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Tweed Quantified Conceptual Sediment Transport Model

TWEED SAND BYPASSING

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Contents

1. Introduction

1.1 Background

The Tweed River Entrance Sand Bypassing Project (TRESBP), now referred to as Tweed Sand Bypassing (TSB), is a joint initiative of the New South Wales and Queensland governments that has the dual objectives of

- Establishing and maintaining a navigable depth at the Tweed River Entrance; and
- Achieving and maintaining a continuing supply of sand to southern Gold Coast beaches at a rate that is consistent with the natural littoral drift.

The sand bypassing system aims to meet these objectives in perpetuity by pumping of sand slurry via a jetty mounted pumping system at Letitia Spit and dredging of the Tweed River entrance area. The sand bypassing system has been fully operational since 2001.

The TSB has adopted a 2015-2024 Project Strategy. A priority of the Project Strategy over the next five years (2017-2021) is the rapid growth in knowledge and understanding of the TSB's operating environment and its interrelationships with and effects on coastal processes. The knowledge building is achieved through development and ongoing operation of a so-called Sand Transport Information System (STIS). The STIS seeks to build the knowledge through a series of work packages. This report presents the outcomes of work package STIS001 of the STIS.

Figure 1-1 Locality map of STIS Project Area

1.2 Study Scope

The scope of this study involves the following task components:

- Based on existing available information held by TSB, synthesise and describe the current understanding of the geomorphic processes
- Develop a series of quantified conceptual models that depict and describe the key pathways and mechanisms for sand transport through the STIS Project Area
- Identify the critical knowledge gaps that exist in the current understanding of the sediment transport processes operating within the STIS, including the effects of TSB's sand bypassing operations, and recommend methodologies to fill these knowledge gaps

This report was prepared by Jacobs with the understanding that this is primarily a document for internal use by the TSB organisation. It has been assumed that the reader has a level of knowledge of coastal dynamics, the TSB operations and the STIS Project Area in general.

1.3 Historical Data and Reports

There is a considerable amount of monitoring data, relevant previous investigations and reports relating to the sediment transport processes in the Project Area (Refer to Figure 1-1) and in the region generally. Information reviewed and considered in this study includes:

- Previous technical reports and papers (as referenced)
- Hydrographic surveys conducted regularly by TSB
- Wave time-series data obtained from the Tweed River and Point Lookout wave buoys
- Dredge and sand pumping logs
- Historical aerial photographs
- Historical photographs
- Sediment budget analysis data
- Streamflow data from the Tweed River streamflow gauge at Uki

As part of the study Jacobs has compiled a reference register, which describes the nature and aspects covered in key information sources considered in this study and provides details on the time parcel and geomorphic compartment it relates to.

2. Coastal Processes

2.1 General Considerations

Coastal processes essentially involve the movement of water (eg. waves and currents) and sediment (mostly sand) within and around the coastal zone. Sediment dynamics includes sand transport (1) within the mostly dry sandy beaches, (2) in the intertidal swash zone, and (3) in the deeper nearshore waters, and can be both alongshore transport (parallel to the shoreline) and cross shore transport (in the direction of wave travel, often more or less perpendicular to the shoreline).

Coastal processes are influenced by:

- **Regional geology,** which sets the structure of the coastal zone.
- **Local geomorphology**, which is affected by and affects other coastal processes, but particularly in the case of the Tweed River entrance area, has been significantly modified by human intervention, including the operation of the TSB.
- **Waves**, generated offshore (swell) and locally during storms, including variability in the wave climate over seasonal, inter-annual and decadal time scales.
- **Ocean water levels**, generated from tides and amplified during storms.
- **Nearshore currents**, generated by the combined effect of breaking waves, winds, tides and regional oceanic processes.
- **Coastal Entrance Dynamics**, which in the case of the Tweed River may contribute to currents around the entrance relating to tides and catchment flows
- **Wind**, which can generate wind driven (Aeolian) sediment transport

The natural coastal processes influencing the supply and movement of sand through the STIS Project Area are complex. The coastline is exposed to a moderate to high wave climate with significant seasonal variability. Consequently, the coastal zone across the STIS Project Area is highly dynamic. The mechanism of sand bypassing around the Tweed River entrance and around Point Danger is extremely complex due to the intricate interaction of numerous oceanic and estuarine processes that are of significance there.

This section of the report provides a description of the key coastal processes affecting the STIS project area, synthesised from previous studies and existing data.

2.2 Geology and Geomorphology of the STIS Project Area

The STIS Project Area consists of the coastal zone between Fingal Head in New South Wales and Currumbin in Queensland. It includes approximately 13 km of shoreline, comprising a number of sandy beaches controlled by the rocky headlands and offshore islands (Fingal Head, Point Danger, Snapper Rocks, Elephant Rock, Currumbin Rock and Cook Island), the Tweed River entrance and a number of groyne structures (Kirra Point groyne, Miles Street groyne, Currumbin groyne).

Regionally, the Project Area is part of a long coastal unit that experiences a continuous northerly alongshore transport of sand extending from around the Clarence River in the south to Moreton Bay in the north. This coastal unit has a series of major controlling headlands past which the sand is moved by the prevailing waves.

The beaches as we see them today result from the morphological evolution of the continental shelf and coastline predominantly during the late Quaternary period covering two epochs, most notably:

- The late Pleistocene covering the last 120,000 years including the last ice age; and

- The Holocene covering the past 10,000 years of the most recent warmer post-glacial period.

During the late Pleistocene, mean sea levels fell to reach a level of about 120m below the present level during the peak of the last ice age (about 18,000 years ago). From 18,000 to 6,000 years ago, sea levels rose back quickly to around present levels.

