatcher;
- Potential water quality degradation: this primarily addresses impacts at the extraction location. It is assumed that land-based extraction would all be carried out ‘in the dry’, so there would be no potential for impact within the surrounding receiving water environment. Where extraction can potentially be carried out to depths of about -0.5m AHD, it is assumed that most of this would be done at low tide, or within areas tightly controlled by bunds or silt curtains. The CSD has the potential for water quality degradation, especially if the working face hits a pocket of finer silts (as the CSD agitates the sand with a cutter prior to sucking it into the intake pipe). Again, this could be managed through operational controls, such as silt curtains. The Sand Shifter would have a very minor / negligible potential for water quality degradation given that the jet pump fluidized sand, which is then sucked into the receival pipe (all within a buried environment).
- Supernatant discharge on beach: this is only relevant for options that pump sand to Jimmys Beach. The discharge operations would involve the sand settling out of the slurry within

containment areas. The residual water from the slurry, called the supernatant, would be released directly to the tidal waters adjacent to the beach (which are Marine Park, and thus requirements for water quality would need to be confirmed through consultation with EPA and Marine Parks Authority). Any fine material that does not settle on the beach would be carried into the adjacent waters, where there would be potential for increased turbidity and possibly lower dissolved oxygen (if there is detrital organics included within the sandflow) in the immediate nearshore zone. Supernatant from the Sand Shifter operations will be at very low rates (as it will be spread more evenly across the whole year rather than specific nourishment campaigns). The beach discharge of the Noosa Beach application of the Sand Shifter is shown in Figure 3-7.

- Potential seagrass impacts: this relates to potential reduction in light attenuation and fine sediment settlement onto seagrass in the nearshore zone near the nourishment area resulting from the supernatant discharged directly onto the Jimmys Beach nourishment area, as discussed above (also noting the significantly lower impact of supernatant from the Sand Shifter operations).

Figure 3-7 Beach discharge of Sand Shifter at Noosa, showing limited impact on recreational amenity (image courtesy SSM P/L)

- Changes to hydrodynamics: Removal of sub-aerial sand from either location would not impact on hydrodynamics. It is also assumed that the rate of nourishment of the beach is also sufficiently small to not affect local wave or tidal flow patterns (indeed tidal currents are quite small close to shore). The main potential for impact relates to removal of subaqueous sand. For the CSD at Yacaaba, there would be only a minor potential for change to hydrodynamics, as works would be quite contained to a local area around the sand shoal. For the Sand Shifter in the Lower Myall River eastern channel, the proposed operations would involve extraction and pumping of small amounts of sand on a regular basis (i.e. ~ 400m^3/week). Moving small amounts regularly would limit the local changes to the entrance area associated with the creation of a 'crater', with regular tidal movements easily able to infill the crater. It is unlikely that the small amount of sand movement into the crater would have a measurable impact on tidal hydrodynamics and interaction with the Lower Myall River.

- Changes to bathymetry, sedimentation and shoaling patterns: any changes to hydrodynamics will potentially lead to changes in sedimentation and shoaling patterns. For the Lower Myall River (as discussed in Section 3.3.3.1), removal of the entrance sand spit (or part thereof) will lead to a morphological response, wherein stronger tidal flows will typically lead to scouring of sands across the entrance shoals and deposition on the sea-side of the ebb-tide delta. It is considered that a weakening of tidal flows over the past 10 years or so has resulted in sand from the seaward edge of the delta being reworked onto the shoals by swell waves. The varying balance between tides and waves is the driver for the dynamism of the entrance channel area.

  For the Yacaaba sandwave (as discussed in Section 0), it is expected that extraction of subaerial or subaqueous sediments will not have a significant impact on the morphodynamics of the local sand shoal, due primarily to a relatively limited impact on tidal hydrodynamic processes (as the hydrodynamics are more governed by the extensive shallow nearshore shoals rather than a localised build-up of sand on the shoreline). The consequence of this, however, is that any extraction of sand from Yacaaba sandwave is unlikely to be resupplied for some time, essentially constraining the volume of material that can be extracted from this location over an expected design life, or potentially leaving a relict dredge hole as part of the local aquatic landscape.

The Social and Environmental Factors have been qualitatively assessed using the rating scale given in Table 3-4.

Table 3-4 Rating scale for Social and Environmental Impacts

Impact Level	Description
Negligible	no measurable impact or cause for concern
Minor	Monitor potential for impact, some minor mitigation may be required
Moderate	Mitigation required, some minor lasting impacts may be possible
Major	Effective mitigation may not be possible, potential "deal breaker"

The results of the qualitative assessment of Social and Environmental Factors for the six potential nourishment options are presented in Table 3-5.

Table 3-5 Potential Social and Environmental Impacts for Nourishment Options

	Nourishment Option					
Description	**YSS-1* (land-based)**	**YSS-2 (hopper)**	**YSS-3* (CSD)**	**LMR-1 (land-based)**	**LMR-2 (hopper)**	**LMR-3* (SandShifter)**
SOCIAL						
Disturbance to beach users (recreational and commercial)	Moderate	Minor	Negligible	Minor	Minor	Negligible
Disturbance to street/road users and residents	Minor	Minor	Negligible	Moderate	Minor	Negligible
Visual amenity impacts	Moderate	Minor	Minor	Minor	Minor	Negligible
ENVIRONMENTAL						
Disturbance to threatened species / key habitats	Moderate	Negligible	Negligible	Minor	Negligible	Negligible
Potential water quality degradation	Negligible	Negligible	Minor	Negligible	Negligible	Minor
Supernatant discharge on beach	Negligible	Moderate	Moderate	Negligible	Moderate	Minor
Potential seagrass impacts	Negligible	Minor	Moderate	Minor	Minor	Negligible
Changes to hydrodynamics	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
Changes to bathymetry, sedimentation and shoaling patterns	Minor	Minor	Moderate	Minor	Minor	Minor
RELATIVE SCORE	**8**	**7**	**8**	**7**	**7**	**5**

** These options may have limitations in implementation due to logistical or functional constraints, as highlighted in Table 2-1.*

The overall relative score for each potential nourishment option giving consideration to social and environmental factors (refer Table 3-5) was then weighed against the two financial factors, as given in Table 3-6, to establish an overall preferential ranking for the nourishment options.

The Financial Factors considered in the evaluation include:

- Total lifecycle cost: this is typically taken as 20 years based on capitalisation and subsequent depreciation of major infrastructure investment. Total lifecycle costs were taken from Table 3-2. Although the Sand Shifter (LMR-3) came out cheapest, there is a high degree of uncertainty regarding the operational costs of the Sand Shifter, given the unknown frequency and cost of equipment recovery (e.g. for blockage, general maintenance or equipment repair) . As such, the hopper options from both sites (YSS-2 and LMR-2) are considered the overall cheapest options. The CSD option was clearly the most expensive.

- Annual recurrent cost / affordability: Annual costs of up to around $100,000 are potentially affordable by Council without the need to rely on additional funding from State Government. This scale of cost has been typical for undertaking emergency nourishment works following erosion events in recent years. The hopper-based options could potentially meet this affordability limit if the loading and spreading of the material was carried out using Council staff and existing Council equipment. The Sand Shifter option also has a low annual recurrent cost, in the order of $100,000, if there is no requirement for equipment recovery. The uncertainty associated with this assumption means that the hopper-based options are the most affordable. .

The outcome of the nourishment options assessment, as presented in Table 3-6, favours a fixed in place hopper arrangement. Both Lower Myall River entrance sand spit and the Yacaaba sandwave would be suitable sites for a hopper, although the greater in-situ supply of sand at Lower Myall River would favour this site over Yacaaba.

Subject to further detailed technical investigations, the Sand Shifter may also be a preferred option, however, this would be based on the assumption that it does not encounter regular blockages and that the equipment can be recovered at minimal cost for periodic maintenance and repair. At present, the viability of recovering the equipment from such a remote location is questioned.

It is envisaged that Council would need to develop a viable and equitable financial model to source revenue from local residents to cover the annual recurrent costs of the works, as well as Council's contribution towards capital investment (e.g. levies, rates contributions).

Table 3-6 Summary of Outcomes from Options Evaluation of Cost and Benefit/Impact

	Nourishment Option					
Description	**YSS-1* (land-based)**	**YSS-2 (hopper)**	**YSS-3* (CSD)**	**LMR-1 (land-based)**	**LMR-2 (hopper)**	**LMR-3* (SandShifter)**
Total Lifecycle Cost	Expensive	Cheapest	Most expensive	Expensive	Cheapest	Unknown
Annual Recurrent Cost Affordability	Unaffordable	Possibly affordable	Unaffordable	Unaffordable	Possibly affordable	Unknown
Social / Environment Impacts	Most impact	Next best	Most impact	Next best	Next best	Least impact
Overall Rank	**4**	**2**	**5**	**3**	**1**	**-** [#]

** These options may have limitations in implementation due to logistical or functional constraints, as highlighted in Table 2-1.*

[#] *The Sand Shifter may also be a suitable option provided it can be demonstrated that the equipment would not be susceptible to blockage and could be recovered from the channel on a periodic basis at minimal expense for routine maintenance and repairs.*

4 CONCLUSIONS AND RECOMMENDED NEXT STEPS

4.1 Beach Nourishment Processes and Equipment

- The on-going nourishment approach adopted to date, which has involved periodic dredging using CSD from Yacaaba, is the most expensive and least effective method of nourishment, particularly where large quantities of sand are placed on the beachface which is then rapidly reprofiled by waves. Finding competitive tenders for CSD in Port Stephens has become more challenging in recent years given historical difficulties with such operations;
- The application of a CSD in the Lower Myall River is not worthwhile as a source of nourishment sand, as it would only be economic if it involved significant stockpiling of sand on Winda Woppa spit. As there is already an ample supply of sand in this location, there is no advantage for Jimmys Beach nourishment to placing more sand there. This conclusion does not consider any apparent advantages to the river itself that may result from periodic dredging;
- Extracting sand from existing sub-aerial deposits at the Winda Woppa sand spit is considered viable. Transportation of this material to Jimmys Beach can be either by trucking or by pumping. Pumping would involve the construction of a fixed hopper where sand would be mixed with water to create a slurry that is then conveyed by jet pumps. Although pumping has high upfront costs, the lower operational costs makes pumping considerably more economic than trucking when considered over a design life of more than 10 years. Trucking along roads may require some infrastructure upgrading to provide suitable access to the sand source and also on-going repairs / upgrades to the public roads. Alternatively, trucking along the beach face using all-wheel drive vehicles can be carried out, but has the potential to affect recreational and commercial users. It may also affect sensitive environments and may be limited by sea state (including tides);
- Sand extraction from the sub-aerial deposits at the Yacaaba sandwave would also be viable with sand potentially transported via trucks or pumped via a fixed hopper. Trucking from Yacaaba would have the additional constraints of migratory bird habitat, while the section of foreshore between Jimmys Beach and the sandwave is also more regularly used by the public for beach walking, fishing, wind-surfing and 4WD-ing;
- The Lower Myall River entrance at the end of Winda Woppa sand spit would be suitable a Sand Shifter, which could provide a steady on-going supply of sand to Jimmys Beach. The viability of a Sand Shifter is still unresolved, however, and further investigations would be necessary to determine the susceptibility of the equipment to blockage and the potential to recover the equipment from such a remote location for the purposes of regular maintenance and repairs;
- Upfront investment required for installation of a fixed hopper arrangement would be about two and a half times the cost of recent CSD campaigns; and
- Taking into consideration the social, environmental and financial factors (over a 20 year design life), the preferred nourishment option is a fixed hopper on Winda Woppa spit, with sand loaded manually into the hopper by Council staff for hydraulic transport to Jimmys Beach. While the necessary capital funding is being sourced for this preferred option, Council can commence extraction from Winda Woppa spit utilising land-based trucking, following some minor improvement to facilitate access to and from the sand spit. On-going use of trucks will likely necessitate repairs to bitumen on public sections of roadway.

4.2 Works Approvals Process

Under the provisions of SEPP (Infrastructure) 2007, waterway or foreshore management activities may be carried out by or on behalf of a public authority without consent on any land. This means that development consent under the *Environmental Planning and Assessment Act 1979* is not required for the proposed nourishment works. Notwithstanding, works are still subject to other legislation and planning provisions, including the *Fisheries Management Act 1994* and the *Marine Parks Act 1997* and associated *Regulations*.

Any works on the foreshore or in the water below high tide level will be within the Port Stephens – Great Lakes Marine Park. As such, these works will be subject to the legislation and operational plans relevant to the Park. The Marine Parks Authority (MPA) will therefore be a major stakeholder for any proposed nourishment works at Jimmys Beach, and will need to grant permission to undertake the works. The marine park zonings in the vicinity of Jimmys Beach is presented in Figure 4-1, which shows a Sanctuary zone covering the deep *Posidonia* bed located immediately offshore from Barnes Rock, while surrounding areas are General Use.

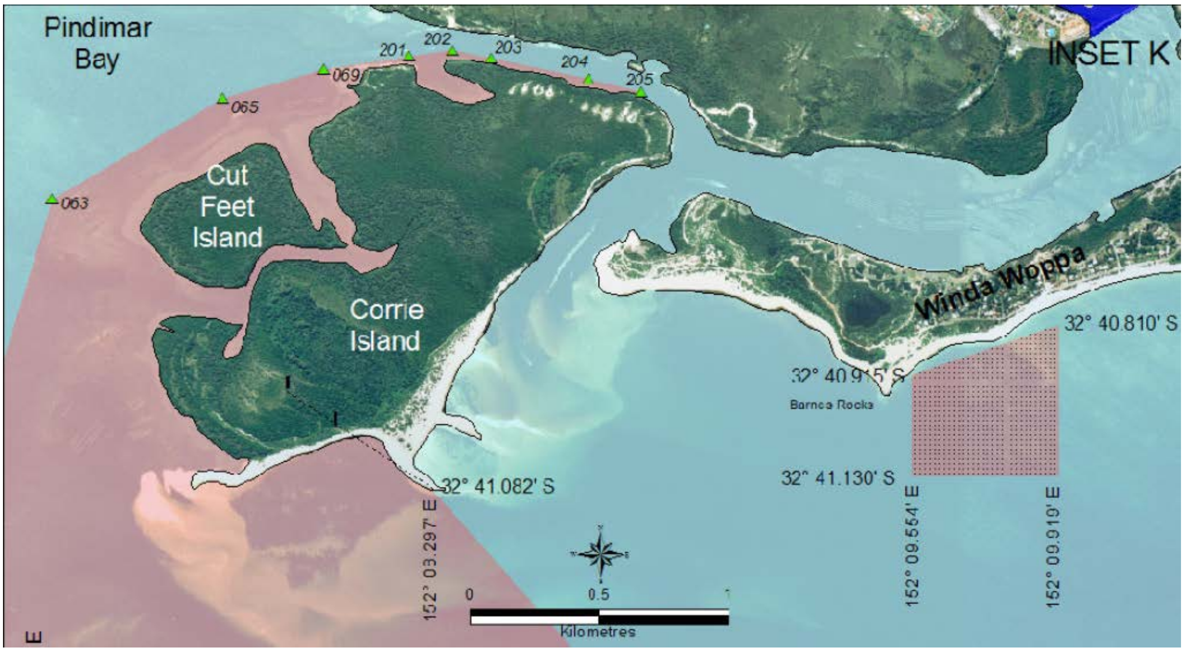


Figure 4-1 Port Stephens – Great Lakes Marine Park Zonings at Jimmys Beach (blue is general use; pink is sanctuary zone)

A Review of Environmental Factors (REF), or Environmental Impact Statement (EIS) in the event that significant environment impacts are predicted, will need to be prepared in order for Marine Parks Authority to assess impacts prior to granting permission. As the seabed in marine parks remains as Crown land, a licence under the *Crown Lands Act 1989* permitting the works will also be required. The Land and Property Management Authority (LPMA) will therefore be another major stakeholder. Concurrence from the Minister for Environment under the provisions of the *Coastal Protection Act 1979* and concurrence from the Minister for Primary Industries under the provisions of the *Fisheries*

Management Act 1994 (with respect to dredging – as a Sand Shifter may be deemed a form of dredging) would also be required as part of the Crown lands licence.

An environmental protection licence under the *Protection of the Environment Operations Act 1997* may also be required if the works are considered to constitute pollution of waters. This may be the case in respect to discharge of supernatant directly onto the beach as part of nourishment works.

4.3 Recommended Next Steps

The recommended next steps for Council are as follows:

1. Prepare an REF or EIS in support of consent applications to MPA and LPMA for extraction of sand from both Winda Woppa spit and Yacaaba sandwave. This may simply be an amendment to the current approvals for extraction. Liaison with government agencies and other stakeholders will be necessary in preparation for submission of a consent / licence applications. This would include as a minimum MPA, LPMA, DPI-Fisheries and OEH.

   Having consent to extract from both locations will provide greater flexibility for management in the future. The approvals should also incorporate transportation of sand by both trucking and hydraulic pumping. Trucking can commence immediately without any significant capital outlay. Also, it is highly unlikely that sand would be hydraulically pumped from both sites. Therefore, in the longer term, sand would be pumped from the preferred site and possibly supplemented with occasional trucking from the alternative site. As consents are likely to be required from both the LPMA and MPA, a single REF that meets the environmental assessment requirements of all agencies will need to be prepared;
2. Implement trial nourishment process wherein sand is manually extracted from Winda Woppa spit and trucked to the main erosion hot spot on Jimmys Beach on a regular basis (say 4 or more times per year, to minimise the volume moved per campaign). Assuming that nourishment is not in direct response to an erosion threat, the operations can spans 2 or more weeks thus minimising the demand for trucks, then impact on roads and the disruption to residents;
3. HOLD POINT: Undertake a review of the nourishment program. This would include a review of the fate of sand placed onto the beach (refer Section 4.4 for further details) as well as the efficacy of the adopted manual loading and trucking process (from an affordability perspective).

   If it is concluded that nourishment using sand from Winda Woppa spit is having a measurable and deleterious impact on sediment processes and accumulation patterns along Jimmys Beach, then modify trial by using sand sourced from Yacaaba sandwave (subject to any transportation restrictions associated with environmental and recreational impacts). Reassess after an appropriate period.

   If it is concluded that trucking is not an affordable solution, then seek external funding for the capital investment associated with hydraulic pumping equipment (i.e. hopper arrangement from the Winda Woppa sand spit or Yacaaba sandwave), and continue with steps below.
4. Prepare detailed designs, technical specifications and cost estimates for the hopper, associated pipeworks and discharge arrangements. In preparing designs, further consideration should be given to the Sand Shifter option, with direct liaison with manufacturers and existing users to

determine suitability and practicality for use at the Lower Myall River entrance. Should the Sand Shifter option prove to be cheaper (over the design life) and less problematic that a hopper arrangement, then amendments to the approvals should be sought allowing extraction from the subaqueous shoals of the river entrance;

5. Call for competitive tenders to construct and install capital infrastructure. Select prefer tenderer and undertake contract works. After agreed hand-over period, Council to assume full responsibility for on-going operations of the continuing nourishment program.

It is expected that the process to achieving the final goal of a fully operational on-going nourishment program would take in the order of 5 years, depending on the availability of external funding. Until such time, Council should continue with their 'emergency' nourishment program drawing sand from Deadmans dune until it is depleted, after which land-based operations and trucking could be considered from Winda Woppa sand spit (or Yacaaba sandwave) as an interim measure.

4.4 Recommended Monitoring and Further Investigations

Monitoring and further investigations are recommended to supplement trial nourishment works in order to confirm understanding of sediment processes along Jimmys Beach. The following activities are proposed:

- Priority 1 - Beach profile monitoring along the entire foreshore (and nearshore areas), from Yacaaba Headland to the Eastern Channel of the Lower Myall River. This monitoring should capture ground level / seabed level data from the hind dunes to the edge of the seagrass. It is important that these profiles are surveyed on a regular basis (at least every three months) and over a reasonable period of time representing different dominant wind and wave conditions (5 years minimum would be reasonable). The necessary data can be collected relatively rapidly using quad-bikes and jet skis kitted out with appropriate survey equipment (*Cost assumed to be about $10,000 every 3 months*). Ideally, hydrosurveys of the broader flood tide delta should also be carried out on a regular basis (say every 1 – 2 years) to capture any change to shoal patterns, tidal channels and offshore deposition areas. To complement the future beach profile data, all historical beach survey data held by OEH should also be recovered from archives and validated prior to processing;
- Priority 2 - Sediment tracers could be introduced as part of future nourishment campaigns. This would enable the specific tracking of the nourished sand. Caution in interpreting results is required as the destination of nourished sand may differ from one nourishment campaign to the next depending on prevailing environmental conditions, especially conditions immediately after the sand placement when the beach profile is out of equilibrium and most susceptible to reworking and adjustment. It is expected that the a proportion of sand lost from Jimmys Beach is directed offshore, so tracer analysis would need to recover samples from offshore locations as well as along the shoreline both east and west of the nourishment zone (*Cost assumed to be about $80,000*);
- Priority 3 - Cross-shore sediment transport modelling should be carried out at Jimmys Beach to determine the extent of storm-based erosion, and to determine the fate of eroded sediment and the propensity for return of this sediment onto the beachface during post-storm fairweather conditions. The latest shoreline modelling packages, such as EVO-MOD (developed in-house

by BMT WBM), include both cross-shore and longshore processes, and are considerably more powerful than previous industry packages such as SBEACH and GENESIS. Consideration of integrated cross-shore and longshore transport is important at Jimmys Beach. EVO-MOD is also able to predict shoreline response to sea level rise, taking into account the geomorphology of the coastline (including the impacts of Barnes Rock, the incipient salient, etc) and a future wave climate at the beachface. Importantly, the process of conducting such modelling would require a detailed review of the current and historical hydrosurvey and beach survey data (photogrammetric and other), which will also assist in a more detailed understanding of coastal processes (*Cost assumed to be about $40,000*).

5 REFERENCES

Ainley LB (2007) *Sediment transport on Jimmys Beach.* School of Geosciences, University of Sydney Honours thesis 109pp

Bagnold R.A. (1963). Mechanics of Marine Sedimentation, In *The Sea*, Ed, Mill, M.N., Interscience, New York.

Bailard, J.A. (1981). An energetics total load sediment transport model for a plane sloping beach, *Journal of Geophysical Research*, **86**, C11, 10,938 – 10,954.

Bailard, J.A. and Inman, D.L. (1981). An energetics bedload model for a plane sloping beach: local transport, *Journal of Geophysical Research*, **86**, C3, 2035-2043.

Bailard, J.A. (1984) A Simplified Model for Longshore Transport, *Proceedings of the 19th International Conference on Coastal Engineering*, ASCE, Houston, 1454-1470.

Bayram, A., Larson, M., Miller, H.C., and Kraus, N.C. (2001). Cross-shore distribution of longshore sediment transport: comparison between predictive formulas and field measurements, *Coastal Engineering*, **44** (2), 79-99.

Bayram, A., Larson, M. and Hanson, H. (2007). A new formula for the total longshore sediment transport rate, *Coastal Engineering*, **54**, 700-710.

BMT WBM (2011) *Sediment and Hydrodynamic Assessment of the Lower Myall River Estuary and Preparation of Management Recommendations*, Prepared for Great Lakes Council, BMT WBM Pty Ltd, Broadmeadow

CGC Dredging (2012). *CGC Cooper Group of Companies, Projects, Dredging* [Online], Available: <http://www.cgcgroup.com.au/>

Cholinski MP (2004) *Sandwave dynamics at Port Stephens, NSW* School of Geosciences, University of Sydney Honours thesis 150pp

Coastal Engineering Research Center [CERC] (1984). *Shore Protection Manual*, 4th Edition, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Dean, R.G and Dalrymple, R. A. (2002). *Coastal Processes with Engineering Applications*, Cambridge University Press, Cambridge 2002, pp475.

deVriend,HJ, Capobianco,M, Chesher, T, de Swart, HE, Latteux, B And Stive, MJF (1993) Approaches to long term modelling of coastal morphology: a review, *Coastal Engineering*, **21**, 225-269

DHH (2010) *SWAN Scientific and Technical Documentation*, Delft University of Technology, Faculty of Civil Engineering and Geosciences

Fredsoe, J. and Deigaard, R. (1992). *Mechanics of Coastal Sediment Transport*, World Scientific, 370pp.

GLSC and PWD (1985) *Jimmys Beach Management Report* Prepared by Great Lakes Shore Council in conjunction with Public Works Department of NSW

GLSC (1987) *Jimmys Beach Restoration Scheme: Environmental Impact Statement*. Prepared by Great Lakes Shire Council

Gordon A (1982) *An assessment of beach processes in the Hawks Nest Region* Coastal Engineering Branch Working Paper, Public Works Department of NSW

Inman D.L. and Bagnold R.A. (1963). Littoral processes, In: *The Sea*, Ed, Mill, M.N., Interscience, New York, 3:529-533.

Jelliffe (2003) *Environmental Impact Statement: Jimmys Beach sand extraction and beach nourishment scheme* Prepared for Great Lakes Council. Jelliffe Environmental Pty Ltd, Coffs Harbour

Jiang AW, Ranasinghe R, Cowell P (2011) Hydrodynamic variability along a low-energy estuarine beach located in an open estuary *Australian Journal of Civil Engineering* **9**:1 113-128

Kamphuis, J.W. (1991). Alongshore Sediment Transport Rate, *Journal of Waterway, Port, Coastal and Ocean Engineering*, ASCE, **117**, 6, 624-640.

Kamphuis, J.W., Davies, M. H., Nairn, R.B. and Sayao, O.J. (1986). Calculation of Littoral Sand Transport Rate, *Coastal Engineering,* **10**, 1-21.

Komar, P.D., and Inman D.L. (1970). Longshore Sand Transport on Beaches, *Journal of Geophysical Research*, **75**, 30, 5914-5927.

Kraus, N.C., Gingerich, K.J. and Rosati, J.D. (1988). Towards an Improved Empirical Formula for Longshore Sand Transport, *Proceedings of the 21st International Conference on Coastal Engineering*, ASCE, 1183-1196.

Kraus, N.C., Farinato, R.S. and Horikawa, K. (1981). Field Experiments on Longshore Sand Transport in the Surf Zone: Time Dependent Motion, On-Offshore Distribution and Total Transport Rate, *Coastal Engineering in Japan*, **24**, 171-194.

Kumar, V.S., Anand, N.M., Chandramohan, P., and Naik, G.N. (2003) Longshore sediment transport rate – measurement and estimation, central west coast of India, *Coastal Engineering* **48**, 95-109.

Larangeiro, S. H. C. D, and Oliveira, F. S. B. F. (2003). Assessment of the Longshore Sediment Transport at Buarcos Beach (West Coast of Portugal) Through Different Formulations, *CoastGIS '03*, Genova, Italy.

Masselink, G. and Hughes, M.G. (2003). *Introduction to Coastal Processes and Geomorphology*, Hodder Arnold, London, 354pp.

Miller, H. C. (1998). Comparison of storm longshore transport rates to predictions, *Proceedings of 26th International Conference on Coastal Engineering*, ASCE Press.

Miller, H. C. (1999). Field measurements of longshore sediment transport during storms, *Coastal Engineering*, **36**, 301-321.

MHL (2000) *Jimmys Beach Coastline Management Review: Conceptual Sediment Budget and Beach Nourishment Practices*. NSW Department of Public Works and Services, Manly Hydraulics Laboratory MHL1041

MHL (2001) *Jimmys Beach Coastline Management Review: Draft Management Strategy*. NSW Department of Public Works and Services, Manly Hydraulics Laboratory MHL1094

MHL (2007) *Environmental Monitoring Documentation for Jimmys Beach Renourishment Program: Environmental Management Strategy*. NSW Department of Commerce, Manly Hydraulics Laboratory MHL1612

Patterson Britton (2005) *Jimmys Beach sand extraction and beach nourishment scheme: Statement of Environment Effects Addendum*. Prepared for Great Lakes Council, Patterson Britton and Partners Pty Ltd, North Sydney

PWD (1987) *Jimmys Beach Erosion Study* NSW Public Works, Coastal Branch

Schoonees, J.S. and Theron, A.K. (1996) Improvement of the Most Accurate Longshore Transport Formula, *Proceedings of the 25th International Conference on Coastal Engineering*, ASCE, 3652-3665.

Slurry Systems Marine (2007), *Innovations in Sand Pumping* [Online], Available: <http://www.ssm.com.au>

Smith, E.R., Ebersole, B.A. and Wang, P. (2004). *Dependence of Total Longshore Sediment Transport on Incident Wave Parameters and Breaker Type*, US Army Corps of Engineers, CHETN–IV–62.

Thom BG, Shepard M, Ly C, Roy PS, Bowman GM, Hesp PA (1992) *Coastal geomorphology and late quaternary geology of the Port Stephens-Myall Lakes area.* Department of Biogeography and geomorphology, ANU Monograph No. 6, 407pp

Van Rijn, L.C. (2005). *Principles of Sedimentation and Erosion Engineering in Rivers, Estuaries and Coastal Seas*, Aqua Publications, Amsterdam, 580pp.

Van Rijn, L.C. (2001). *Longshore Sediment Transport*, Report No. Z3054.20 Delft Hydraulics, Delft, The Netherlands.

Vila-Concejo A, Short AD, Hughes MG, Ranasinghe R (2007) Flood-tide delta morphodynamics and management implications, Port Stephens, Australia *Journal of Coastal Research* **SI50** 705-709

Vila-Concejo A, Short AD, Hughes MG, Ranasinghe R (2009) Formation and evolution of a sandwave on an estuarine beach *Journal of Coastal Research* **SI56** 153-157

Vila-Concejo A, Hughes MG, Short AD, Ranasinghe R (2010) Estuarine shoreline processes in a dynamic low-energy system *Ocean dynamics* **60** 285-298

Vila-Concejo A, Austin TP, Harris DL, Hughes MG, Short AD, Ranasinghe R (2011) Estuarine beach evolution in relation to a flood tide delta *Journal of Coastal Research* **SI64** 190-194

Wang, P., Ebersole, B.A. and Smith, E.R. (2002). *Longshore Sand Transport – Initial Results From Large Scale Sediment Transport Facility*, US Army Corps of Engineers, CHETN–II–46.

Wang, P., Kraus, N.C., and Davis, R.A. Jr. (1998). Total Longshore Sediment Transport Rate in the Surf Zone: Field Measurements and Empirical Predictions, *Journal of Coastal Research* **14(1)**, 269-283.

Watson P (1997) Port Stephens sand nourishment projects: evaluation, monitoring and sustainability *Proc. Aust. Ports & Harbours Conference*, Christchurch NZ

Watson P (1999) *Volumetric analysis of photogrammetric data for Jimmys Beach* Department of Land and Water Conservation, Coastal Management Program

Watson P (2000) Jimmys Beach, Port Stephens, NSW: An expensive learning experience in coastal management. *Int Conf. On Coastal Engineering*, Edge, BL (editor) Sydney, ASCE: 3566-3579

PART B – Supporting Technical Assessment of Coastal Sediment Processes

6 TECHNICAL REVIEW OF JIMMYS BEACH SEDIMENT DYNAMICS

6.1 Review of Previous Investigations of Jimmys Beach

6.1.1 Previous Studies under NSW Coasts & Estuaries Program

6.1.1.1 Pre-Nourishment

Jimmys Beach has been a known erosion area for many decades, however, it has only become a significant cause of concern since the Winda Woppa peninsula was developed for residential properties in the 1970s. As part of a broader assessment of beach erosion around the Great Lakes area, Gordon (1982) developed a heuristic conceptual model of Jimmys Beach based on consideration of wind, waves and currents. From his qualitative assessment, Gordon concluded that littoral drift east of Barnes Rock was essentially towards Yacaaba Headland. As the orientation of Jimmys Beach swings more SE at its eastern extremities (to face south-west), the combined effect of sea and swell counterbalances the easterly littoral drift causing deposition and a thickening of the Yacaaba isthmus that had been observed since the 1960s. Gordon considered that, historically, the isthmus would have been a pathway for the sediment to be transported by Aeolian processes onto the ocean beach (Bennetts Beach) under the influence of strong westerly winds, but this has now been largely impeded by establishment of dune vegetation.

PWD (1987) undertook a detailed Erosion Study of Jimmys Beach, which involved various field measurements, including the construction of a temporary groyne over an 8 month period (in 1984). The study found that severe erosion on Jimmys Beach during the monitoring period was the result of combined ocean swell wave energy and alongshore currents that were induced by wind waves and wind stress effects, which transported sand in an easterly direction. During fair-weather conditions, PWD estimated easterly transport of 17,500m^3/year and westerly transport of 12,500m^3/year, (giving a net 5000m^3/year easterly transport). It is assumed that these values were determined for the main area of erosion on Jimmys Beach, and are not necessarily constant along the whole beach alignment. Based on photogrammetric profiles of the eroded beachface, PWD calculated there had actually been some 8000m^3/year of erosion, meaning that approximately 3000m^3/year occurred during non-fair-weather (i.e. storm) conditions. It is unclear from the study whether the 1984 emergency nourishment works induced a temporarily higher rate of erosion as the beach profile adjusted to the sudden bulk deposition of sand on the beachface.

On his review of the document, Professor Doug Foster (UNSW) noted the uncertainties associated with the extremities of the system and the apparent sink for the sediment. Notwithstanding, he commented that the conclusion of dominant easterly sediment transport along Jimmys Beach was reasonably well supported.

A Management Report (GLSC & PWD, 1985) and supporting EIS (GLSC, 1987) were prepared on the basis of the PWD Erosion Study, which outlined a proposal for immediate and on-going nourishment as a means of addressing erosion at Jimmys Beach. The Management Report also considered a range of structural options, but discounted these mostly on costs and aesthetic grounds. The Management Report investigated various sources of sand for nourishment purposes, including the Yacaaba isthmus and Corrie Channel (Lower Myall River Eastern Channel). The Management

Report and EIS led to the approval and execution of nourishment works carried out in 1988, 1992, 1995 and 1998 (although the staging of these works was somewhat different from the annual campaigns proposed in the EIS, but total volume nourished was as proposed, i.e. 300,000m^3 over 10 years). The Management Report recommended the Yacaaba isthmus as the preferred site for sourcing of nourishment sands, because this was considered the terminus for sand naturally eroded off Jimmys Beach. Contrary to this recommendation, Corrie Channel was actually chosen for the nourishment works because of improved logistics and lower costs (e.g. more sheltering from swell and shorter distance for pumping from a dredger).

6.1.1.2 Post-Nourishment

Watson (1997, 1999, 2000) provides a comparison of survey profiles of Jimmys Beach (east of Barnes Rock) for the period 1991 to 1997. The findings indicate a rate of erosion well in excess of previous calculations of longshore transport as well as previous measurements of beach erosion. The increased rate (recorded as 17,500m^3/year between 1992 and 1995, and then 26,300m^3/year immediately after the 1995 nourishment works) was considered to be higher due to the beach profile imbalance induced by the nourishment. Watson also outlined that volumetric analysis of photogrammetric profiles of the whole Jimmys Beach embayment (from Kururma Cres to Yacaaba Head) showed no net sand loss between 1963 and 1983 (only a rotation of the shoreline alignment, with recession in the western portion and accretion in the eastern portion of the embayment). This conclusion was predicated on the assumption that the beach system was ‘closed’, with no other significant longshore inputs or outputs of sediment along the beach compartment. From 1985 to 1999, Watson calculated that sediment accumulated adjacent to the Yacaaba isthmus at a rate of 11,900m^3/year, or 170,000m^3 in total. This sediment accumulated almost exclusively in one location forming a ‘sandwave’ protuberance on the shoreline.

MHL (2000) were commissioned to carry out photogrammetric analysis of beach profiles, and calculated a design short-term storm bite of about 50m^3/m for most of the beach, and up to 70m^3/m (equivalent to 8m linear storm bite) in some isolated sections (it is assumed that this storm bite related to extreme wave conditions and water levels during storms). MHL also established long term recession trends from photogrammetry, giving lineal recession of ~0.4m/year (in the absence of nourishment) for the key erosion area, a recession of 0.09m/year for the NE corner of the embayment, and substantial accretion adjacent to isthmus. From the rates calculated by MHL, the NE corner can be considered relatively stable, given the low rates of recession and the expected accuracy of the photogrammetric analysis.

MHL adopted the conceptual model of easterly sediment transport along Jimmys Beach, but at an increased transport rate of 20,000m^3/yr, which more reflects the post-nourishment erosion rate measured by Watson. A Management Strategy was also produced by MHL (2001), which proposed further nourishment (initially 40,000m^3 and then twice per year of 10,000m^3 ea.) plus construction of a buried toe wall (in addition to changes to local planning provisions and implementation of an emergency management plan). Sand for the nourishment was to be sourced from Yacaaba isthmus nearshore shoals given that this is the likely terminus of sand eroded from Jimmys Beach (and in light of the rapid accumulation of sediment in that location over the preceding 15 year period). An EIS for Jimmys Beach Sand Renourishment (Jelliffe, 2003) covering the MHL strategy works (excluding the toe wall) was prepared, as well as an addendum to this (Patterson Britton, 2005) that changed the nourishment transport process from the original trucking to an alternative of pumping via a temporary pipeline at the back of the beach. Approval was gained for up to 90,000m^3 of nourishment, comprising an initial bulk material campaign and follow-up maintenance nourishment. The nourishment works carried out in 2008 – 2010 (refer Table 1-1) fall under this approval. A series of environmental monitoring and emergency management plans were prepared to support the nourishment campaigns (MHL, 2007).

6.1.2 University of Sydney Studies

The University of Sydney School of Geosciences has been studying Port Stephens and Jimmys Beach in detail for about 10 years, mostly under the direction and supervision of Dr Ana Vila-Concejo. Cholinski (2004) undertook an Honours thesis on the evolution and migration of the sandwave at Yacaaba isthmus. Cholinski considers that the sandwave has evolved since 1980 from transverse bars moving on-shore. He also states that the sandwave migrated westward (or more accurately northward) at a rate of 70m/year, but only as far as the central part of Yacaaba Barrier. The source of sediment onto the sandwave according to Cholinski was oceanic in origin, based on historical observations, aerial photographs and charts. Ainley (2007) supported this hypothesis by sediment composition and texture analysis of the material on the sandwave. Vila-Concejo *et al.* (2007) also noted that the Winda Woppa spit west of Barnes Rock extended westward by some 275m between 1994 and 2006, continuing a process of westward growth reported in Thom *et al.* (1992). These conclusions supporting a net westward transport of sand along Jimmys Beach were contradictory to the previously held conceptual model of Jimmys Beach, which involved eastward transport of sand along the foreshore.

Recognising these differences, the Yacaaba sandwave dynamics were revisited by Vila-Concejo *et al.* (2009). Their assessment confirmed previous reports of gross shoreline accumulation along the Yacaaba isthmus between 1968 and 1986, with the sandwave undergoing periods of development, growth and erosion over the period 1986 to 2001. *Vila-Concejo et al.* concluded that westward migration of the sandwave was actually not clear, and that it had mostly stabilised in its present location with only a small further migration between 2006 and 2008. In order to provide more certainty around the coastal processes of Jimmys Beach, Vila-Concejo *et al.* (2010, 2011) carried out a detailed field study measuring wind, nearshore waves and currents, and beach profiles through topographic surveys. The results of the fieldwork show that March 2007 to April 2008 experienced overall erosion of the beach and sandwave of approximately 42,000m^3. This is equivalent to a loss of 10m^3/m over the entire shoreline, or approximately 2 metres net landward recession. During this period severe and extreme storms occurred in June and July 2007 (including the devastating Pasha Bulker Storm). Surprisingly during the stormy June-July period, the sandwave actually accumulated a volume of approximately 65,000m^3. Vila-Concejo *et al.* inferred that large south-east waves delivered sand onto the sandwave sourced from either the outer parts of the flood tide delta or from sand accumulating south of Yacaaba Head in what would be an incipient ebb-tide delta.

Field measurements undertaken by Vila-Concejo *et al.* (2010, 2011) during the observation period indicated that westward currents generated by storm ocean waves can entrain sediment at the shoreline for 50% of the time. By contrast, the observations indicated that eastward currents tended to be weak, even under strong westerly wind conditions. Vila-Concejo *et al.* (2010, 2011) considered it unlikely that these easterly currents would have the energy needed to counteract the large southerly ocean storm waves that periodically propagate into the estuary.

The largest erosive episode on Jimmys Beach during the study period was March – May 2007 (prior to the severe storms of June 2007). This particular period did contain a few storms after an extended calm period. The study did not show a clear direction for longshore sediment transport in the key erosion zone. Significant westward extension of Winda Woppa spit, however, including 200m between 2006 and 2008, led Vila-Concejo *et al.* to infer that at least some of the sand eroded from Jimmys Beach was directed westward onto the spit. This conclusion by Vila-Concejo *et al.* did not consider the substantial erosion of the shoreline to the west of Barnes Rock, which was clearly a supply of sediment for the rapid accretion of the Winda Woppa spit over this period (BMT WBM, 2011).

6.2 Longshore Sediment Transport Calculations

Longshore sediment transport rates were assessed along the shoreline spanning from Barnes Rock through to Yacaaba Headland (refer Figure 1-1), utilising empirical equations with input from numerical modelling. The empirical equations were derived by a range of authors, which have been revised through numerous field studies of sand transport along coastlines.

6.2.1 Longshore Sediment Transport Equations

Sediment transport in water can be represented in terms of scouring and advection / dispersion processes. In the surf zone, both current and wave actions significantly alter the scouring and transport processes. The calculation of longshore transport rates is considered to be relatively inaccurate. Therefore, different methods for calculating the longshore transport have been considered in deriving representative values. Previous assessment of formulae to estimate longshore sediment transport along shorelines within Port Stephens (BMT WBM, 2011) identified the following three formulae as appropriate:

- The *CERC* (CERC, 1984) formula. This is probably the most commonly used longshore sediment transport formula in engineering practice. It applies to coastal sediment transport on sandy beaches, however, it is not reliant upon sand grain size, and the formula has frequently been found to over-estimate sediment transport, particularly in low wave conditions (see Smith *et al.* 2004; Kumar *et al.* 2003; Wang *et al.* 1998). As such, it provides a conservative estimate of sediment transport;
- The *Kamphuis* (1991) equation. This formula was found to provide the best fit to measured data, in a comprehensive study of 52 formulas with 123 data sets (Schoonees and Theron, 1996), and as such has been widely used in engineering practice. Subsequent studies (e.g. Smith *et al.* 2004; Wang *et al.* 1998; Miller 1998) have suggested the formula may underestimate to overestimate longshore sediment transport under low wave conditions. This equation additionally includes grain size and beach slope as part of the calculation of longshore sediment transport;
- The *Van Rijn* (2001) formula. This formula was developed from an existing and frequently applied sediment transport formula for estuaries, and incorporates grain size, beach slope, and additionally incorporates longshore currents, such as tidal or wave driven currents, which may be of relevance to Jimmys Beach shoreline. Using field data, Van Rijn (2001) found this formula yielded better approximations of the measured data than the CERC and Kamphuis equations.

A detailed description of the history of development of longshore sediment transport formulae, the level of accuracy and the formulae appropriate to this assessment is provided in Appendix A.

There are a number of parameters required by these formulae in order to calculate a rate of transport and, in the absence of adequate field data to provide input, numerical modelling has been used to provide additional data for input to these calculations.

6.2.2 Numerical Modelling

Two numerical models were utilised to provide input on wave characteristics and tidal velocity, as required in the empirical equations noted above.

6.2.2.1 Wave Modelling

The Simulating WAves Nearshore (SWAN) model is a spectral coastal wave model code developed by the Technical University of Delft in the Netherlands and may be configured to explicitly account for all relevant processes of propagation, generation by wind, interactions between the waves and decay by breaking and bottom friction with diffraction being included in an approximate manner (DHH, 2010).

A previously developed wave model (refer BMT WBM 2011) covering the Port Stephens / Myall Lakes Estuary (Figure 6-1) was utilised to propagate “deep water” data measured at the WaveRider buoys inshore to the area of interest for the present study. The model computes irregular waves in nearshore areas, based on variables such as deep water wave conditions, wind, bottom topography, currents and tides. For further details of the wave model development including bathymetry, geometry and boundary conditions, refer to Appendix B and BMT WBM (2011).

Two categories of waves may be contributing to the longshore transport, namely:

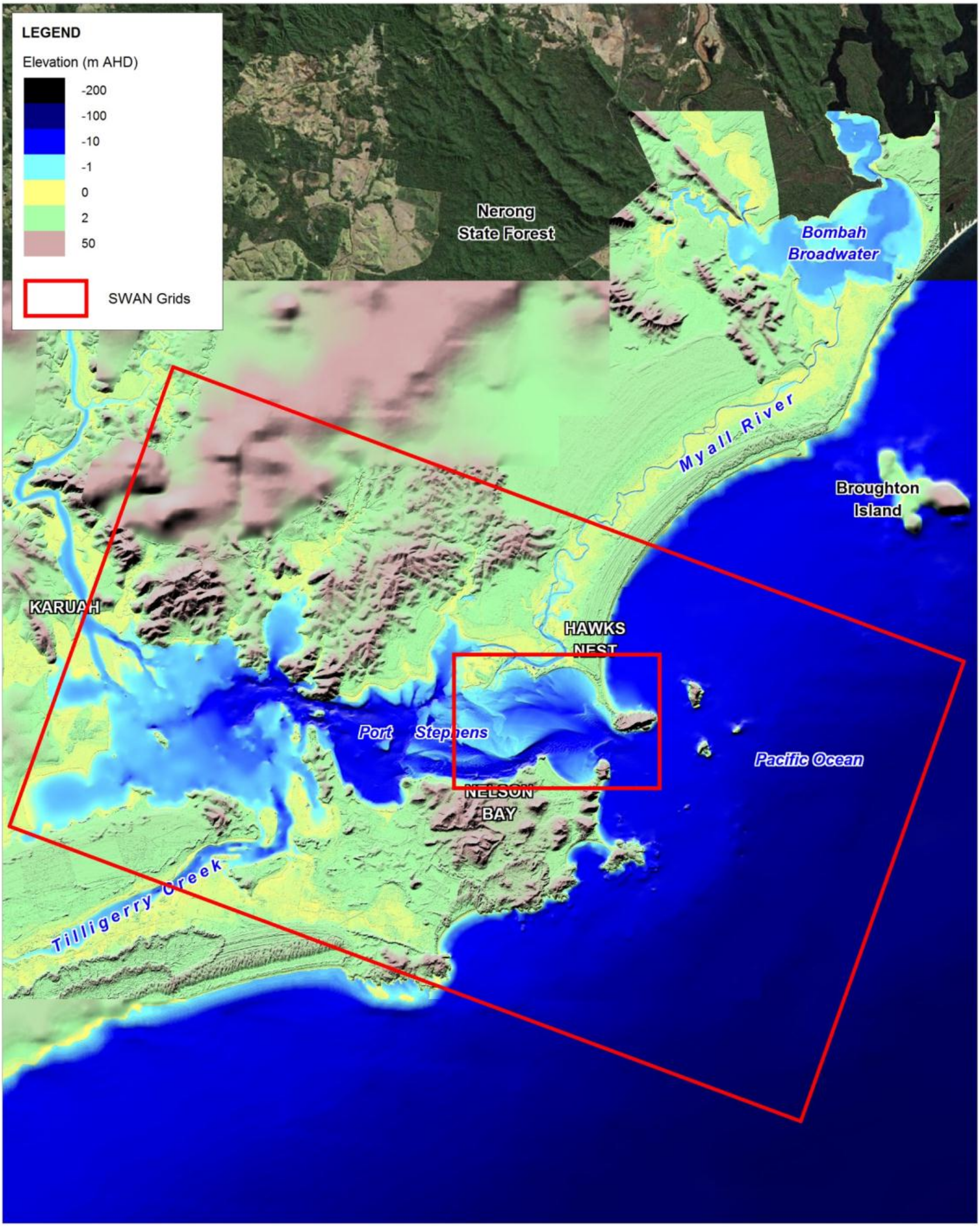
- Local wind waves caused by winds blowing over the surface of Port Stephens; and
- Ocean swell waves propagating in through the entrance of Port Stephens.

The following sections describe the identification of suitable ranges of swell and wind conditions, as well as their application for extraction of wave model data, at a number of transects within the study region (see Figure 6-2).

<u>Swell waves</u>

Ocean swell statistics were derived by analysing the WaveRider data from Sydney over a period of 15 years. Data were organised into 22.5 degree bins. Swell occurred between bearings of 45 and 225 degrees (NE to SW) due to the orientation of the coastline. The proportion of time swell occurs from each direction is given in Figure 6-3.

The data in each directional bin was further subdivided into bins based on the wave period which ranged between 4.5 and 17 seconds. Each of the direction/wind speed bins was assigned a probability based on the proportion of time winds fell within that bin in the wave record. Bins with a probability of less than 0.01% were considered to be statistically insignificant. Probability distributions of swell wave heights for each of these bins were obtained though statistical analysis. Wave height cases were defined for each bin representing an exceedance probability of 20, 40, 60 and 80%.



Title:

Wave Model Extents

Figure: 6-1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Title:
Location of Transects

Figure: 6-2

Rev: A

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Approx. Scale

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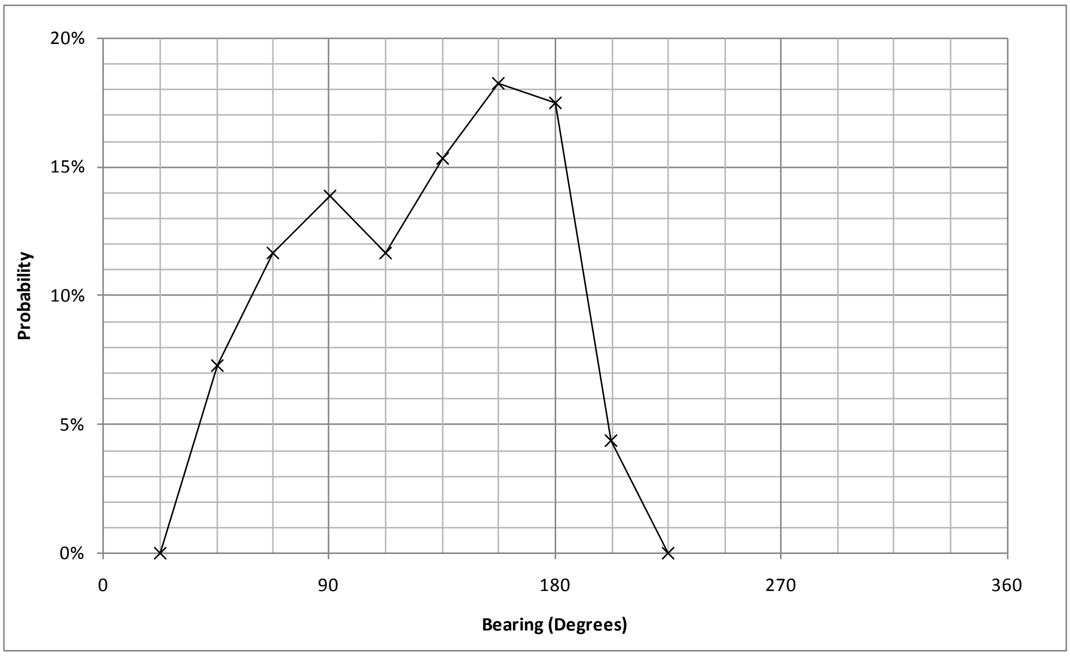


Figure 6-3 Prevalence of Ocean Swell from each direction (measured counter-clockwise from North)

A SWAN wave model simulation was subsequently executed for each case, using a direction, period and wave height representative of that case. The height and direction of the resultant breaking wave was determined and used in the longshore transport calculation.

Wind waves

Wind statistics were derived from the 20 year wind record collected at Williamtown, and data organised into 45 degree bins. The proportion of time wind occurred from each direction is provided in Figure 6-4.

The data in each directional bin were subsequently subdivided into bins based on ranges in wind speed of 2 km/h. Wind data from each directional bin was ranked in order of probability based on the statistical analysis previously undertaken. All bins with a probability greater than 0.3% were considered as separate scenarios. All other cases were considered to be statistically insignificant.

A SWAN wave model simulation was executed for each case, using a direction and wind speed from the representative bins. The height and direction of the resultant breaking waves was determined and used in the longshore transport calculation. As well as wave direction, period, breaker height and depth for each of the wind and swell conditions were considered.

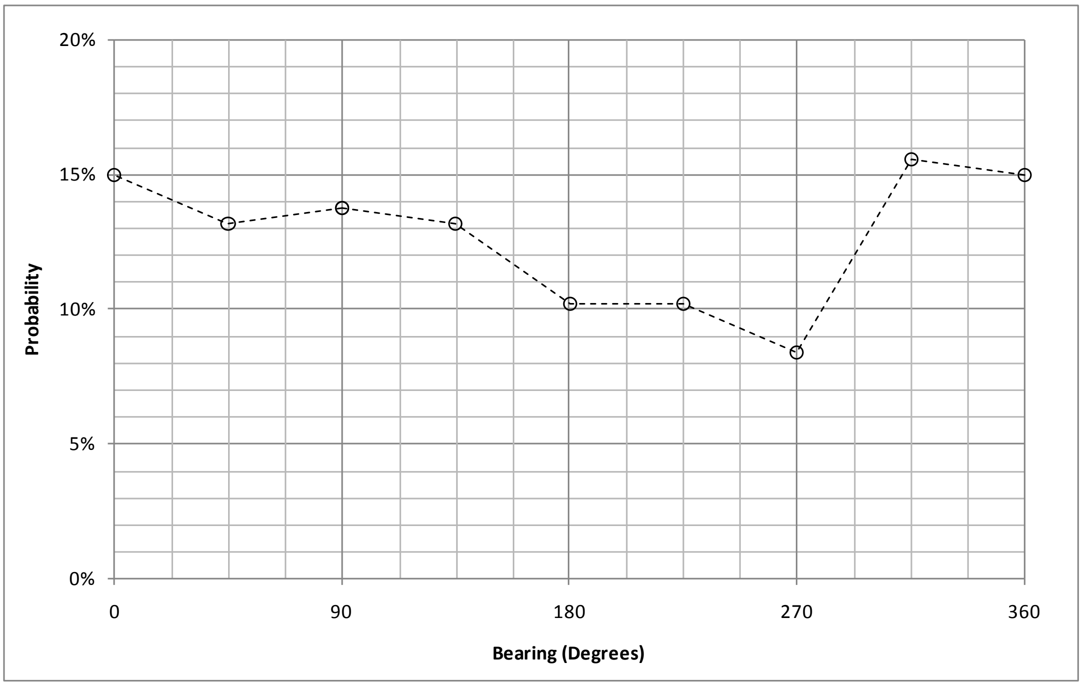


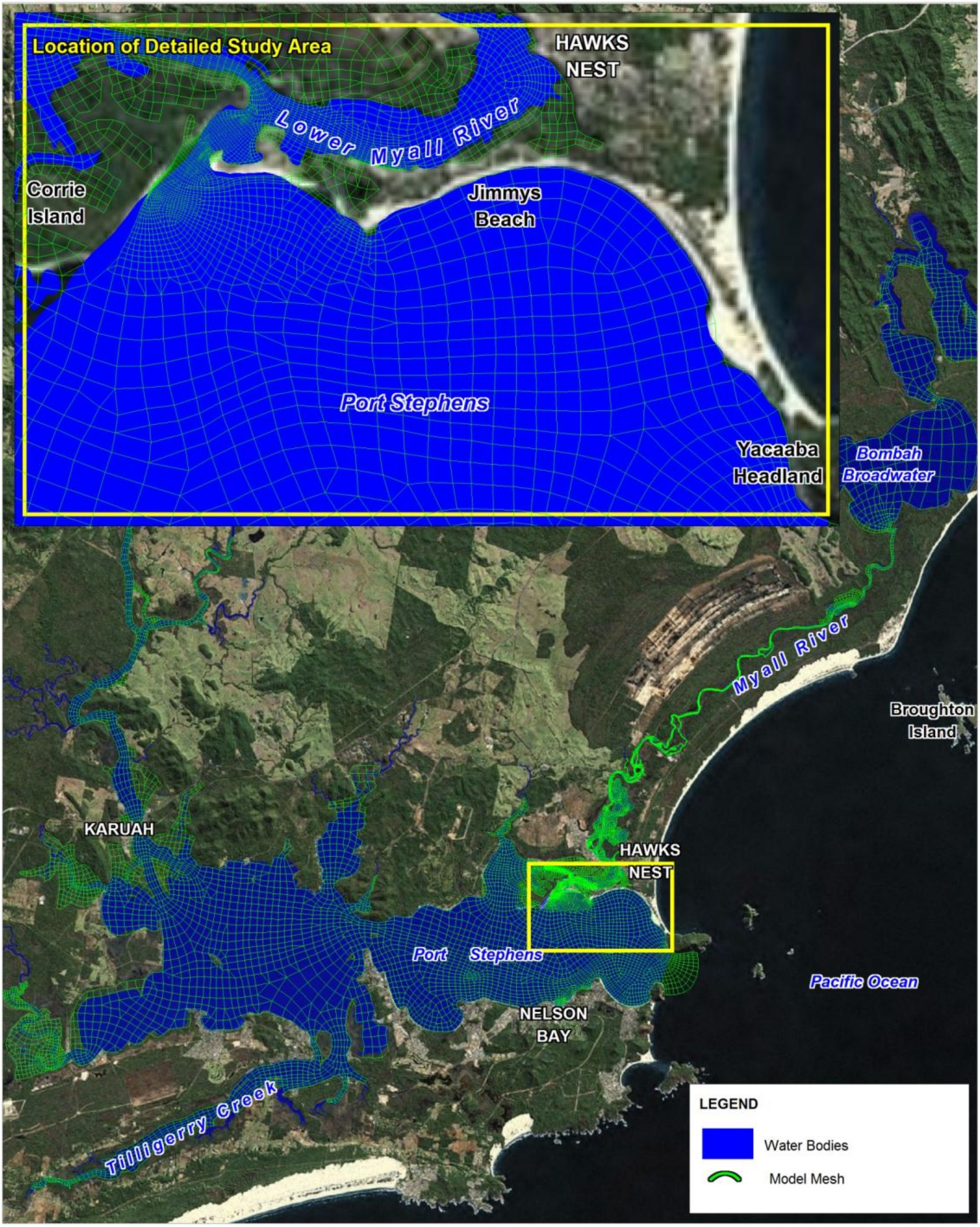
Figure 6-4 Prevalence of Winds from each direction (measured counter-clockwise from North)

6.2.2.2 Tidal Modelling

An existing hydrodynamic model (TUFLOW-FV) (Figure 6-5) of the Port Stephens / Myall Lakes Estuary was developed and calibrated previously (refer Appendix B and BMT WBM, 2011). TUFLOW-FV is a two dimensional finite volume model code that solves the conservative integral form of the non-linear shallow water equations (NLSWE) (i.e. assuming that pressure varies hydrostatically with depth). It including viscous flux terms and source terms for Coriolis force, bottom-friction and various surface and volume stresses.

To define tidal current velocities along the shoreline of the study region the following process was followed:

- Mean spring tide was applied as an ocean boundary to the hydrodynamic model to drive tidal currents, for 30 days. Mean spring tides have been shown to adequately represent the tidal cycle without the interference of storms, wind or wave components (deVriend *et al.* 1993);
- Tidal velocity magnitudes were extracted, hourly, from locations along each transect (see Figure 6-2); and
- Mean tidal velocities were calculated by averaging results over a number of tidal cycles, with the sign of the mean tidal velocity defining the direction of the mean tidal current i.e. negative values resulted in landward flow and positive values resulted in seaward flow, with compass direction depending on each transects location relative to the shore normal (that is, flow perpendicular to the shoreline).



Title:
TUFLOW FV Model Extents

Figure: 6-5

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N 0 5 10km Approx. Scale

BMT WBM
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Mean tidal currents (Figure 6-6) were found to be variable along the study region shoreline. Between Transects 56 and 73 there is a preference for westward (flood-tide dominated) tidal currents, whilst from Transect 74 to 85 there is a preference for south easterly tidal currents (ebb-tide dominated). Transects 86 to 94 are influenced by the Yacaaba sandwave and extensive shallow nearshore shoals.

The mean tidal velocities close to the shoreline are small, however, when combined with the stirring effects of breaking waves, may yield the potential for transport.

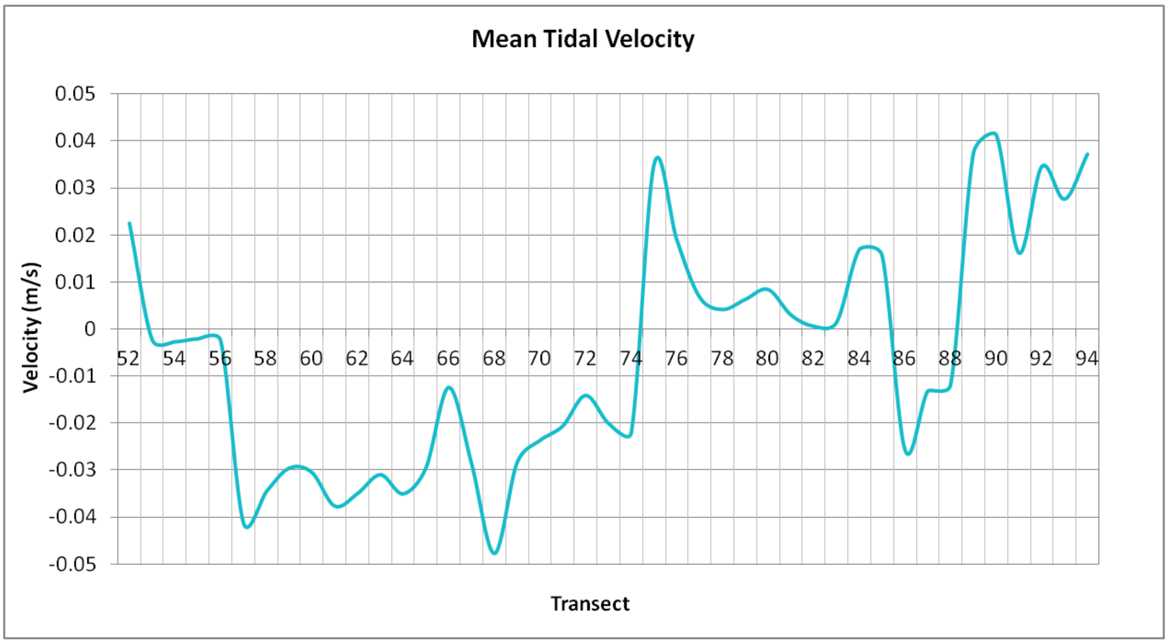


Figure 6-6 Mean tidal velocity at each transect (positive values are eastward; negative values are westward) – refer Figure 6-3 for Transect locations

6.2.3 Annualised Longshore Sediment Transport Rates

Longshore transport rates were calculated at 43 transects established along Jimmys Beach, from Barnes Rock through to Yacaaba Headland, as shown in Figure 6-2. For longshore transport calculations, it is necessary to define the characteristics of breaking waves. As discussed above, SWAN was used to determine breaking wave directions and heights along these transects for numerous local wind wave and ocean swell wave conditions.

Based upon sediment sampling conducted by MHL (1993), a median (d_{50}) grain size for shoreline sediments near Jimmys Beach was assessed to be 0.47 mm. Values for sediment density, bulk density of in-situ sand, and mud fraction recommended by Van Rijn (2001) were used. The values are considered reasonably representative for this site, and any localised variation from the adopted values is unlikely to represent a significant effect on the estimated overall impact from any proposed sand removal.

Beach slopes, from the wave breaking location to the shore, were extracted from the numerical model and were specific for each transect and wave breaking location.

The CERC, Kamphius and Van Rijn formulae were all investigated as part of this assessment with the following conclusions:

- the CERC formula is commonly applicable to high energy storm conditions, but generally over predicts by up to an order of magnitude;
- the Kamphuis equation can also over estimate rates for low wave breaking wave heights, although it generally underestimates longshore sediment transport on high energy open coasts; and
- the Van Rijn formula has an advantage over the other formulae in that the tidal current (as opposed to the current generated by waves) is also an input to the calculation.

Annualised calculations of longshore sediment transport have therefore adopted the Van Rijn computations, which are believed to be the most appropriate for the study region. The annualised sediment transport rate represents the average longshore sediment transport over one year. The rate is calculated by identifying the average number of days per year for which each condition occurs (i.e. specific wind or swell condition), and multiplying those days by the transport rate relevant to the condition. Total transport rates from each of the wave parameters and respective days per year occurrence were added to determine an average annual rate of transport.

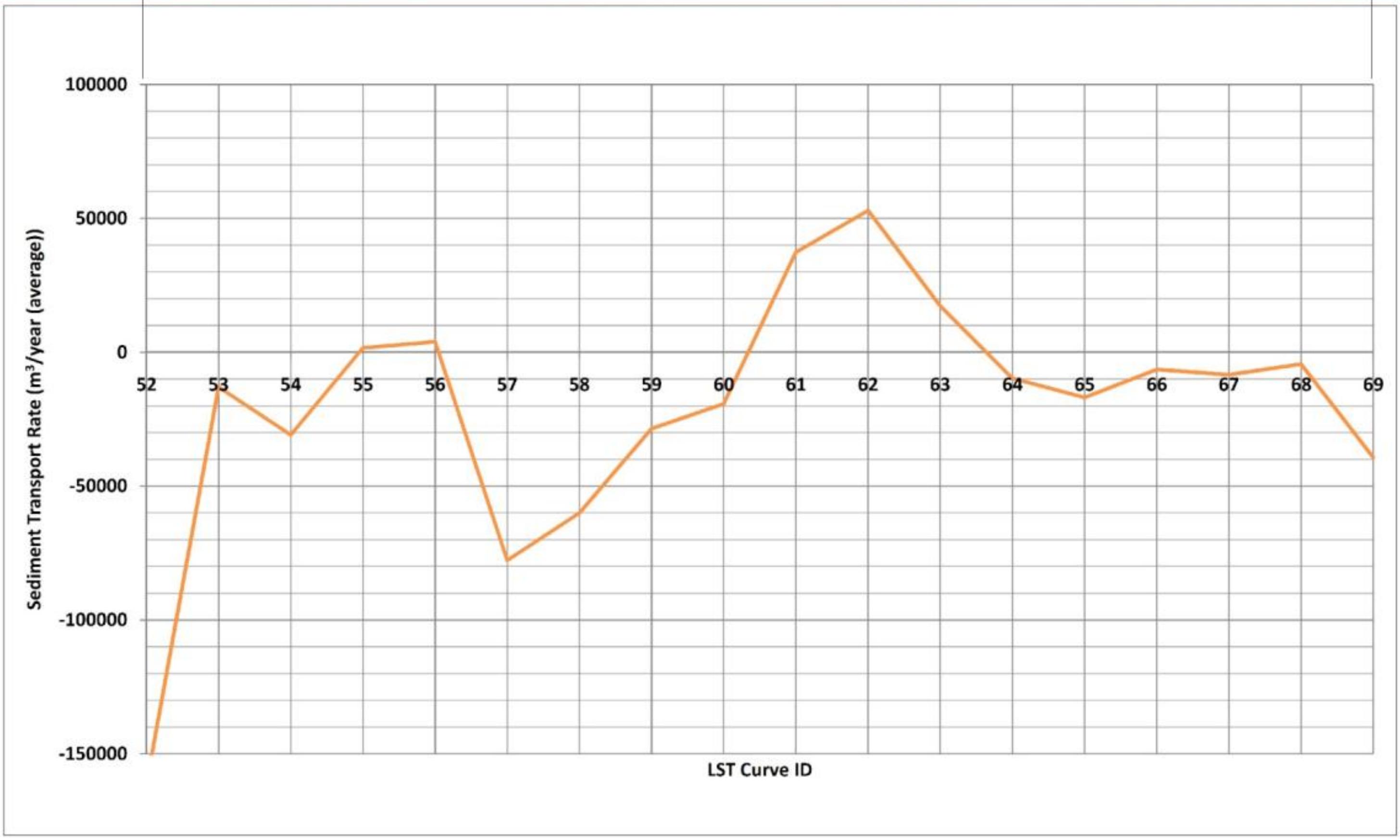
6.2.3.1 Results

A summary of annual net longshore transport rates generated by statistically weighted wind wave and swell conditions is presented in Figure 6-8 and Figure 6-9, respectively, while the total net longshore rate (summing both swell and wind contributions) is presented in Figure 6-7 for the shoreline section of key erosion interest, along the Western Jimmys Beach foreshore.

For these figures, positive values for transport indicate an eastward direction of sandflow, while negative values indicate a net westward direction for longshore transport. Swell waves dominate longshore sediment transport potential, and are approximately an order or magnitude larger than wind waves. This is not surprising, as the swell waves have a wave height at the shoreline that are considerable larger that wind waves. Close review of the results indicates that tidal currents provide a very small contribution to total longshore sediment transport.

The results indicate that there is some variability to both direction and magnitude in net longshore transport potential along the shoreline. Interestingly, the results indicate a 'null point' around the main erosion zone on Western Jimmys Beach, with sediment transport being directed away from this point in both directions. To the west of the null point (Profiles 57-59) there is a net westward longshore sediment transport potential, while immediately east of the null point (Profiles 61-63) there is a net eastward sediment transport potential. This is consistent with independent analysis by Jiang et al. (2011), who also calculated opposing longshore transport directions in this vicinity.

Apart from the Western Jimmys Beach section (including around Barnes Rock) and the shoreline closest to Yacaaba Headland, total longshore transport has been calculated to be quite small. This is considered reasonable given there is limited obliquity of the shoreline to the incoming swell waves (and wind waves are small in comparison).



Title:

Annualised Total Longshore Sediment Transport (Transects 52 - 69)

Figure: **6-7**

Rev: **A**

N

0 200 400m

Approx. Scale

BMT WBM

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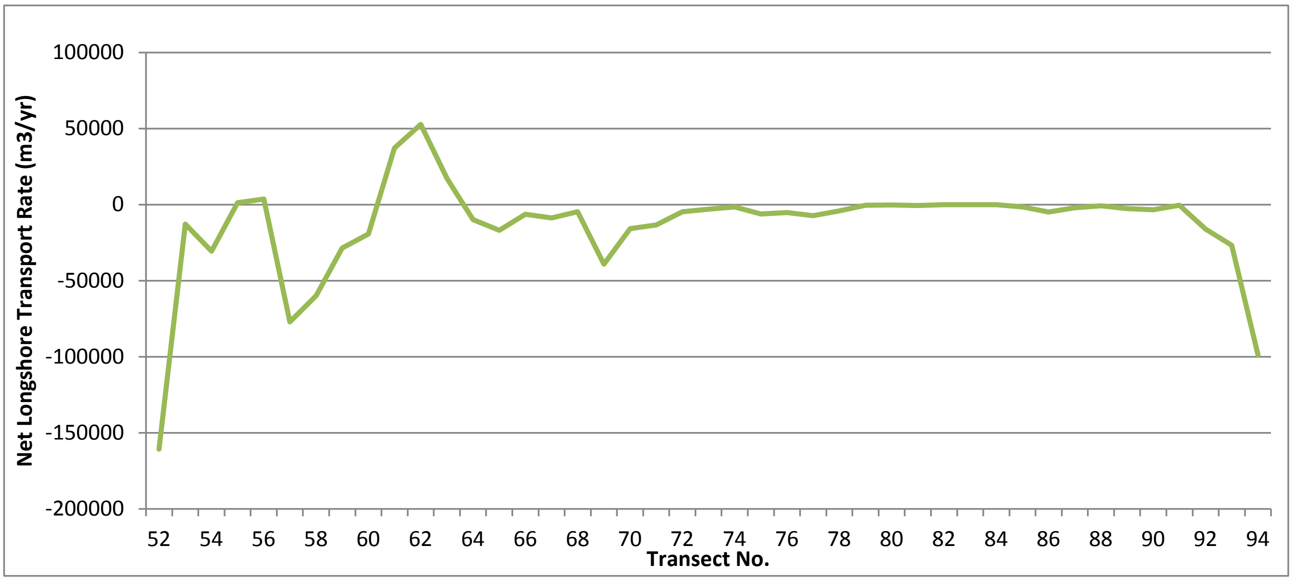


Figure 6-8 Net Longshore Transport Rate from Swell Waves

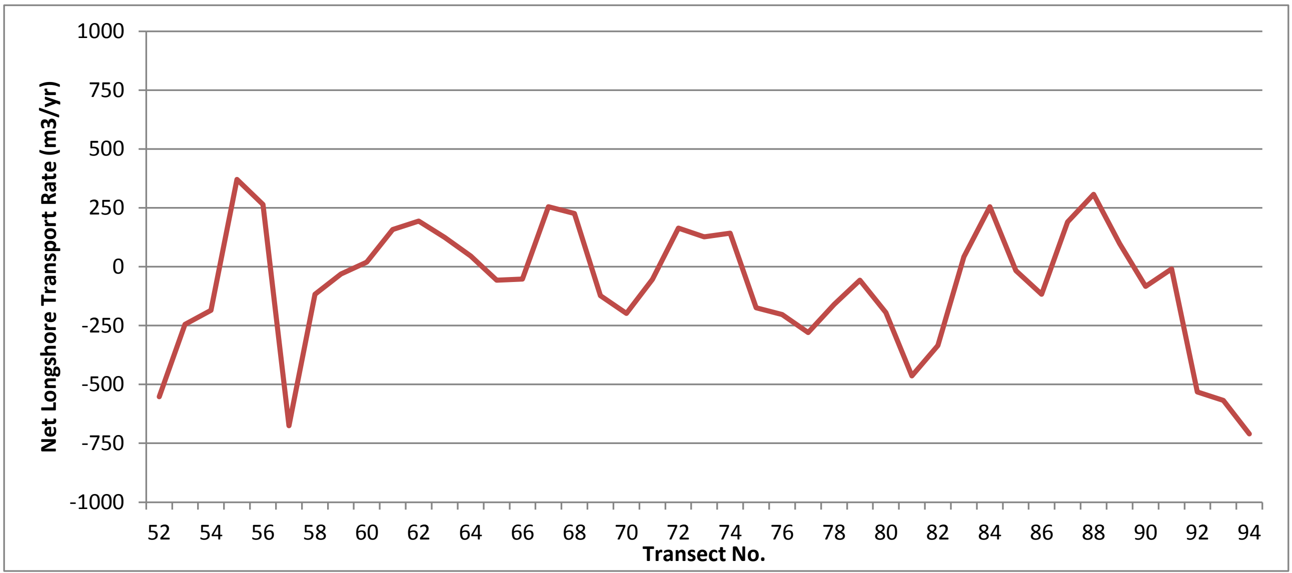


Figure 6-9 Net Longshore Transport Rate from Wind Waves

6.3 Conceptual Understanding of Beach Processes and Required Beach Nourishment Rate

It is not the intent of this study to reach an agreed position of the coastal hydrodynamic and sediment dynamic processes along Jimmys Beach, however, it in the context of assessing long-term options for beach nourishment, it has been necessary to consider the expected fate of eroded sand and the rates of sand loss from the main hot spot area of Jimmys Beach. In this regard, we have drawn from information provided in previous studies and research (refer Section 6.1), as well as interpretation of recent and historical air photography and Marine LiDAR data of Port Stephens. This has also been complemented with the longshore sediment transport analysis presented in Section 6.2.

To assist in describing the coastal and sediment transport processes, the shoreline is separated into four main sections, as shown in Figure 6-10, although it is recognised that there is still interaction between these components. From west to east, these compartments are:

- Winda Woppa spit and Lower Myall River, which extends from the Lower Myall River eastern channel to Barnes Rock;
- Western Jimmys Beach, which extends from Barnes Rock to the northern-most corner of the Jimmys Beach embayment approximately in line with the tourist park;
- Eastern Jimmys Beach, which extends from the tourist park to the northern side of the Yacaaba sandwave; and
- Yacaaba sandwave, which incorporates the sandwave feature as well as the shoreline to south, extending to Yacaaba Headland.

The main area of erosion is located within the Western Jimmys Beach section.

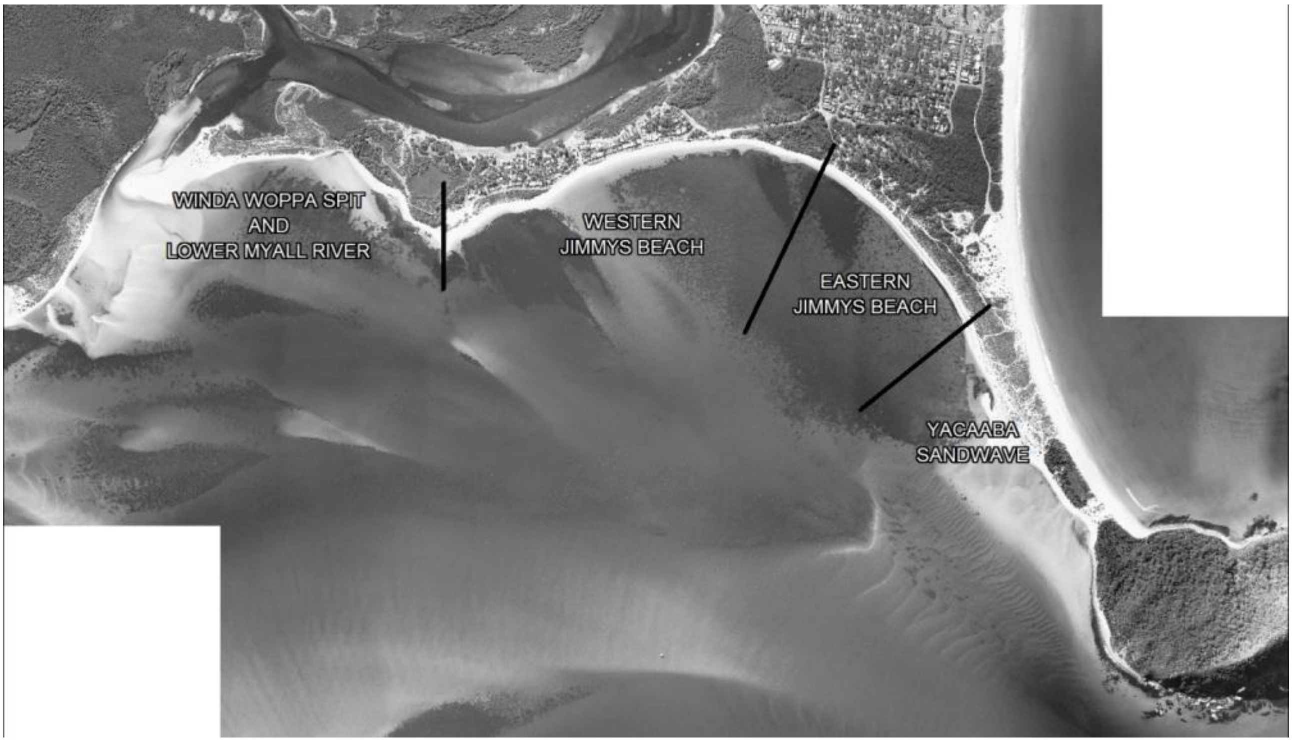


Figure 6-10 Regions of the Jimmys Beach coastal compartment

6.3.1 Western Jimmys Beach

The shoreline of Western Jimmys Beach contains the main erosion zone between Karurma Crescent and Gemalia St on Winda Woppa peninsula. Western Jimmys Beach has been subject to numerous periods of nourishment over the past 30 years, with most placement of sand being restricted primarily to a 200m long section of foreshore immediately adjacent to The Boulevard in the vicinity of Guya St. A timeline of nourishment episodes was given in Table 1-1.

Barnes Rock forms the western control for this beach compartment, however, approximately 500 metres east of Barnes Rock is another apparent control point located immediately offshore of the beach that forms an incipient salient on the shoreline. It is reported anecdotally that ballast rock from old cedar ships accessing the Myall River may have been dumped at this location, although this is unconfirmed. Nonetheless, historical imagery indicates that this more easterly control point has remained completely stationary in the nearshore zone for at least the last 60 years.

6.3.1.1 Longshore Sediment Transport Processes

Changes in lateral shoreline position along Western Jimmys Beach foreshore have been assessed by digitisation of the waterline in historical air photographs. Whilst it is recognised that the waterline does vary with tide, the relatively steep beachface limits this potential semidiurnal variability to about +/- 5m around MSL. Figure 6-11 shows the shore-normal change in waterline over the period 1951 to 2010 at seven transects east of Barnes Rock (refer Figure 6-2 for locations of transects). The figure highlights the response of the beach profiles to broadscale beach nourishment events, as well as natural cycles of erosion and accretion. The profiles provide a telling story of erosion and beach response to nourishment episodes as described below.

Initially, all beach profiles accreted between 1951 and 1963. Between 1963 and 1966, the beach profiles in the main erosion zone and further to the east (Transects 59,61,64 and 68) all experienced notable erosion, while beach profiles around the incipient salient and Barnes Rock experienced accretion, suggesting that at least some of the eroded sand was transported westward by longshore processes. Further erosion of the whole shoreline then occurred up to the 1980s, when the nourishment campaigns commenced. Interestingly, only Transects 52 and 68 are notably eroded compared with the 1951 beach position, while at all of the other transects, the shoreline is similarly placed in 1951 and 1980.

Some 190,000m^3 of sand was placed on the beach between 1984 and 1993. The response of the beach over this timeframe based on lateral shoreline movement was significant accretion around the incipient salient, approximate stable alignment through the main erosion zone, and continuing erosion at the eastern end of the beach compartment. Again, this response suggests some longshore sediment transport in a westerly direction from the main erosion zone. This observation is supported by the longshore sediment transport calculations based on swell wave conditions described previously in Section 6.2. The more easterly profiles (Transects 64, 68) in fact demonstrate erosion over the period of nourishment, suggesting that if easterly transport is dominant across these beach profiles, they are either also experiencing storm erosion (offshore) sediment transport, or the sand passes through these sections but is not being accreted onto shore.

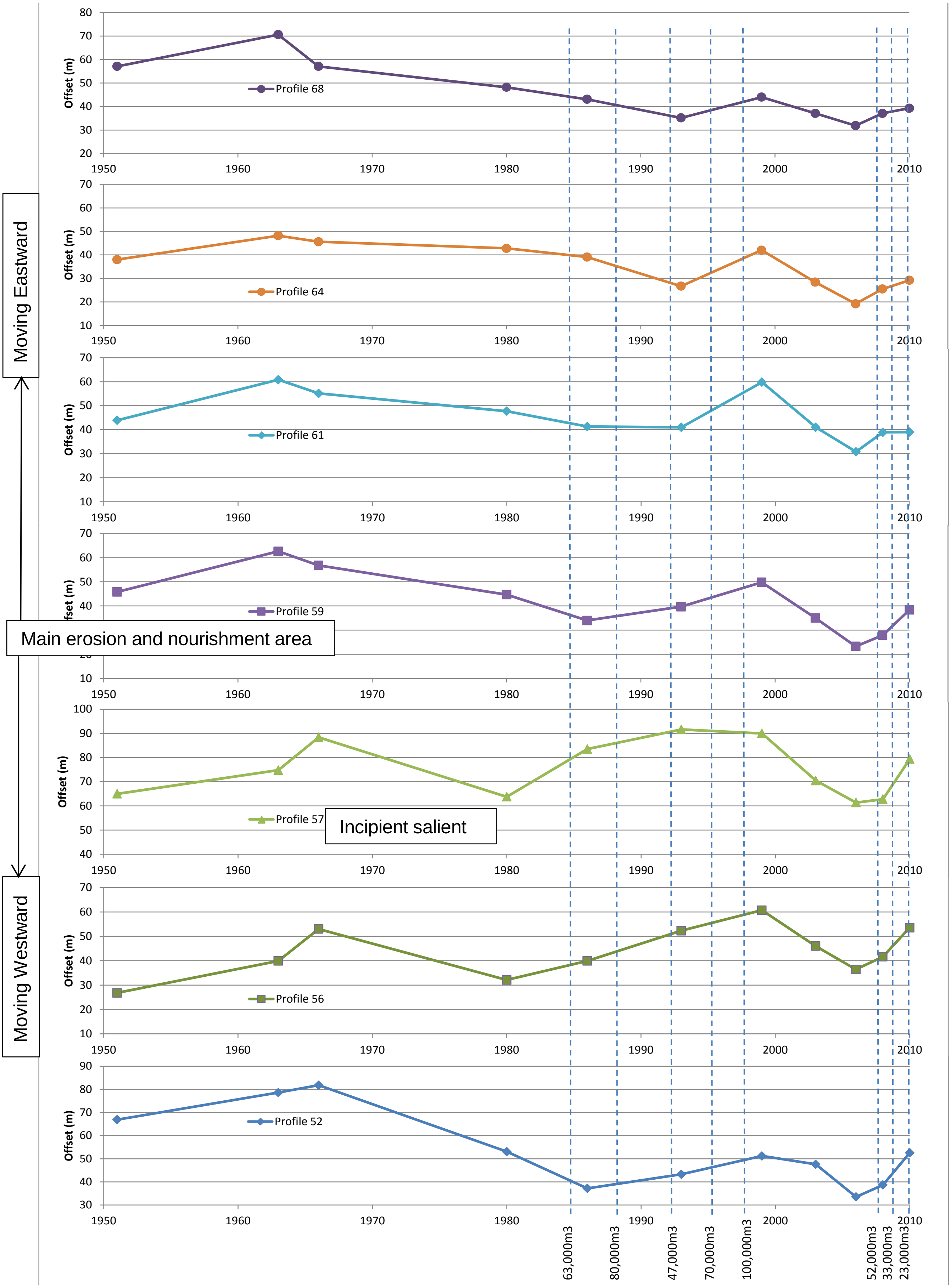


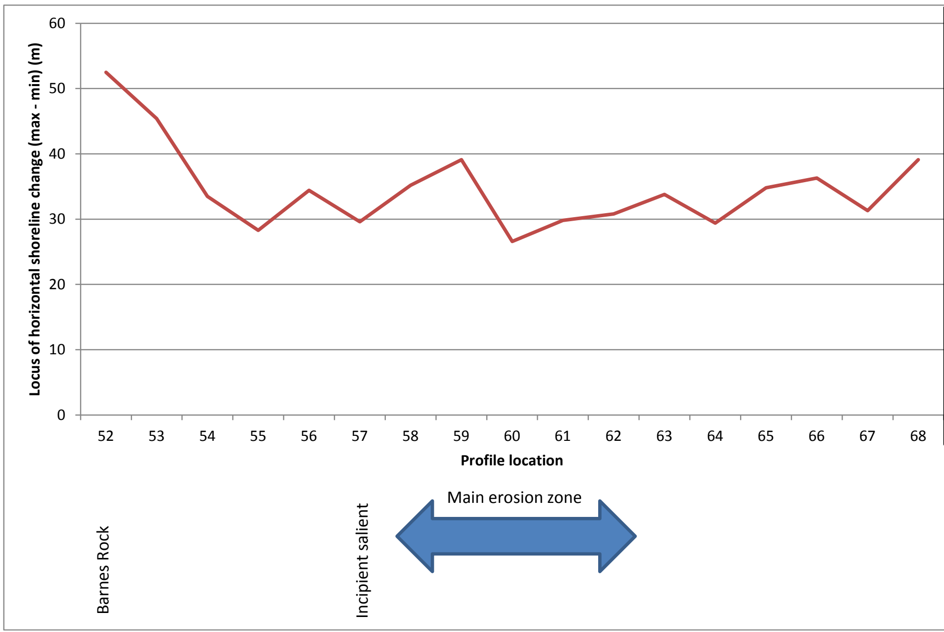
Figure 6-11 Horizontal Changes to Beach Transects in Response to Major Nourishment Campaigns

Between 1993 and 1999, another 170,000m^3 of sand was placed on the beach, with the 1999 beach profiles reflecting this nourished state. The main area of erosion (which is the main area of nourishment) showed the greatest accretion between 1993 and 1999, with the degree of accretion diminishing both eastward and westward from this location. In fact, the profiles show that the incipient salient did not actually accrete (as the nearshore control point, which is acting as a submerged groyne, was probably already at its maximum sand-carrying capacity before the additional nourishment – see Figure 6-11), but accretion in both profiles adjacent to Barnes Rock suggests that there was still westward longshore transport in response to the nourishment. An overall accretion on the shoreline to the east of the main nourishment area also suggests that there was some eastward longshore sediment transport in response to the major nourishment event (and possibly some beach recovery through onshore transport at the more easterly profiles as they had not previously responded to the nourishment episodes). It is considered that the very large volume of sand placed on the beach at this time would have resulted in the beach being temporarily imbalanced, with sand moving rapidly eastward, westward and offshore in response.

No major nourishment occurred during the period 1999 to 2008 (only emergency works were undertaken when infrastructure was immediately threatened by erosion). The entire beach eroded significantly during this period from 10 metres at the eastern end to 30 metres in the main erosion zone and around the incipient salient. Between 2008 and 2010, approximately 100,000m^3 of sand was again placed on the beach. All beach profiles showed a positive response to this nourishment with accretion along the entire shoreline, but again, the response was greatest for the profiles to the immediate west of the nourishment zone (with up to 20 metres accretion) compared to the response by profiles to the east (with up to 10 metres accretion).

As discussed in Section 6.2, the main erosion zone appears to be a 'null point' for longshore sediment transport, with eroded sand potentially transported in both a westward and eastward direction. The westward directed sand appears to migrate along the shoreline through the incipient salient and then behind the Barnes Rock tombolo, where it then enters a somewhat separate sediment compartment (refer discussion in Section 6.3.2). Detailed surveys of beach profiles during the 1990s also indicated 'leakage' of nourishment sand to the west and around Barnes Rock at a rate of approximately 5,000m^3/yr (refer Watson 1997, 1999, 2000). Some easterly sand transport was also observed after nourishment in the 1990s of approximately 7,000 m^3/yr (refer Watson 1997, 1999, 2000), which was also observed by the construction of a temporary groyne as part of the original PWD Erosion Study in 1985 (although the details of this, including the actual location of the groyne, are not readily available).

As shown in Figure 6-12, the width of Jimmys Beach has varied by at least 30 metres over the past 60 years. The locations of greatest variability are on the eastern sides of Barnes Rock (Transect 52) and the eastern side of incipient salient (Transect 58 & 59). This suggests that these profiles tend to fill and deplete similar to the updrift side of a "leaky" shore-normal groyne, providing some evidence of westward movement of sand, for this section of the shoreline at least.



	Most landward	Most seaward
52	1986, 2006, 2008	1963, 1966
53	1980, 2006, 2008	1966
54	1986	1966
55	1951, 1980	1963, 1966
56	1951	1999, 2010
57	1951, 1980,06, 08	1966, 1999, 2010
58	2006, 2008	1963
59	2008	1963, 1966, 1999
60	2006	1963, 1966, 1999
61	2006	1999, 1963
62	2006	1963
63	2006	1963
64	2006	1963
65	2006	1963
66	1993, 2006, 2008	1963
67	1993, 2006	1963
68	2006	1963

Figure 6-12 Maximum shore-normal shoreline change, east of Barnes Rock (refer Figure 6-2 for profile locations)

6.3.1.2 Cross-shore Sediment Transport Processes

As shown in Figure 6-13 (Watson, 1999), some 20,000m^3 of sand was lost from Sectors 2 and 3 between Feb 1996 and Feb 1997, during which time there was essentially no change in volume in either Sector 5 to the east, or Sector 2 to the west. From this, it may be considered that sand has been removed from the beachface via cross-shore processes. Interestingly, cross-shore processes have not features significantly in the literature to date regarding Jimmys Beach, as it has been assumed that any erosion of sand from the beach by cross-shore processes during storm conditions would be returned to the beach during subsequent fairweather conditions.

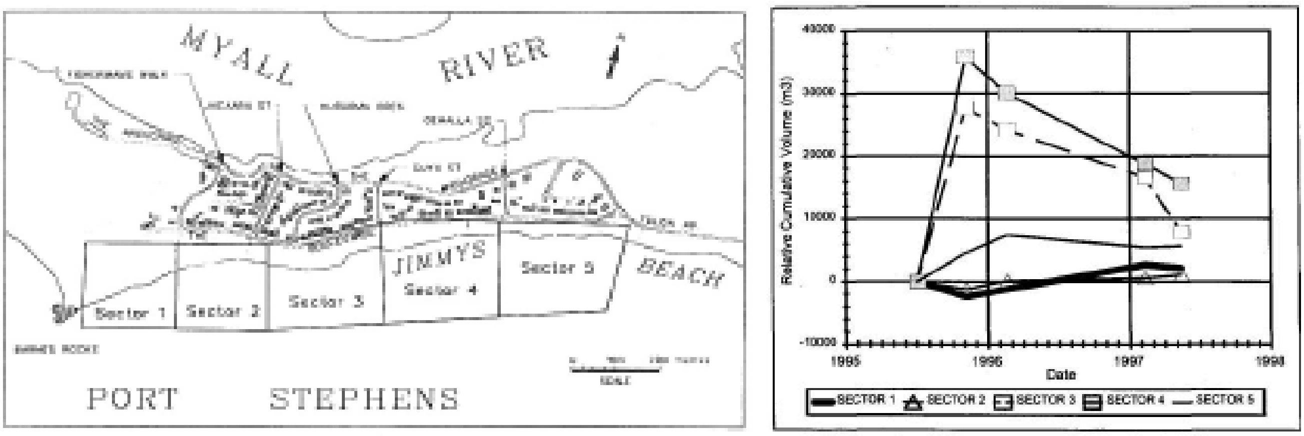


Figure 6-13 Beach Volume Change: 1995 – 1998 (source: Watson, 1999)

BMT WBM

The annualised longshore sediment transport calculations presented in Section 6.2 indicated that with the exception of the area in the immediate erosion zone, longshore transport potential along the Jimmys Beach shoreline is relatively small. Even when considering wind waves, the longshore sediment rates would generally be insufficient to transport significant quantities of sand from one side of Jimmys Beach to the other.

Cross-shore sediment transport rates have not been estimated to date. For this report, air photography and examination of the marine LiDAR has been used to hypothesise about cross-shore transport processes and sediment pathways. The marine LiDAR is presented in Figure 6-14, while the recent air photo and corresponding seabed contours are shown in Figure 6-15.

While much of the seabed of the Jimmys Beach embayment is vegetated with seagrass, there remains a swathe of bare sand directly in front of the main erosion area (immediately east of the control point for the incipient salient). This area of bare sand is observed throughout the aerial photography, even as adjacent regions became (re)colonised by seagrasses. As the seabed levels in this unvegetated swathe are the same as other nearby vegetated areas, it is considered that mobility of the bed sediments would be the main factor preventing seagrasses from becoming established. A review of the marine LiDAR and associated seabed contours also shows an offshore sand bar in depths of about 4 metres in this location (i.e. offshore of Transects 58-60), while an apparent seaward-oriented delta extends offshore to depths of about 5 metres (refer Figure 6-14 and Figure 6-15). This delta also tends to migrate towards the west, presumably under the influence of flood tide currents.

The marine LiDAR (see Figure 6-14) also highlights accumulation of sediment on the eastern side of the submerged control that forms the incipient salient on the shoreline. This build-up, which extents more than 200 metres offshore, provides further evidence of the net westward longshore transport occurring at this location.

Further to the east, there is another apparent cross-shore process occurring at approximately Transects 65 and 66. At this location, a shallower shoal has formed offshore in water depths of 2.5 – 3 metres. The marine LiDAR suggests that sand on this shoal is being carried westward (presumably under the influence of flood tide currents) along a pathway that is some 300 metres from the shoreline (see Figure 6-14). It is expected that the rate of sediment flux along this path is much lower than through the unvegetated swathe to the west, given that seagrasses have become established over the shoal since the 1990s. It is worth noting the proximity of this shoal to the area where easterly longshore transport reduced to near-zero levels, as presented previously in Section 6.2. It is considered that the reduction in potential easterly longshore sediment transport would result in a localised accumulation of sand on the beachface, which is then transported offshore by cross-shore processes, creating the shallow nearshore shoal seen in the bathymetric data. This section of the shoreline corresponds to a change in beach alignment, so it is reasonable to assume that this location has a tendency for accretion.

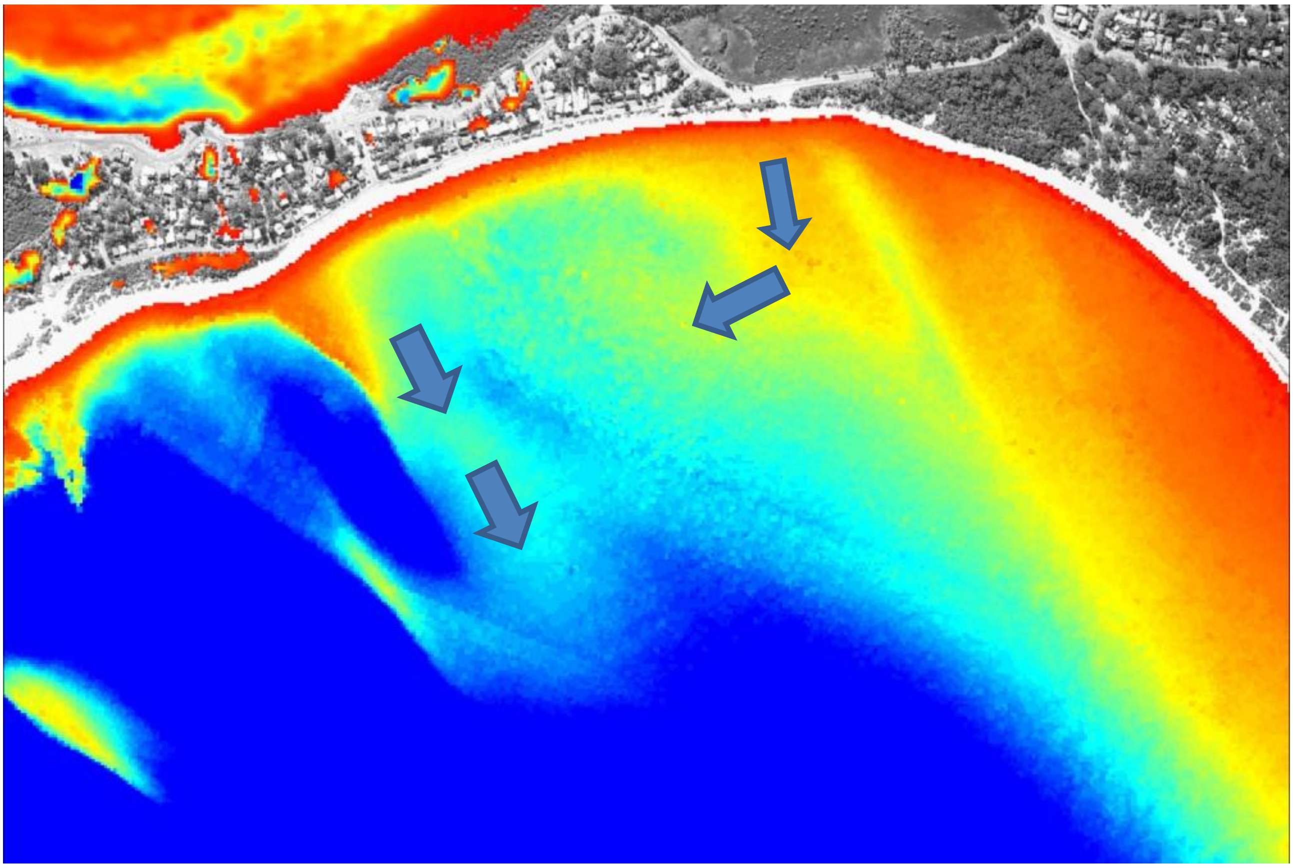


Figure 6-14 Marine LiDAR nearshore DEM, to -5m AHD, and assumed cross-shore sediment pathways

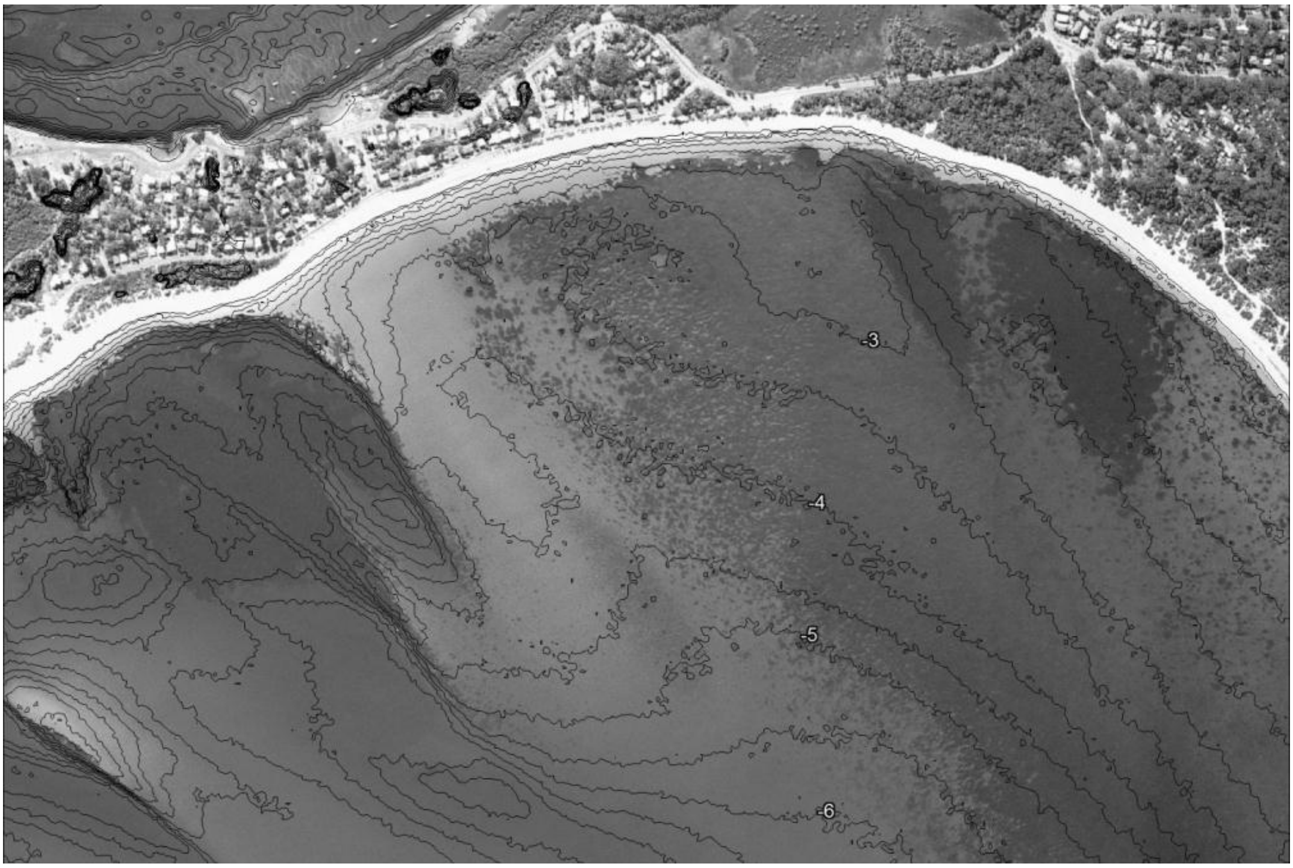


Figure 6-15 2010 Airphoto and 0.5m contours

6.3.2 Winda Woppa Spit and Lower Myall River Entrance

As discussed above, some of the sand that is eroded from Jimmys Beach is reworked by longshore processes, through the incipient salient that forms behind the submerged control point and across the tombolo behind Barnes Rock. To the west of Barnes Rock, sand is reworked along the shoreline ultimately accumulating on the Winda Woppa sand spit, within the entrance of the Lower Myall River.

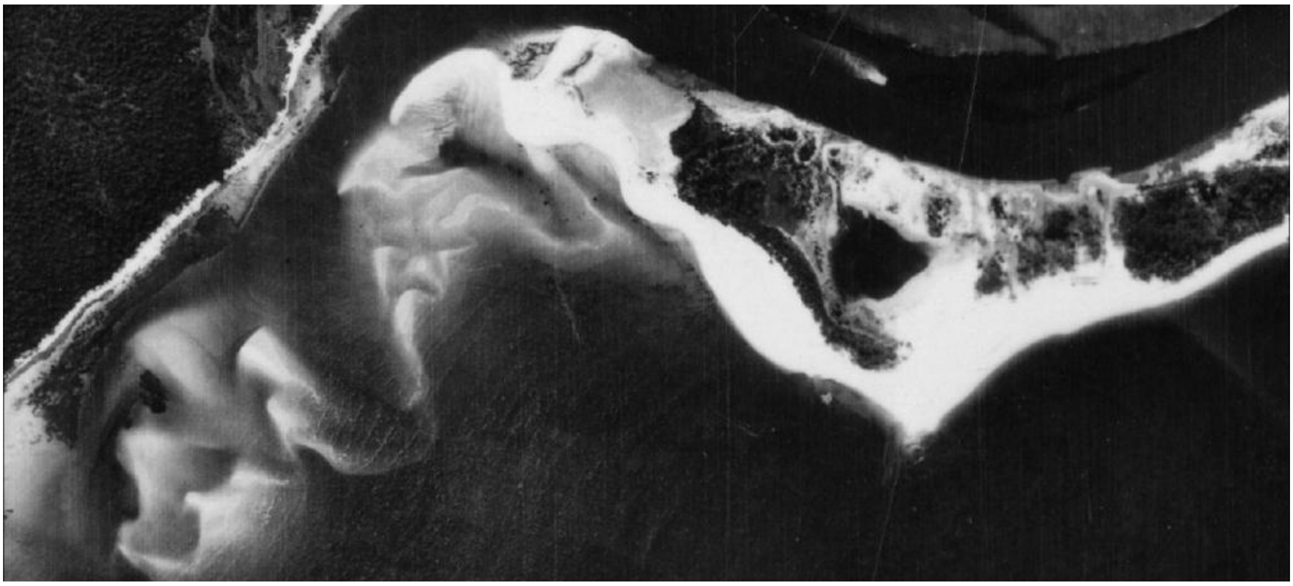
In 1963, a large 'slug' of sand was located on the shoreline to the immediate west of Barnes Rock (refer Figure 6-16). This slug continued to move westward during the 1960s, eventually creating a rapid extension to the sand spit in the mid 1970s (refer 1977 air photos, Figure 6-16). The origins of the sand slug are not immediately clear, however, the 1963 air photo also shows significant sand build-up around Barnes Rock, suggesting that at least some of this sand had been sourced from longshore sand transport from Jimmys Beach. The period 1952 to 1962 was particularly stormy, including 10 extreme storms where offshore significant wave height exceeded 6m (see MHL, 2007). It is also possible that the sand slug was enhanced by Aeolian processes, with dunes behind Jimmys Beach and around Barnes Rock generally devoid of vegetation at that time.

A second significant 'slug' of sand is noted on the shoreline in the 1986 aerial photo when compared to the 1980 aerial photo. This includes smothering of some previous dune vegetation suggesting that the sediment influx occurred relatively rapidly. Again, transport of sand along the foreshore from east of Barnes Rock appears to be the only mechanism for conveyance of the sand slug. Beach nourishment occurred in 1984 and 1985, following significant erosion in 1983. It is considered that a proportion of the sand eroded from Jimmys Beach (both the in-situ material and the artificially placed nourishment) had been transported westward around Barnes Rock delivering sand to the western foreshore.

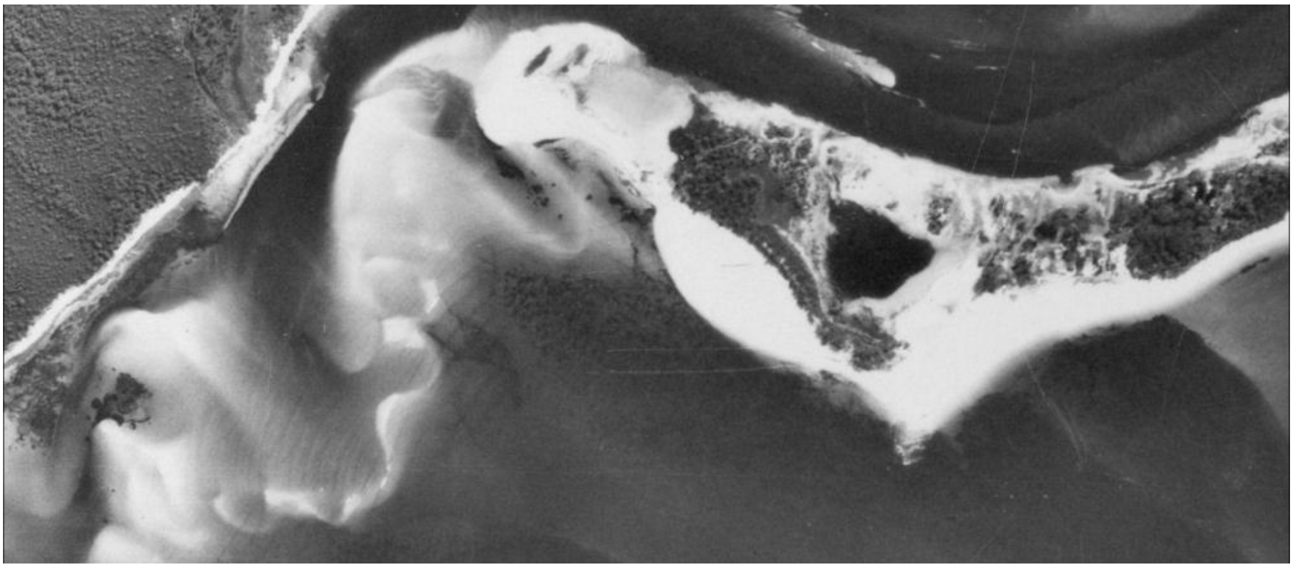
A rudimentary volumetric analysis indicates that ~ 20,000m^3 of sand was contained within the sand slug on the western foreshore in 1986. The 1986 air photo also shows sediment washover of the tombolo behind Barnes Rock as well as significant broadening of the incipient salient (see Figure 6-11) (with a volume of at least another 10,000m^3). Thus, westward longshore transport could account for up to about 25% of the sand lost from the beach (assuming that the 60,000m^3 of nourishment replaced an equivalent volume of in-situ sand that had been eroded prior to nourishment).

The shoreline west of Barnes Rock remained mostly stable during the major nourishment campaigns of the 1990s except for some early signs of scalloping, wherein there were localised pockets of foreshore recession feeding the longshore transport demand in this area driven by the obliquity of the shoreline alignment to the incoming swell waves. Interestingly, however, in the early 2000s when there was no nourishment, the foreshore recession accelerated markedly with some 40m recession between 1999 and 2001, and a further 50m recession between 2001 and 2003. The 'scalloped' shape to the shoreline is considered to be indicative of active longshore transport processes, which has ultimately led to accretion and substantial extension of the Winda Woppa sand spit further into the entrance channel of the Lower Myall River. The accelerated recession after 1999 suggests that the nourishment during the 1990s had in fact contributed to stability of the shoreline through westerly sediment transport from Jimmys Beach, and when nourishment ceased, natural processes continued to erode the Winda Woppa shoreline and extend the spit into the Lower Myall River entrance.

1951



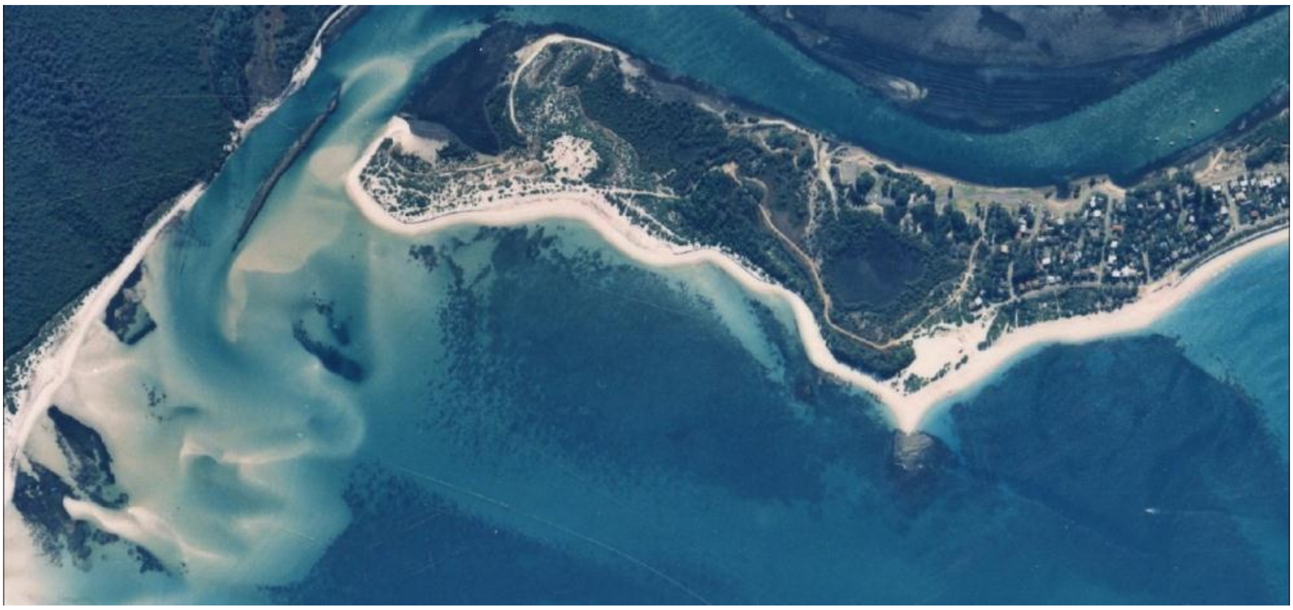
1963



1966

1977

1986



1994

1999

2003

2010

Figure 6-16 Historical Changes to Winda Woppa Spit and Lower Myall River Entrance

The Eastern Channel entrance of the Lower Myall River is highly dynamic, with sediment processes in this locality being influenced by ocean swell, wind waves, tides and flood flows (BMT WBM, 2011). The dynamism of the area, and the natural growth and extension of Winda Woppa spit, is highlighted by the fact that Myall Point, a previous 2km long finger of sand extending south from the end of Winda Woppa, was completely destroyed during coastal storms in 1927 and 1929.

BMT WBM (2011) undertook a volumetric analysis of sand accreted in the Eastern Channel between 2001 and 2009 and compared this to the amount of erosion experienced on the foreshores west of Barnes Rock. From the approximate balance in volumes, it was concluded that the sediment that infilled the channel between 2001 and 2009 was primarily sourced from localized erosion west of Barnes Rock, with a sediment transport rate of approximately 12,000m^3/year.

Nourishment of Jimmys Beach resumed in 2008. Comparison between the 2008 and 2010 aerial photos shows a widening of the beach profile for a distance of some 500m to the west of Barnes Rock, as well as broadening of the tombolo and the incipient salient (refer Figure 6-11). This again suggests that a proportion of the nourished sand has been directed westward and is supplying sand to the shoreline west of Barnes Rock.

Based on the behaviour of the shoreline and the accretionary response within the Myall River entrance channel, it is considered that the longshore sediment transport demand along the western foreshore (equivalent to about 12,000m^3/yr) will be met by either sand entering the beach compartment behind Barnes Rock as a result of erosion of Jimmys Beach (including adjustment of the shoreline in response to nourishment), or by the erosion of in-situ sands on the western foreshore. Thus, although sand from Jimmys Beach is contributing to the accretion within the Lower Myall River entrance channel, the rate of accretion is actually independent of the rate of erosion (or nourishment) on Jimmys Beach, as any shortfall in sediment supply from Jimmys Beach will be met by erosion of the local foreshore. This means that future nourishment of Jimmys Beach has the potential to deliver sand to the shoreline west of Barnes Rock, which will likely satisfy some of the longshore sediment transport demand, and would likely limit the extent of on-going recession of this shoreline.

As suggested by BMT WBM (2011), continued build-up of sand in the Eastern Channel will increase the likelihood that the channel could close completely under severe to extreme storm conditions. Once the Eastern Channel is closed, tidal flows into and out of the Myall River will be conveyed completely through the northern channel.

6.3.3 Eastern Jimmys Beach

The eastern shoreline of Jimmys Beach, adjacent to the Yacaaba isthmus and excluding the sandwave formation area, accreted substantially over the period 1963 to 1986 (refer Figure 6-17). 1963 is the earliest air photo available, so it is unknown whether substantial accretion was also occurring prior to this time. Whilst this accretion is well documented in past studies, there has previously been little attention given to the change in the immediate nearshore zone adjacent to the area of accretion. In 1963 and 1966, the nearshore zone was shallow for a distance of about 200 metres offshore, and characterised by a series of shore-normal transverse sandbars. Indeed the whole eastern side of the embayment down to Yacaaba Headland contained similar transverse sandbars.

Figure 6-17 Movement of sand from nearshore bars onshore, 1966 – 1986 (1977 base map)

Between 1963 and 1986, the nearshore zone adjacent to Yacaaba isthmus deepened and stabilised, as evidenced by the rapid growth of seagrass across this whole section over this period, and the relative stability of the seagrass coverage to date. The period prior to the early 1960s was particularly stormy, and it is quite possible that erosion of the shoreline during this period delivered an excess of sand to the nearshore bars along the eastern foreshore. Fairweather conditions during the 1960s to 1980s would have resulted in these nearshore sandbars being reworked onshore under dominant swell and wind wave conditions.

The stability of the shoreline since 1986 in spite of the significant nourishment campaigns on Western Jimmys Beach is indicative of relatively weak longshore sediment transport along Eastern Jimmys Beach. Any eastward net longshore transport would be expected to progressively 'fill out' the shoreline in a northward direction as sand accretes against the sandwave. This has not been observed.

6.3.4 Yacaaba sandwave

This section of shoreline is located along the Yacaaba isthmus, adjacent to the Yacaaba Headland, extending northward for a distance of about 1km. The most significant feature of this shoreline is a sandwave formation around 500 m north of Yacaaba Headland.

Shallow sand shoals extend offshore from this section of shoreline for a distance of up to about 400 metres, and are observed in all historical air photos and records. Indeed Vila Concejo *et al.* (2010) sourced a historical chart that was drafted by the crew of The Beagle (c. 1836) that documented a dominant bulge in the shoreline at this location, or at the very least, shallow shoals that extended some distance offshore that prevented the vessel from getting closer to the shoreline during its survey transects (refer Figure 6-18). The observation of these shallow shoals and adjacent perturbation along the shoreline in 1836 suggest that the sandwave formation is natural and has occurred periodically well before the urban development on Winda Woppa peninsula and subsequent nourishment of the Jimmys Beach shoreline.

Figure 6-18 C. 1836 chart drafted by The Beagle (sourced from Vila Concejo et al, 2010) (note the presence of Myall Point, as well as Barnes Rock and other shoreline variations along Jimmys Beach and Winda Woppa)

The offshore limit of the shallow shoals is a deep ebb-tide dominated channel. Bed forms in this channel observed in the marine LiDAR data indicate considerable sediment transport on the ebbing (outgoing) tide. Indeed this strong ebb tide sediment transport has resulted in an incipient ebb tide delta on the southern side of Yacaaba Headland as shown in Figure 6-19, which was also noted by Vila Concejo *et al*. (2010).

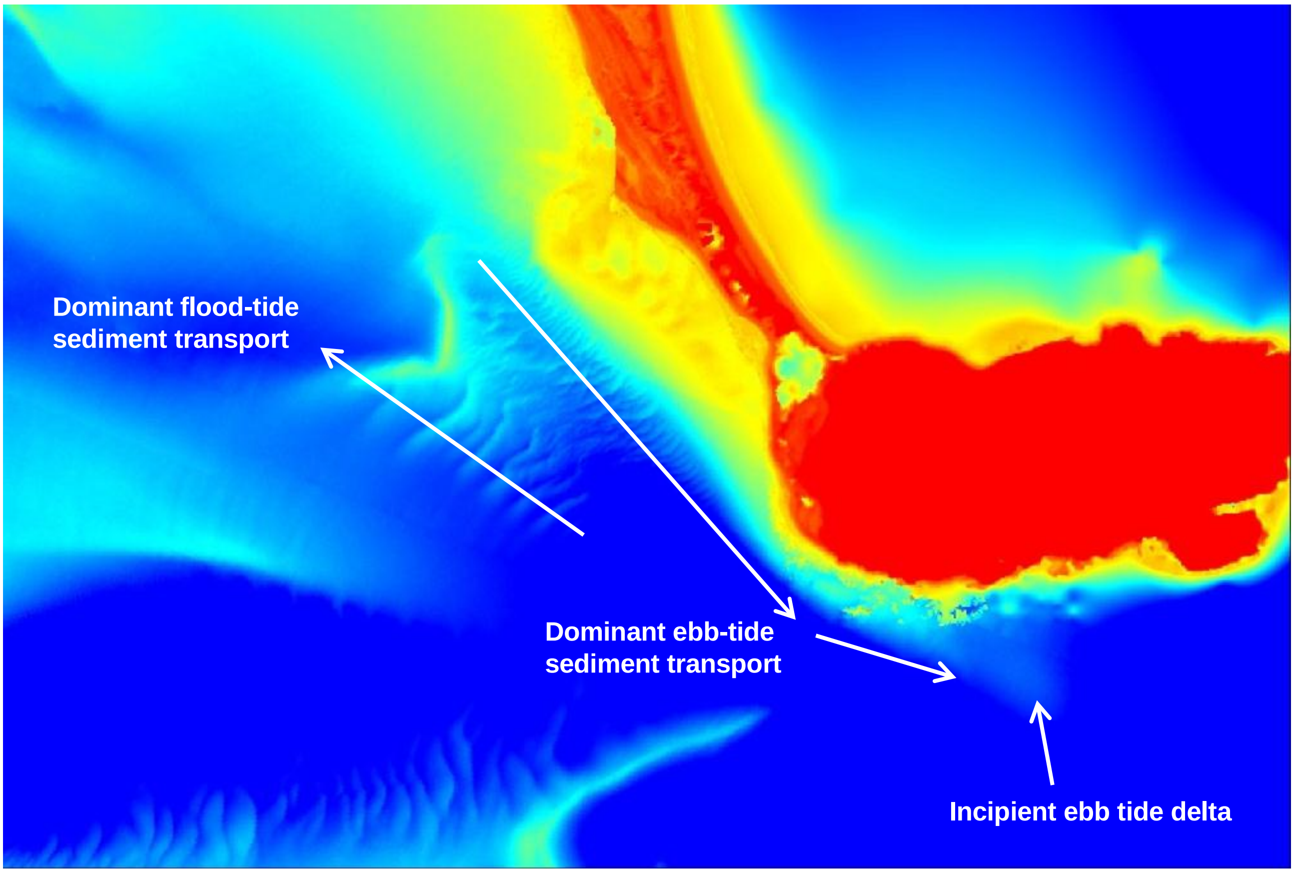
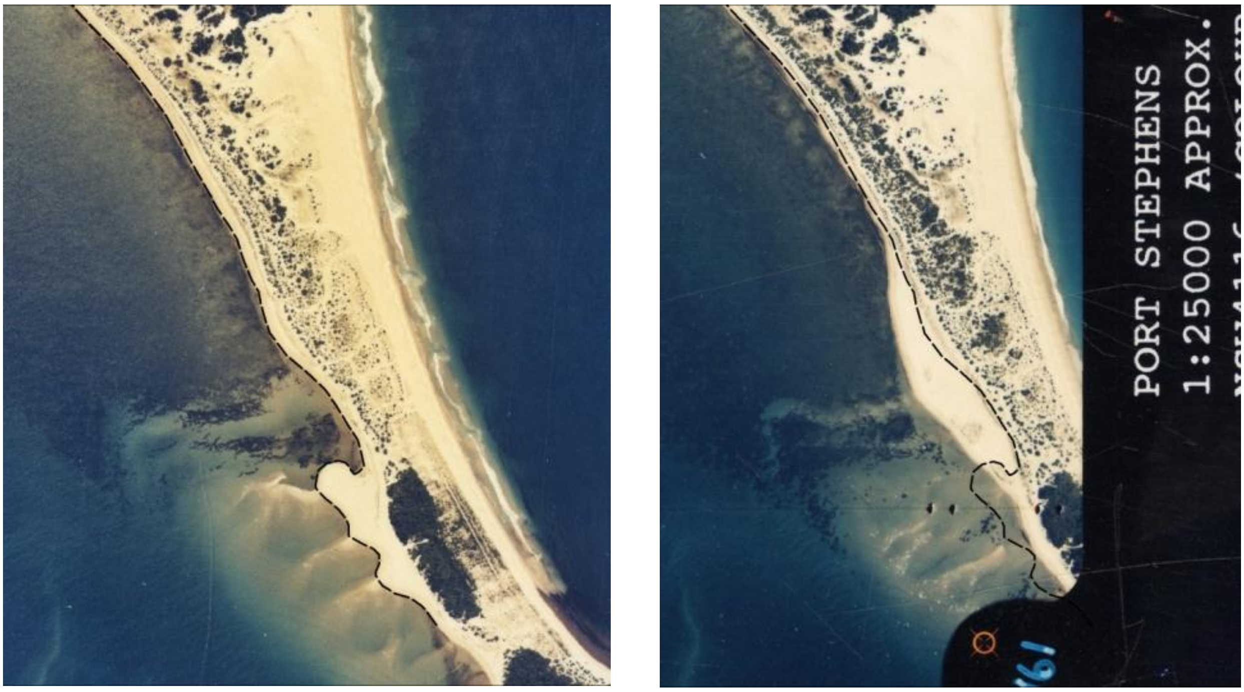


Figure 6-19 Marine LiDAR data showing ebb tide dominant bedforms close to the Yacaaba shoals, adjacent to flood tide dominant bedforms further westward, and an incipient ebb-tide delta on southern side of Yacaaba Headland

It is hypothesized that strong ebb tide flows within the adjacent deep channel deposits sand on the outer edge of the sand shoal (similar to how a river channel creates a natural levee with overbank flow). Swell waves then rework these sand deposits towards the shoreline in the form of transverse bars. Occasionally, and possibly under the influence of larger swell waves, sand is reworked onto the shoreline over a very short period, causing a localised and temporary widening of the beachface immediately north of Yacaaba Headland, in the form of a 'slug' of sand. This sand is then transported alongshore to the north by the incident swell waves (as indicated by the longshore sediment transport calculations, see Section 6.2).

During the storms of May – June 2007 (including the Pasha Bulker storm over the June long weekend), Vila Concejo *et al.* (2010) measured growth of the Yacaaba sandwave of some 65,000m^3. Vila Concejo *et al* assumed that the sand was sourced from either the outer parts of the flood tide delta or from the incipient ebb-tide delta on the southern side of Yacaaba Headland (see Figure 6-19) under the influence of flood tide currents and waves. However, a strong ebb-tide channel is located immediately adjacent to the shoals, which would inhibit sand transport onto the shoals from flood-tide processes. It is more likely that the sand that contributed to the growth of the sandwave previously was held within the adjacent shallow nearshore shoals and transverse bars, which were scoured to a greater depth during the larger wave conditions, with the entrained sediment pushed onshore by the enhanced wave activity during this period. After the event, it is considered that ebb tide processes would then have re-supplied the outer edge of the 'depleted' sand shoals with new sand from the ebb tide channel.

The process of accretion of sand onto the sandwave appears to involve 'slugs' of relatively large sand quantities within a very localised area. This process is apparent in the comparison between the 1986 and 1993 air photos (refer Figure 6-20). In 1986, there was a large 'slug' of sand moving north along the shoreline. By 1993, this slug had moved northwards as a result of onshore transport to form the 'sandwave'. The volume of the 1986 sand slug roughly accords with the size of the 1993 sandwave (noting that the 1993 shoreline south of the sandwave returned to a relatively depleted condition). A similar process is also evident in the 1994 air photo, showing a large sandmass on the shoreline to the south of the sandwave, which is clearly being transported alongshore towards the sandwave. The rapid change and very localised growth of the shoreline producing these features is likely to be the result of strong onshore transport driven by large swell events. The period 1984 to 1986 was particularly stormy with 10 Category A storms and 4 Category X storms (see MHL, 2007), which may have provided the required conditions to transport marine sand from the shallow nearshore bars onto the beachface by 1986, which was subsequently transported alongshore onto the sandwave.



1986

1993
(1986 waterline shown dotted)

Figure 6-20 Yacaaba Sandwave development: 1986 – 1993

Cholinski (2004) observed an initial sandwave in 1981 that was migrating west. Air photos indicate that subsequent 'slugs' of sand were also pushed onto the shoreline and then migrated north to attach to the pre-existing sandwave (such as that observed in the 1994 air photo) causing continued growth of the sandwave on the southern side (similar to the way that sand builds up on the updrift side of a shore-normal groyne). As a result, the apex of the sandwave moved south by 100 metres between 1986 and 1993, and a further 150 metres by 2003. These observations confirm the direction of longshore sand sourcing (refer Figure 6-21), providing evidence that the growth of the sandwave is not substantially contributed to by sediment originating from the north

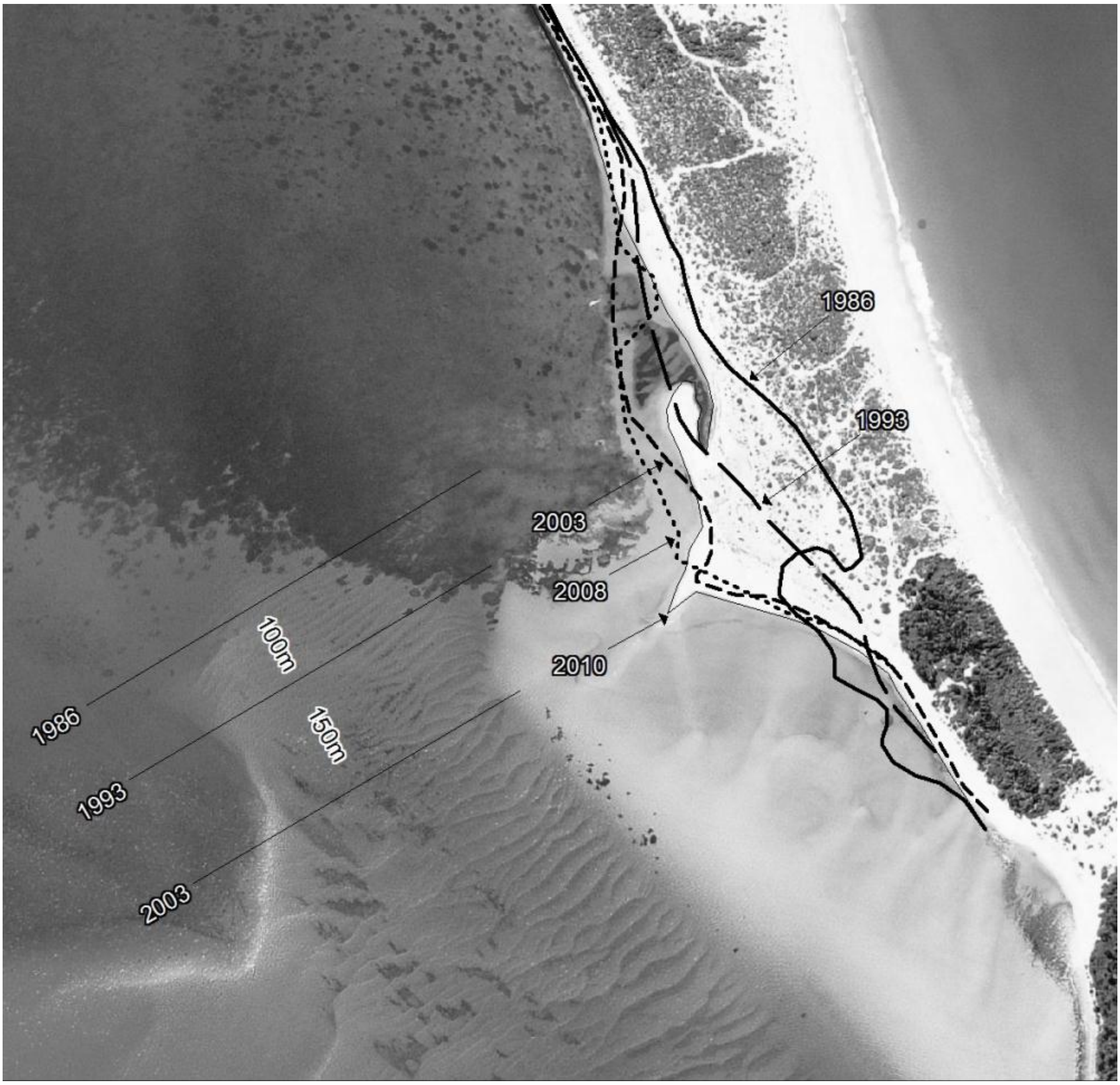


Figure 6-21 Sandwave growth and migration

Since 2008, a cutter suction dredger has been working on the northern side of the sandwave to extract sand for nourishment purposes, and has created a deep borrow hole (see Figure 6-22). Some 100,000 – 120,000m^3 of sand has been extracted from the sandwave to date. As of June 2012, there had been relatively little infilling of the borrow hole. Indeed the only infilling of the hole to date appears to have been the result of swell waves pushing sand into the hole from the apex of the sandwave to the south, rather than any longshore sediment transport from the north, as previously assumed and documented in the EIS (Jelliffe, 2003). This provides further confirmation of the conclusion that the sandwave is supplied from the marine shoals to the south.

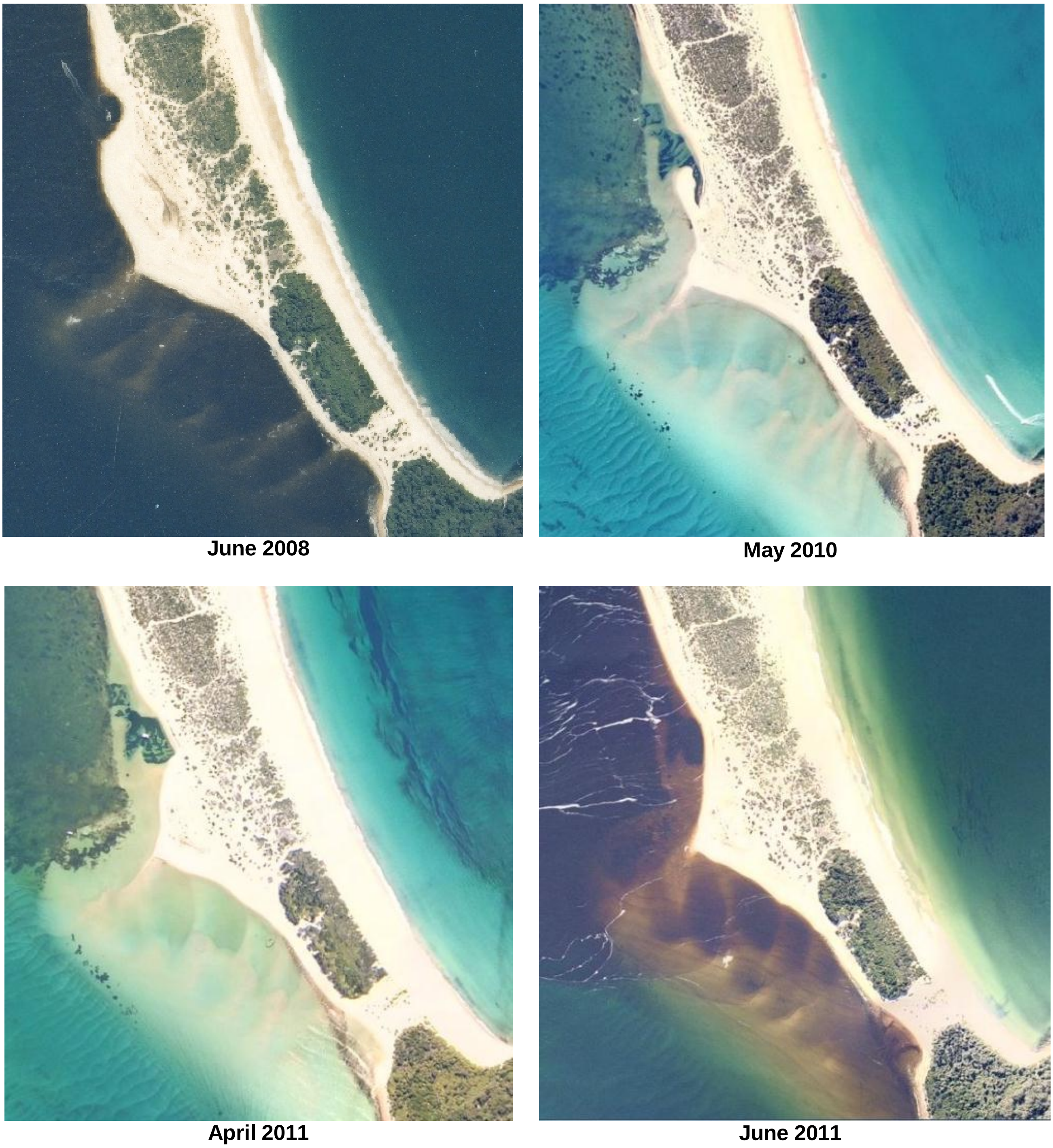


Figure 6-22 Yacaaba Sandwave Dredge Hole Changes 2008-2011

It is not clear how sandwaves are initiated, that is, why or how a ‘bump’ initially forms along the shoreline upon which the sand ‘slugs’ accrete. The fact that the chart drawn by The Beagle (refer Figure 6-18) shows a similar location for a sandwave in 1836, however, lends weight to natural processes, such as the influence of some geomorphic controlling factor, or a change in transport patterns caused by the change in shoreline alignment due to the sandwave itself. Alternatively, the sandwave formation may relate to a net easterly current further offshore of the Eastern Jimmys Beach shoreline (such as due to ebb tides combined with westerly wind waves) that counter-balances the northwards sediment transport from the marine shoals, holding the sandwave in position. The pointed 'apex' of the sandwave suggests there may be opposing currents in action at this location. Further data and analysis is required to fully understand the initiation and stable formation of the sandwave features.

6.3.5 Beach Nourishment Rate

Based on an appreciation of coastal sediment transport processes along Jimmys Beach, as described in the preceding sections, it is considered that sand eroded from the main erosion zone of Jimmys Beach may be directed offshore by cross-shore processes, as well as westward towards the incipient salient and Barnes Rock, and eastward along the shoreline. The relative dominance of these transport routes would likely depend on prevailing climate and meteorological conditions.

For the easterly directed sediment, it is considered that the sand could potentially be reworked offshore as the beach changes alignment along the northern edge of the embayment, or may contribute to shoreline accretion along Eastern Jimmys Beach or the sandwave. The terminus of the westerly directed sediment is ultimately the eastern channel of the Lower Myall River / Winda Woppa sand spit.

The rate of erosion of Jimmys Beach is dependent on storm events, dominant meteorological (notably wind and wave) conditions, and any artificial placement of sand on the beach (i.e. nourishment) that would create a localised 'out-of-balance' profile of the beach. After nourishment, Jimmys Beach has been observed to erode at a rate in the order of 20,000m^3/year. It is considered that this rate may be artificially high due to the out-of-balance beach alignment, and that a smaller scale of nourishment would lead to a lower annual erosion rate. Also, single storm events are known to erode a volume in the order of 10,000m^3 over a few days, necessitating emergency nourishment works to protect the roadway (as was demonstrated most recently in June 2012). The longshore 'null point' on Jimmys Beach means that very little sand moved alongshore has the opportunity to return to the point of erosion. Under the right conditions, it is possible that sand eroded by cross-shore processes could return onto the beachface if the sand remains within relatively shallow nearshore bars. The cross-shore processes of Jimmys Beach (including interactions with tidal currents) have not been investigated in sufficient detail to date to comment on the likelihood of cross-shore re-accretion following erosion events. From historical accounts, however, it would appear that the beach has limited capacity to return sediment to the beach, thus leading to the receding shoreline experienced to date.

Between 1999 and 2006, Jimmys Beach eroded at a rate of up to 4 metres/year, which translates to a volume of about 40m^3/m per annum. Nourishment of an equivalent rate over a foreshore length of approximately 500 metres, and covering a beach profile between -1m and +4m AHD, equates to a volume of 20,000m^3/yr. Spreading the nourishment over at least two occasions per year, or immediately following a significant storm erosion event, would help to minimise excessive losses associated with out-of-balance shoreline alignment that may otherwise occur if the volume was delivered in larger but less frequent episodes. More frequent nourishment (at least twice per year), would also likely reduce or indeed eliminate the need for 'emergency' works.

From a planning perspective, the recommended nourishment rate to be adopted is **10,000m^3 per 6 months**. After successive nourishment episodes and if there has been no significant erosion, then further nourishment works could be temporarily suspended (based on a trigger beach width).

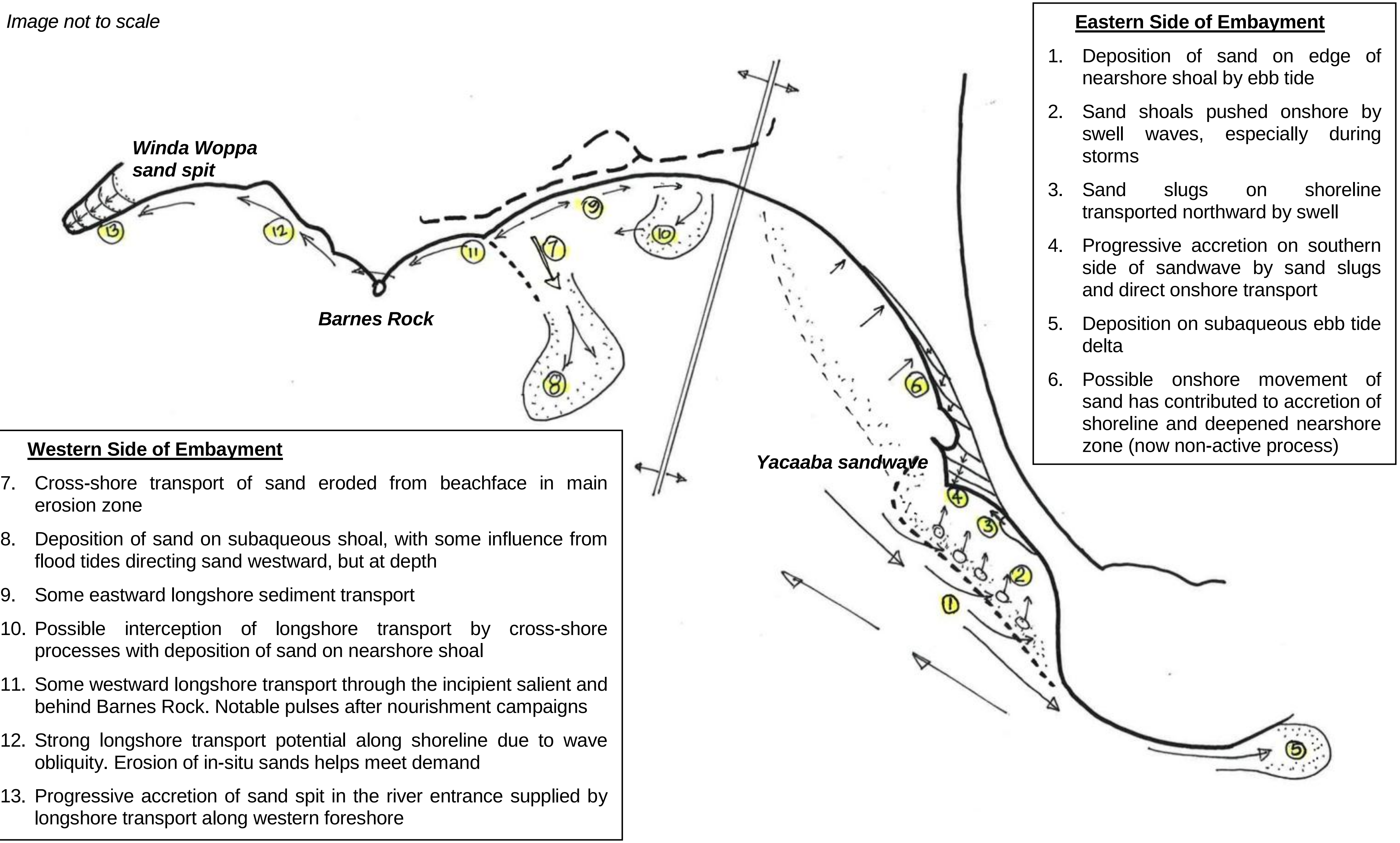
Nourishment should resume following erosion of the beach. Flexibility in the nourishment program to alter the rate of sand supply from one campaign to the next is therefore desirable.

The two potential sources for nourishment are the Lower Myall River Entrance Channel / Winda Woppa sand spit, and the Yacaaba sandwave. Based on the discussions above, a proportion of the sand placed on Jimmys Beach will be transported to the Lower Myall River Entrance Channel, so there is some mechanism for sediment recycling if nourishment sands were to be sourced from this location. For Yacaaba sandwave, it is possible that some of the sand eroded from Jimmys Beach is reworked along the shoreline to accrete on the sandwave, however, it is more likely that the sandwave is sourced by sand pushed onshore from the adjacent shallow nearshore shoals. Thus, the on-going suitability of the sandwave for nourishment would be dependent on recovery of the borrow area under the influence of dominant swell and other coastal processes.

6.4 Key Conclusions Regarding Sediment Sources, Sinks and Pathways

- The main findings of this investigation are summarised in the conceptual model shown in Figure 6-23.
- The sediment transport processes occurring on the eastern and western side of the Jimmys Beach embayment appear to be quite different. The main erosion zone on Jimmys Beach is at a longshore transport ‘null point’. Sand is eroded from this area and is potentially transported both westward and eastward along the shoreline, as well as offshore. The relative dominant direction of transport is expected to be a function of prevailing meteorological conditions (including swell and wind wave directions and magnitudes);
- In the absence of on-going nourishment, the Winda Woppa sand spit will continue to accrete by sand sourced from continued erosion of Jimmys Beach as well as erosion of the shoreline west of Barnes Rock. Nourishment of Jimmys Beach is not expected to change the rate of sand accretion at Winda Woppa, although it may reduce the on-going erosion of the western shoreline;
- Nourishment should involve smaller and more frequent campaigns to avoid out-of-equilibrium beach alignments that promote rapid erosion to return to a more natural alignment. Based on historical rates of erosion and accretion, the ideal nourishment strategy would involve placement of approximately 10,000m^3 of sand onto the Jimmys Beach ‘null point’ every 6 months;
- Although historically there has been considerable accretion on the Yacaaba sandwave, the rate of recovery of the sand shoal following recent dredging works has been slow. Morphology modelling also flags future recovery of extraction areas as an issue, which questions the viability of this location as a long-term sustainable source for nourishment sands. The assessment described herein indicates that the sandwave is dominantly supplied by northerly transport, with sand mostly accumulating on the southern side of the sandwave, rather than the northern side where the dredge hole is located. Notwithstanding, accumulation of sand on the sandwave is driven by periodic larger events, which are inherently unpredictable;
- The large volume of in-situ sand on the Winda Woppa sand spit, along with the strong tidal dynamics of the entrance shoals at the mouth of the Lower Myall River, would provide for a suitable supply of sand from this location for future nourishment needs (totalling some 400,000m^3 over a design 20 year period). As such, the Lower Myall River entrance area

(comprising the subaerial Winda Woppa spit and the adjacent channel entrance) is likely to be a more appropriate location for sand sourcing than the Yacaaba sandwave (subject to further field trials).



Eastern Side of Embayment

1. Deposition of sand on edge of nearshore shoal by ebb tide
2. Sand shoals pushed onshore by swell waves, especially during storms
3. Sand slugs on shoreline transported northward by swell
4. Progressive accretion on southern side of sandwave by sand slugs and direct onshore transport
5. Deposition on subaqueous ebb tide delta
6. Possible onshore movement of sand has contributed to accretion of shoreline and deepened nearshore zone (now non-active process)

Western Side of Embayment

7. Cross-shore transport of sand eroded from beachface in main erosion zone
8. Deposition of sand on subaqueous shoal, with some influence from flood tides directing sand westward, but at depth
9. Some eastward longshore sediment transport
10. Possible interception of longshore transport by cross-shore processes with deposition of sand on nearshore shoal
11. Some westward longshore transport through the incipient salient and behind Barnes Rock. Notable pulses after nourishment campaigns
12. Strong longshore transport potential along shoreline due to wave obliquity. Erosion of in-situ sands helps meet demand
13. Progressive accretion of sand spit in the river entrance supplied by longshore transport along western foreshore

Figure 6-23 Conceptual Model of Sediment Transport at Jimmys Beach

APPENDIX A: LONGSHORE SEDIMENT TRANSPORT EQUATIONS

Introduction

Longshore Sediment transport is the movement of sediment within the nearshore zone of the coast by waves and currents, and is also termed littoral transport (CERC, 1984). Sediment transport in the nearshore zone consists of two directional components: on and offshore movement, known as cross-shore transport; and movement alongshore, known as longshore transport.

In the dynamic surf zone, both cross-shore transport and longshore transport under waves and currents occur simultaneously. Cross-shore transport is said to be largely dependent on the breaker type and height, sediment size and beach slope (CERC, 1984). Longshore transport is said to consist of the entrainment of sediment by the incident waves, which is then transported by the longshore component of the incident wave energy and the longshore current generated by the waves (CERC, 1984).

Technically, sediment transport comprises two modes of transport, namely bed load and suspended load transport. However, for the purpose of this summary the two modes of transport are not differentiated but are considered together, as they are essentially driven by the same mechanisms within the surf zone, namely waves and currents, and instead the total sediment transport is discussed.

Cross-shore transport models are concerned with on and offshore directed sediment transport under waves (oscillatory currents, at various wave frequencies), and return flow currents. Cross shore transport models in part evolved out of seeking to understand and predict the formation of various morphological features in the surf zone, particularly sand bars, and the various ripple forms (Dean and Dalrymple, 2002). In turn, the morphological features (particularly ripples) have been studied for their impact upon sediment entrainment and transport. Present research and models often differentiate between suspended and bed load transport, and usually focus on a particular area within the surf zone (eg, offshore of breaker line, breakpoint, shoreward of the breaker line, swash zone, etc).

Where short term changes to the shoreline and beach morphology are of primary interest, the cross-shore transport models are of most use. Morphological features in the surf zone (such as sand bars and their cross shore location) are often transient, and reflect the prevailing wave conditions over the scale of hours to days (for storms), to weeks or months (for fair weather, or average conditions). During short term processes such as during storm events, large changes in surf zone morphology may occur, including erosion at the beach face and the formation and offshore migration of sand bars; changed length, shape and spacing of ripples; and rip current formation and spacing. The storm morphology is typically short lived, with a reshaping of the beach under average waves over weeks to months towards a low wave profile, and this usually includes restoration of the beach face after storm erosion. Cross shore transport models may help to accurately simulate the offshore movement of sand (and erosion) during the storm, and to simulate the onshore movement of sand bars and accretion at the beach face during average (lower) wave conditions.

Longshore sediment transport is also dependant upon prevailing wave conditions, and may be highly variable over the short term. However, when the range of wave conditions (height, period and direction) over a year are input to longshore sediment transport calculations, long term, (eg, annual) transport rate and direction of transport along a shoreline can be determined, and the potential for long term erosion issues to arise assessed. Over the long term, erosion will occur when the supply of sediment to a beach compartment falls below the loss of sediment from the compartment (CERC, 1984).

The longshore transport rate is considered to be directly related to incident waves (and wave power); and the longshore current, as generated by the incident waves. The direction of longshore transport is dependent upon the angle of wave approach, and the transport volume is largely determined by the breaker height and type (CERC, 1984), as well as grain size and beach profile (slope). The longshore transport is also sensitive to the angle at which waves approach the shoreline.

When considering long term changes to the shoreline, such as removal or construction of beach structures in the surf zone or modifications to bathymetry, the calculation of annualised longshore transport (LST) rates are appropriate to determine the long term impact upon the shoreline, eg, erosion, accretion or stability. LST calculations may be used to determine net transport (transport rates and direction are summed such that opposing directions cancel, and the dominant transport direction is determined) or gross transport (the total quantity of transport regardless of direction) along a shoreline over the long term. The net transport rate reflects the dominant wave climate (direction, height, breaker type) along the shoreline.

The evolution of equations to calculate longshore transport, and the advantages and variations between these formulas is discussed below. The relevance of the equations selected for use in the current project is also explained.

Longshore Sediment Transport Rate Formulas

Energy Flux Model: the development of the CERC equation

The first models of longshore sediment transport were based on the concept that the total amount of sediment moved along the shore was related to the amount of energy available in waves arriving in the nearshore zone (termed the longshore energy flux). The longshore energy flux per unit length of beach was empirically correlated with the volume of sand moved by the waves (although accurate field measurements of sand transport were originally lacking, and only rough estimations based on measurements of sand trapped at structures were available). (Dean and Dalrymple, 2002)

Bagnold and Inman (1963) expressed this concept in terms of an immersed transport weight, introducing sediment porosity to convert sand weight to volume. That is, the immersed sand transport (*I*) is proportional to the alongshore wave power (*P*) per unit length of beach, and some calibration coefficient (K), that is, *I* = K *P*.

Incorporating sediment density, water density, acceleration due to gravity and sediment porosity, this concept was used to form the basic CERC equation:

$$Q = \frac{KP_l}{(\rho_s - \rho)g(1-p)}$$

By substituting the shallow water wave equations, the CERC equation is stated to be:

$$Q = \frac{\rho K \sqrt{g/\gamma_b}}{16(\rho_s - \rho)(1-p)} H_{s,b}^{2.5} \sin(2\theta_b)$$

This equation incorporates the longshore transport rate (Q), an empirical coefficient (K), the density of water (ρ), sediment density (ρ_s), acceleration due to gravity (g), significant wave height at breaking ($H_{s,b}$), breaker index (γ_b) (which is equal to wave height (H_b) divided by water depth (h_b)), breaker wave angle (θ_b), and sediment porosity (p).

The value of the calibration coefficient K has been widely studied in the literature (see discussion by Dean and Dalrymple 2002). Komar and Inman (1970) using field measurements (waves and currents with sensors, longshore transport using sand tracers), determined the value of the empirical coefficient K to be 0.77 (using root mean squared wave height (H_{rms}) in their calculations). Correcting this value by a factor of 2 to convert it to significant wave height (H_s), the Shore Protection Manual (CERC, 1984) prescribes 0.39 for use as the value of calibration coefficient, K.

The CERC equation is the most widely cited formula for calculating longshore sediment transport (LST) rates and has also been extensively used in engineering practice and frequently tested in academic research. For the most part, the CERC equation has been found to significantly overestimate the longshore sediment transport (LST) rate (eg Smith, *et al* 2004; Wang *et al* 2002; Wang *et al*, 1998; Van Rijn, 2001; Kumar, *et al* 2003; Lanrangeiro and Oliveira, 2003).

In particular, the CERC equation was found to greatly overestimate LST in low to average wave conditions (Van Rijn, 2001 found by a factor of 5; Kumar *et al* 2003), and overestimate to a lesser degree in storm wave conditions (Van Rijn, 2001 by a factor of 2). Miller (1998, 1999) found the CERC formula to correlate fairly well with measurements of LST during storm conditions.

The CERC equation has been criticised as not being sensitive to beach slope (tan β) and grain size (D_{50}) (eg, Fredsoe and Deigaard, 1992; Van Rijn, 2001, 2005; Dean and Dalyrymple, 2002). Modifications to the calibration coefficient (K) by del Valle *et al* (1993) to incorporate grain size have still been found to grossly overestimate the LST rate, to a similar extent as found for the prescribed K value from the Shore Protection Manual (Smith *et al* 2004).

Van Rijn (2005) noted that a 10% error in wave height produced a 25% error in LST rate with the CERC formula. Such an error could easily occur where offshore significant wave height is used in replacement of breaking wave height. In addition, the CERC formula does not account for additional longshore currents in the surf zone, eg tidal or wind-induced longshore currents, which may be significant in longshore transport (Van Rijn, 2001; Bayram *et al*, 2007).

Smith *et al* (2004) (and others) note that the CERC formula is not sensitive to breaker type (the surf similarity parameter). Field measurements by Wang *et al* (2002) showed plunging breakers produced considerably greater (2.65 times) LST rates than spilling breakers. The CERC formula, which takes no account of beach slope or wave period, was found to more greatly overestimate LST rates for spilling than for plunging breakers (Wang, *et al* 2002).

The Kamphuis (1991) equation:

The CERC equation was re-evaluated by Kamphuis *et al* (1986) to incorporate median sediment grain size (D_{50}) and beach slope, and again by Kamphuis (1991) to incorporate wave period. The resulting Kamphuis equation takes the form:

$$Q_m = 2.27 H_{s,b}^2 T_p^{1.5} m_b^{0.75} D_{50}^{-0.25} \sin^{0.6}(2\theta_b)$$

Where Q_m is the longshore transport rate in mass, $H_{s,b}$ is the significant wave height at breaking, T_p is the peak wave period, m_b is the beach slope near breaking, D_{50} is the median grain size and θ_b is the wave incidence angle at breaking.

A comprehensive study of 123 appropriate data sets and 52 equations found the Kamphuis (1991) relationship yielded the best estimations compared with measured data (Schoonees and Theron, 1996). As such, the Kamphuis (1991) equation has also been extensively used in engineering practice and research.

Subsequent to Schoonees and Theron (1996), additional testing has typically indicated LST rates calculated with Kamphuis (1991) vary from an overestimate (Wang *et al* 1998, Van Rijn, 2001), to an underestimate (Wang *et al*, 2002, Smith *et al* 2004) of the measured LST rates in low wave conditions. For storm wave conditions, the Kamphuis equation was shown to underestimate LST rates by up to one order of magnitude (Miller, 1998; Van Rijn, 2001).

The Kamphuis (1991) equation was found to predict LST rates equally well for both plunging and spilling breaker types (although the rates were still underestimated compared with measured values). This is thought to be due to the inclusion of wave period, in addition to beach slope, which may provide a representation the surf similarity parameter (Wang, *et al* 2002).

Dean and Dalrymple (2002) noted the Kamphuis (1991) equation to be overly sensitive to the wave incidence angle at values less than 10^{o} (to shore normal).

The Kamphuis (1991) equation is noted to be insensitive to other longshore currents (such as tide- or wind-driven currents) in the surf zone. Such currents may account for a large component of the longshore transport, particularly where the wave incidence angle (to shore normal) is small (Van Rijn, 2001; Bayram et al, 2007).

The Van Rijn (2001) formula:

The Van Rijn (2001) formula was developed out of a need to account for longshore sediment transport during storm wave conditions, and for which (due in large part to a lack of field and laboratory data) the existing and most widely used formulae (CERC, Bikjer and Kamphuis) were not specifically calibrated. The development of the formula also aimed to incorporate tide-driven currents, in addition to wave-driven currents. As noted by Bayram *et al* (2007) and Van Rijn (2001), the effects of tidal currents and wind-driven currents are likely to be present in much of the existing field data used to develop the equations, and so should be included in such equations.

Van Rijn (2001) utilised seven existing field data sets collected during storm wave conditions. This included the DUCK85, SANDYDUCK, SUPERDUCK data collection exercises in the USA by the US Army Corps of Engineers (during 1985 to 1989) which have been widely used in the literature, (eg, Kraus *et al* 1988; Miller, 1998; Bayram *et al* 2001; Bayram *et al* 2007), data sets from Florida also used by Wang *et al* 1998, and data from Egmond, the Netherlands. Where existing data was lacking (particularly for particle size, profile shape and wave period), results from the cross-shore profile evolution model CROSSMOR2000 were used to develop the formula, after calibrating the model to the seven data sets.

Van Rijn (2001) incorporates the effects of grain size, for fine sand to coarse shingle; beach slope profile; and additional longshore current velocities due to wind and tide in addition to breaking wave parameters at the breakpoint (wave height and period) into the LST formula. A separate term is stated for tidal currents. However, wind-driven longshore current velocities were assumed to be included in the calculation of wave-driven longshore velocities, as these effects are inherently present in the field data upon which the formula was calibrated. The work of Bagnold (1963) was adopted to calculate the wave-driven longshore currents. The resulting Van Rijn formula is:

$$Q_m = 42 K_{swell} K_{grain} K_{slope} H_{s,b}^{2.5} V_{eff,L}$$

Where Q_m is the longshore transport rate in mass, $H_{s,b}$ is the significant wave height at breaking, K_{swell} is a correction factor for swell waves (as opposed to a more irregular wave field), K_{grain} is a particle size correction factor incorporating D_{50}, K_{slope} is a correction factor for bed slope (incorporating tan β, the beach slope between the water depth at breaking and the shore), and $V_{eff,L}$ is the effective longshore current velocity due to the waves and tides.

The Van Rijn (2001) formula is applicable to the calculation of LST rates for beaches with grain sizes from 0.15 – 20 mm (fine sand to coarse shingle), for offshore wave heights of 0.5 to 4 m, non- to meso-tidal longshore currents conditions, and for plane to barred beach slope profiles. Calculations with the Van Rijn (2001) formula were found to predict LST rates better than CERC and Kamphuis, for the calibration data sets noted above.

Other investigators (Bayram *et al* 2001; Kumar *et al* 2003) using earlier versions of the Van Rijn formula, developed for rivers and estuaries (Van Rijn, 1984, 1993), have found the LST rate calculations to fit the measured data well, and better than the other equations investigated in concert (eg, Bailard and Inman (1981), CERC and others in Bayram *et al* 2001; and CERC and others in Kumar *et al* 2003).

<u>Energetics Formulae for Longshore Sediment Transport</u>

Bagnold (1963) originally developed a model for bed load sediment transport based on the idea that the energy of the flow exerts a shear stress upon the boundary layer and sediment, and causes the sediment to move. A number of authors have adapted and built upon Bagnold's idea to develop formulas for sediment transport in the surf zone (including Van Rijn (2001), for the wave-driven longshore velocity component of transport, as noted above).

Bagnold and Inman (1963) adapted Bagnold's (1963) idea to flow under waves (oscillatory flow), whereby the wave energy supports the sand grains, and any unidirectional current superimposed upon the wave orbital motion will transport the sand in the net direction of the current.

Bailard (1981) and Bailard and Inman (1981) used the energetics model of Bagnold (1963) to develop transport velocity vectors for oscillatory flow combined with a steady current over a plane sloping bed.

The formula took the form of instantaneous transport vectors for bed load and suspended load, which when averaged over one wave period gave a total transport rate and direction (Bayram *et al*, 2001; Dean and Dalrymple, 2002).

Bailard (1984) modified the formula, using assumptions, to express it in the form of the CERC equation. He developed an expression for the dimensionless calibration coefficient (K) which incorporated breaker angle, beach slope and sediment fall velocity (Dean and Dalrymple, 2002; Smith *et al*, 2004). Smith et al (2004) found the formula overestimated the transport (up to a factor of 4, Smith *et al* (2004)) when compared with field measurements. Bayram *et al* (2001) also found the formula overestimated transport for average wave conditions and underestimated transport for storm wave conditions.

Developments from the CERC (1984) Formula

Kraus *et al* (1988) have also attempted to improve upon the original CERC formula. They made the assumption that the LST rate was proportional to the longshore discharge of water, and included a calibration coefficient (K) which may account for sediment suspension, a threshold value for significant LST and a discharge parameter related to the average discharge of water alongshore. Wang *et al* (2002) found calculations with the Kraus *et al* (1988) formula in good agreement with measured rates for the case of spilling breakers, and to greatly underestimate transport under plunging breakers. Wang *et al* (2002) hypothesise that the standard value given by Kraus *et al* (1988) for K, which relates to sediment suspension, should be calibrated to account for the variation in sediment suspension between plunging and spilling breakers.

Bayram *et al* (2007) utilised Bagnold's (1963) theory to incorporate the effect of longshore current velocities other than that driven by waves (ie tides and winds) upon the longshore transport rate. Bayram *et al* (2007) showed that the rate of LST was proportional to the longshore current additional to the wave energy flux (which entrains and keeps the grains in suspension), and inversely proportional to the sediment fall velocity (ie, grain size). The Bayram *et al* (2007) equation is similar in form to the CERC equation, expressing transport in terms of the efficiency of waves in keeping grains in suspension, but then adds to the calibration coefficient the dependence of the LST rate upon longshore currents other than from waves, and upon grain size.

Bayram et al (2007) used data from Kumar *et al* (2003) and Wang *et al* (2002) (as noted in sections above) to calibrate and verify the formula, and then compare computations with six data sets, including the Duck, USA experiments of 1985-89 (DUCK85, SUPERDUCK and SANDYDUCK), and the longshore sediment transport facility (LSTF) in Mississippi, USA (described in Smith *et al* (2003)). Their coefficient predicted LST rates within a factor of 0.5 to 2 for 62% of data measurements tested.

Other available LST formulas discussed in the literature

Bayram *et al* (2001) tested six well known formulae and compared them with the Duck USA (DUCK58, SUPERDUCK, SANDYDUCK) experiments. Measured hydrodynamics were used wherever possible and the recommended calibration coefficients as given with the formulae were used in the calculations. The six formulae and their relative effectiveness in computing LST rates are described below.

Bijker (1967, 1971) developed a formula for transport under waves and currents based upon a river transport formula. The formula assumes bed load transport to be due to the total bottom shear stress by the waves and currents; and suspended transport calculated from integrating concentration and velocity profiles in the vertical direction, with the reference concentration as a function of the bed load concentration. The formula was found to overestimate transport in all cases. (Bayram et al, 2001)

Engelund and Hansen (1967) developed a formula for bed load transport in a unidirectional current over dunes. Introducing a factor to simulate wave stirring effects, Van de Graaf and Van Overeem (1979) applied the formula to total transport under waves and currents. The formula was found to work reasonably well, however it underestimates transport for graded fine sands and showed large scatter for storm wave cases. (Bayram et al, 2001)

Ackers and White (1973) calculated the total transport load for coarse and fine sediment under a unidirectional current. The coarse sand was assumed to travel as bed load, at a rate proportional to the shear stress upon the sand. Fine sand was assumed to be transported as suspended load and supported by turbulence, which was dependent upon the energy dissipation by bottom friction, and therefore, also dependent on the bed shear stress. Again, Van de Graaf and Van Overeem (1979) modified the formula to include the shear stress exerted by waves. The formula was found to reasonably predict transport, although large scatter was found for storm wave cases. (Bayram et al, 2001)

Van Rijn developed a formula for sediment transport in rivers (1984) which he then extended to estuaries (1993). Bed and suspended loads were calculated separately. The calculation for bed load transport was based upon Bagnold (1963). Suspended load concentration and velocity profiles were integrated vertically in three separate layers, with exponents for each layer based on the empirical expressions for mixing within that layer. The solution by Van Rijn (1993) was found to provide the most reliable estimates for both swell and storm wave conditions, compared with the other formulas. (Bayram et al, 2001)

Watanabe (1992) developed a total transport formula based on entrainment due to the shear stress from stirring and transport based on the longshore current speed. The formula takes the form of a volume of sediment entrained per unit area as proportional to the combined shear stress of the waves and currents (stirring), which is then transported by the mean current velocity (longshore current speed). The formula was said to perform reasonably well, although tended to overestimate transport under swell wave conditions. (Bayram et al, 2001)

Bayram et al (2001) also tested the Bailard and Inman (1981, 1984) formula as discussed above.

Many other authors (not reviewed here) have attempted to develop or modify the empirical formulas for longshore sediment transport. Depending on the purpose of the investigation, other transport formulas may be more or less appropriate. Additional formulae which exist in the literature include, but are not limited to:

- Van de Meer, J.A.W. (1990). Static and Dynamic Stability of Loose Materials, in *Coastal Protection*, Ed. K.W. Pilarczyk, Balkema, Rotterdam.
- Chadwick, A.J. (1989). Field measurements and numerical model verification of coastal shingle transport, in *Advances in Water Modelling and Measurement*, Ed. M.H. Palmer, British Hydromechanics Research Association, Cranfield.

- Madsen, O.S. and Grant, W.D. (1976). Quantitative description of sediment transport by waves, *Proceedings of the 15th International Conference on Coastal Engineering*, ASCE, Honolulu, 1093-1112.
- Walton Jr., T.L. and Bruno, R.O. (1989). Longshore transport at a detached breakwater, phase II, *Journal of Coastal Research*, **65** (9), 667-668.

Conclusions

While a large number of formulae have been discussed, not all are appropriate to all wave and shoreline conditions. Many of the formulas discussed are essentially variants on the widely used CERC equation, and may be more or less appropriate to a variety of field conditions. In this study, an existing and a proposed nearshore wave environment is being investigated. The variation in longshore transport caused by modification to the profile over the long term is of interest (rather than an exact quantification of the longshore transport rate). The formulae chosen (CERC, Kamphuis and Van Rijn) fit the needs of the project appropriately.

The CERC and Kamphuis formulas have been widely applied in coastal engineering practise. The use of the CERC formula can be assumed to provide a conservative estimate. The Kamphuis equation has been shown to fit fairly well with field measurements, and incorporates beach slope, grain size and wave period, components noted to be important in the determination of longshore transport. The more recent Van Rijn formula provides for the additional components found to be lacking in the CERC and or Kamphuis formulae by many authors. The formula of Van Rijn incorporates grain size, beach profile, wave period, and also, additional longshore currents as suggested in the literature to be of importance in calculating LST rates.

APPENDIX B: HYDRODYNAMIC AND MORPHODYNAMIC MODELLING BACKGROUND AND SET-UP

This appendix provides a summary of the wave model (SWAN) and hydrodynamic model (TUFLOW-FV), which have been developed and calibrated for a previous study on the Lower Myall River entrance hydrodynamics and sediment dynamics (BMT WBM 2011).

For numerical modelling investigations, tidal flows and sediment transport occurring within the study area are predicted by the hydrodynamic model (TUFLOW-FV) and morphodynamic model (TUFLOW-MORPH), respectively, with the effect of waves incorporated from the wave model (SWAN). Sediment supply may result from the combined effects of waves and tidal flows. As waves approach the coast, they refract, diffract, shoal (set up) and break. These processes generate forces which act to:

- Drive longshore currents; and
- Set up the water level at the shoreline.

In order to properly model coastal sediment transport processes, it is important to incorporate the resulting wave forces (also known as wave radiation stresses) into the hydrodynamic model. The waves also have a direct effect in stirring sediment from the bed, thus making it more available for transport by the currents. For this reason the spatial wave field also needs to be incorporated into the sand transport model (TUFLOW-MORPH).

Using the numerical models outlined above, the overall morphological modelling process, including the effects that waves and tidal flows have on sediment transport, follow the structure outlined in Figure B1. In all cases, the TUFLOW-FV hydrodynamic model is linked with the SWAN wave model, allowing the passage of wave stresses and the wave field to the hydrodynamic and sediment transport model, and bed elevations / current fields back to the wave model. This approach incorporates the important coastal processes occurring within the estuary that influence its environmental condition and introduce changes to bathymetry over time.

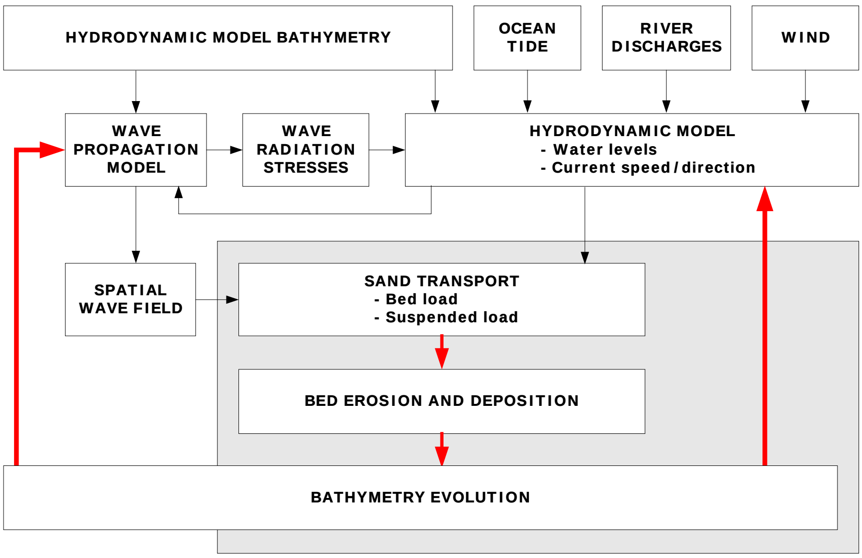


Figure B1 - Combined Hydrodynamic, Wave and Morphological Modelling

Hydrodynamic modelling (TUFLOW-FV)

TUFLOW-FV is a two dimensional finite volume model code that solves the conservative integral form of the non-linear shallow water equations (NLSWE) (i.e. assuming that pressure varies hydrostatically with depth), including viscous flux terms and source terms for Coriolis force, bottom-friction and various surface and volume stresses. The model is currently fully operational as a 2-dimensional and 3-dimensional NLWSE solver, including baroclinic forcing.

The scheme is also capable of simulating the advection and dispersion of multiple scalar constituents (e.g. salinity, temperature) within the model domain. Bed friction is modelled using a Manning's roughness formulation and Coriolis force is also included in the model formulation. The spatial domain (or study area extents) is discretised using contiguous, non-overlapping irregular triangular and quadrilateral "cells". Advantages of an irregular flexible mesh include:

- The ability to smoothly resolve bathymetric features of varying spatial scales (e.g. dredged channels adjacent to broad shoaled areas);
- The ability to smoothly and flexibly resolve boundaries such as coastlines; and
- The ability to adjust model resolution to suit the requirements of particular parts of the model domain without resorting to a "nesting" approach.

The flexible mesh approach has significant benefits when applied to study areas involving complex coastlines and embayments, varying bathymetries and sharply varying flow and scalar concentration gradients. TUFLOW-FV presently accommodates a wide variety of boundary conditions, including those necessary for modelling the processes of importance to the present study including water level and flow variations, wind stress and wave radiation stress, salinity and temperature. The assumption of a vertically well mixed water body means that the two-dimensional TUFLOW-FV adopted in this application is suitable. It is considered that three dimensional processes driven by salinity and / or thermal stratification are not significant issues for the study area, even though they might occur from time to time at some locations in response to fluvial inputs from the Myall Lakes. Sediment transport (erosion / accretion), water quality and tidal flushing are influenced by currents generated from a combination of tides and wave conditions and have been identified as the primary drivers influencing the issues of concern for the study area.

Wave Modelling (SWAN)

The Simulating WAves Nearshore (SWAN) model is a spectral coastal wave model code developed by the Technical University of Delft in the Netherlands.

The computer model developed for the Port Stephens / Myall Lakes Estuary adopts the SWAN spectral wave model to compute irregular waves in nearshore areas, based on variables such as deep water wave conditions, wind, bottom topography, currents and tides. SWAN may be configure to explicitly account for all relevant processes of propagation, generation by wind, interactions between the waves and decay by breaking and bottom friction with diffraction being included in an approximate manner (DHH, 2010).

Wave data, as represented by the significant wave height, period and mean direction of the two-dimensional wave spectrum is often required at coastal locations for coastal applications and modelling investigations. As discussed previously, the TUFLOW-FV hydrodynamic model is linked with the SWAN wave model to allow the passage of wave stresses to the hydrodynamic and sediment transport model to account for wave setup and longshore sediment transport, which influence the environmental condition and introduce changes to bathymetry within the estuary.

The wave model has been used to propagate “deep water” data measured at the WaveRider buoys inshore to the area of interest for the present study.

For the current study, a nonstationary two-dimensional SWAN model was developed to provide inputs to the hydrodynamic (TUFLOW-FV) and sediment transport (TUFLOW-MORPH) numerical models. Further details of the wave model development including bathymetry, geometry and boundary conditions are provided in the following sections.

Model geometry

The SWAN wave model consists of two grids, i.e. a coarse (larger) grid and a nested (smaller) grid with square cell sizes of 100 metres and 30 metres, respectively. The extents of the coarse and nested grids are shown on Figure 6-1.

The purpose of the coarse grid wave model was to define offshore areas to a depth of approximately 100 metres (i.e. approximately 25 to 30 km from the coastline) to ensure that waves entered at the boundary were in similar depths to the waves measured at the Waverider buoys. The coarse grid was orientated 70° in a counter clockwise direction from the positive (easterly) horizontal axis and was extended to the northern extent of Hawks Nest Beach, as far south as Fingal Bay and as far west to cover all of Port Stephens.

The nested grid was used to calculate higher resolution wave information within the bounds of the hydrodynamic model. The nested grid covers the flood tide delta region of Port Stephens and was orientated such that the y-axis is aligned in the north-south direction and the x-axis aligned in the east-west direction (i.e. model grid was not rotated).

Model bathymetry

Bathymetry or bottom topography required for development of the SWAN wave model includes ocean areas seaward of the entrance to a depth of approximately 100 metres. A DEM of nearshore and offshore bathymetry was estimated using depth contours digitised from a 1:150000 navigation chart for the east coast of Australia between Port Jackson and Port Stephens. These data were subsequently merged with other bathymetry data sources including that used for development of the hydrodynamic model to provide complete coverage for both wave model grids.

Model configuration

SWAN models were run in a two dimensional and stationary (i.e. each computation of wave spectra is used as an initial condition for the next set of boundary conditions) mode. Processes included within the model were depth induced breaking (constant) and dissipation by bottom friction (using the standard friction Collins coefficient of 0.015). Spectral wave directions were only considered from the sector between 52° and 262° (i.e. the model only considers waves between the north-easterly and southerly aspects) for the swell waves, and from all directions for the wind waves. The computation grid adopted for both coarse and nested grids was equivalent to the resolution and extents of the input bathymetric grid (i.e. no interpolation of bathymetry was required). Outputs from the model include wave induced force, spectral peak period, peak wave direction, significant wave height and water depth.

Morphodynamic modelling (TUFLOW-MORPH)

The morphodynamic model, TUFLOW-MORPH, is an extension of the hydrodynamic model TUFLOW-FV (described in section). The morphodynamic component simulates patterns of sediment transport as governed by the hydrodynamics and applied boundary forcing. The processes and characteristics incorporated into the model include:

- Sediment transport and bed-evolution (sedimentation and erosion);
- Slumping of unstable slopes (both underwater and adjacent to water bodies);
- Sediment classes and ability to spatially vary sediment properties according to material type;
- Transport rates calculated using recent methods proposed by van Rijn;
- Threshold velocity calculations using a shields criterion; and
- Option to calculate transport based on particle size distribution parameters (D_{10}, D_{50} and D_{90}).

Model bathymetry

TUFLOW-MORPH uses the same geometry as the TUFLOW-FV hydrodynamic model. The calculated sediment transport rates at each cell are applied within the finite volume scheme, utilising an upwind scheme to solve the sediment mass balance equation.

Sediment transport rates are calculated utilising a morphological time step which is larger than the hydrodynamic time step. Following testing, the morphological time step was set to 60 seconds.

While sediment transport is not calculated every hydraulic time step, the mass of sand within the bed is updated every time step. Consequently, the changes to bathymetry caused by erosion and scour have direct feedback to hydrodynamic processes every time step.

Model configuration

The morphodynamic model requires the input of sand grain sizes. Based on data from previous reports, the following sediment characteristics were applied in the shoreline areas:

- D_{10} = 0.16 mm;
- D_{50} = 0.41 mm; and
- D_{90} = 0.70 mm;

The sand within the study areas was assumed to be moderately well sorted marine sands. It was assumed that the in-situ bed material had a dry density of 1850 kg/m^3 (approximately equals sediment with a solid density of 2650 kg/m^3 and a void ration of 0.4).

Currents generated by ocean tide and swell waves are used by the morphodynamic model to drive sediment transport processes. No other specific boundary forcing data are required by the morphodynamic model other than the initial model bathymetry.

Scenario Selection for Morphological Modelling

Historical aerial photographs were examined to identify periods when the Eastern Channel experienced significant infilling and the sand spit grew notably:

- The Spit extended significantly between 2001 and 2009;
- A review of SPOT imagery for years 2005 and 2007 showed that a navigable channel was still present in February 2005 although the western extent of the spit was beginning to encroach on the eastern side of the channel;
- Aerial photos (DECCW) from April 2006 show that the east side (i.e. east of the pile of rock 'ballast' in the centre of the channel) of the channel was blocked by westward migration of the spit at that time.

Based on the timing of these features, wave data between February 2005 and April 2006 were examined. The data revealed that notable swell wave events occurred between March-April 2005 and June-July 2005. The south east facing alignment of shorelines within the study region is most vulnerable to swell waves originating from the south-east (SE). The March-April event had the more significant south-easterly waves and that event was subsequently chosen for analyses. This event was not responsible for all of the spit extension and channel infilling present between February, 2005 and April, 2006, but would have contributed a significant proportion. The time series of ocean wave heights and identification of those originating from the south east in shown on Figure B2.

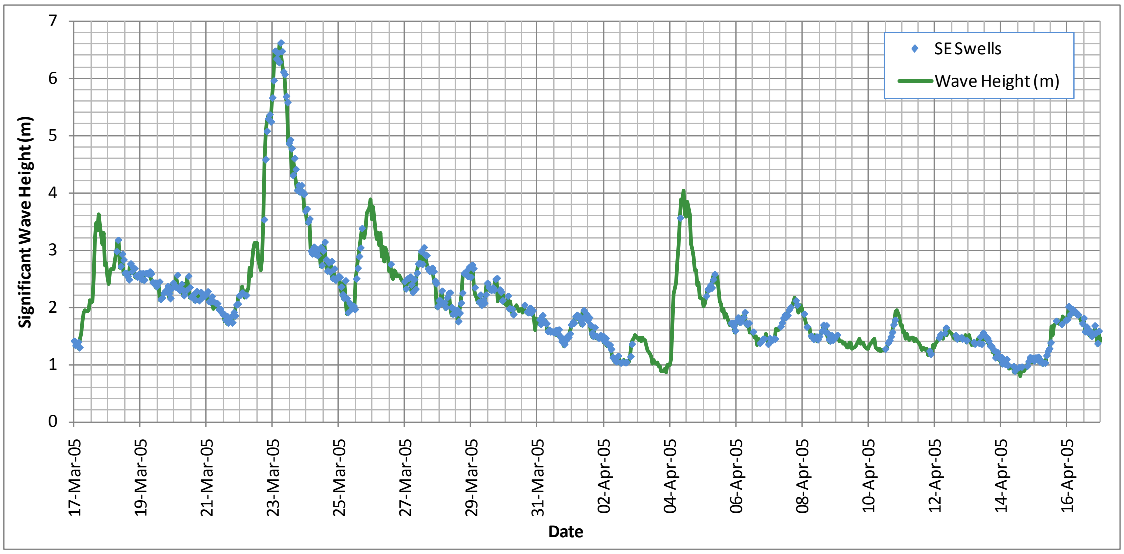


Figure B2 Wave Climate for Sydney from 17th March to 17th April 2005

APPENDIX C: DETAILED COST ESTIMATE FOR OPTIONS

Description	Quantity	Unit	Rate	Option YSS-1	YSS-2	YSS-3	LMR-1	LMR-2	LMR-3
Capital costs									
Construct haul road	10	hrs	$300				$3,000		
Preparation for permanent site works	1	item	$50,000		$50,000			$50,000	$50,000
Hopper and jet pumps device	1	item	$700,000		$700,000			$700,000	
Sand Shifter device	1	item	$750,000						$750,000
Hydraulic pumping instrumentation	1	item	$100,000		$100,000			$100,000	$100,000
Pipeline connections (supply & install)	1	item	$25,000		$25,000			$25,000	$25,000
Supply and install booster pump	1	item	$125,000		$125,000			$125,000	$125,000
Power supply connection to unit and booster	1	item	$300,000		$300,000			$300,000	$300,000
TOTAL CAPITAL				**$0**	**$1,300,000**	**$0**	**$3,000**	**$1,300,000**	**$1,350,000**
Recurrent costs (every 6 months say)									
Site mobilisation and demobilisation	1	item	$10,000	$10,000	$5,000		$10,000	$5,000	
haul road and street repairs	30	hrs	$300				$9,000		
Excavate	140	hrs	$220	$30,800			$30,800		
Loading and spreading	140	hrs	$360	$50,400	$25,200		$50,400	$25,200	
Truck haulage	140	hrs	$350	$49,000			$49,000		
Hopper pumping power usage & maintenance	10,000	cub m	$3		$30,000			$30,000	
Booster pumping power usage	10000	cub m	$1		$10,000			$10,000	$10,000
Sand Shifter power usage &	10000	cub m	$3						$30,000

Description	Quantity	Unit	Rate	YSS-1	YSS-2	YSS-3	LMR-1	LMR-2	LMR-3
maintenance									
Recurrent costs (every 18 months say)									
CSD mobilisation and demobilisation	1	item	$100,000			$100,000			
CSD dredging and pumping	30000	cub m	$17			$510,000			
Loading and spreading	220	hrs	$360			$79,200			
Truck haulage	220	hrs	$360			$79,200			
TOTAL RECURRENT COST PER EPISODE				**$140,200**	**$70,200**	**$768,400**	**$149,200**	**$70,200**	**$40,000**
ANNUAL RECURRENT COST				**$280,400**	**$140,400**	**$512,267**	**$298,400**	**$140,400**	**$80,000**
CONTINGENCY, say	30%								
Total Capital Cost (including contingency)				**$0**	**$1,690,000**	**$0**	**$3,900**	**$1,690,000**	**$1,755,000**
Annual Recurrent Cost (including contingency)				***$364,520***	***$182,520***	***$665,947***	***$387,920***	***$182,520***	***$104,000***
TOTAL OVER 5 YEARS				***$1,822,600***	***$2,602,600***	***$3,329,733***	***$1,943,500***	***$2,602,600***	***$2,275,000***
TOTAL OVER 10 YEARS				***$3,645,200***	***$3,515,200***	***$6,659,467***	***$3,883,100***	***$3,515,200***	***$2,795,000***
TOTAL OVER 20 YEARS				***$7,290,400***	***$5,340,400***	***$13,318,933***	***$7,762,300***	***$5,340,400***	***$3,835,000***
Additional Costs									
Design, Specifications & REF	1	item	$200,000						
Cross-shore modelling	1	item	$30,000						
Tracer study	1	item	$80,000						
Construct temporary groynes	1	item	$80,000						
Beach monitoring (per 3 months)	1	item	$10,000						

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