During the latter part of that sea level rise, sand was brought from the continental shelf to the coastal zone, forming dunes seaward of the former residual Pleistocene barriers. These Holocene dune barriers have subsequently evolved under the influence of contemporary coastal processes. While it is generally considered (Thom 1975; Thom 1984; Stephens et al 1981) that the most recent Holocene period of sand supply to the coast essentially ended about 3,000 years ago, it has been suggested that there remains a small but relatively significant shoreward supply within the coastal unit (Roy et al 1997; Cowell et al 2000; Roy 2001; Goodwin et al 2005, Patterson, 2013). Based on modelling of the coastline evolution processes, Patterson (2013) estimated that there remains a net shoreward supply of sand to the beach system from the lower shore-face along most of the regional coastline between the Clarence River and the Gold Coast of about 1-2m^3/m/year.

Thom et al (1978) suggest that 7,000 years ago mean sea levels were somewhere between 10m and 15m below present and, at this sea level, Cook Island and Fingal Head were acting as littoral barriers along the coastline. The Tweed River would have exited to the sea via Wommin Lake. Letitia Spit, because of the Fingal Head littoral barrier, would probably not be completely developed at that time.

The attainment of present day sea levels, approximately 6,000 years ago, would have drowned these land bridges between existing outcrops of bedrock. The Cudgen to Fingal sand barrier would have moved onshore to occupy, more or less, the present shoreline position. The location of the Tweed River at Wommin Lake would have no longer been stable due to the high longshore sediment flux. The river mouth would have migrated sequentially northwards. The high influx of sediment would have led to the development of Letitia Spit (Refer Figure 2-1).

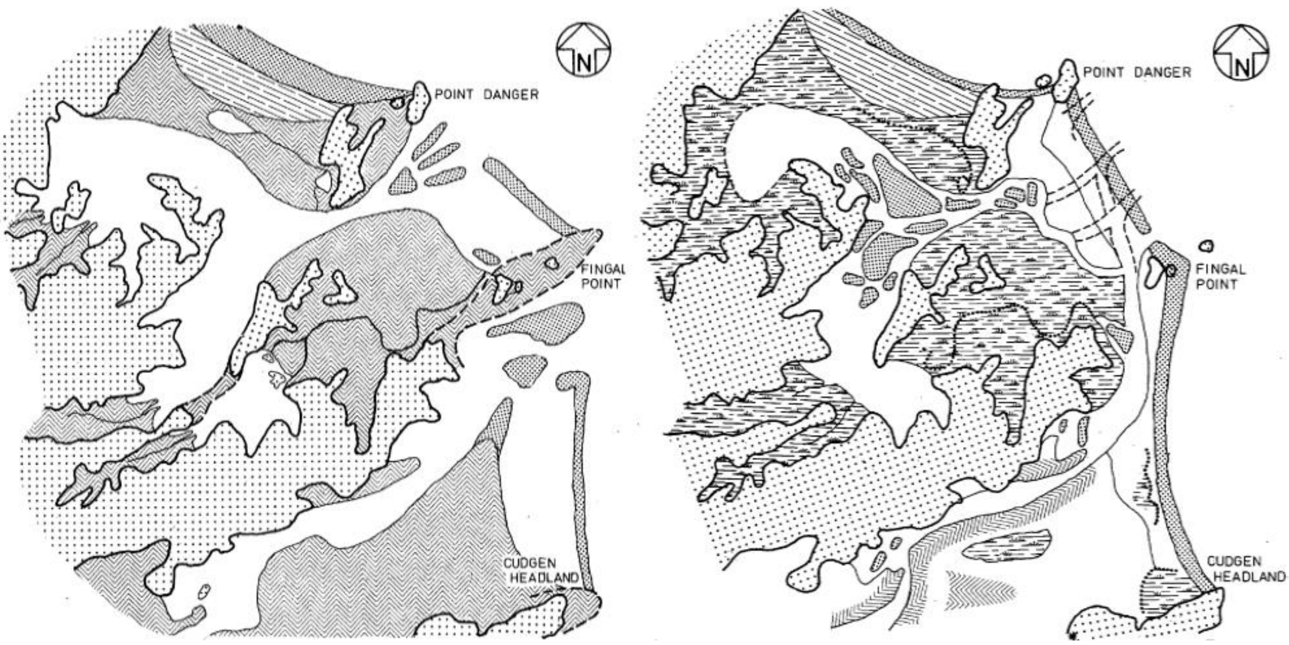

Figure 2-1 Tweed Area Coastal Geomorphology Circa 7000 Years before present (left) and 6000 years before present (right) [Druery and Curedale, 1979]

The northward migration of the Tweed River entrance would have induced a sympathetic migration of the lower reach of Terranora Creek. It is considered that Ukerebagh Passage represents a former Creek course, abandoned during some stage of northward migration. Tidal reworking of sediments within the Terranora estuary would have led to the formation of tidal bay shoals at Boyd's Bay and at the main entrance to the Broadwaters (Druery and Curedale, 1979).

It is important to recognise that the present day entrance to the Tweed River is a relatively recent event in geological terms and there is uncertainty whether or not the reworking of marine sediments within the estuary may still have been an ongoing process, even without human interventions.

The behaviour of the lower Gold Coast shoreline during those processes was extremely complex, affected substantially by the groyne effect of the Fingal reef barrier to alongshore supply at somewhat lower sea levels, with subsequent high resupply as that barrier was submerged by the rising sea (Patterson, 2013). The result was substantial initial shoreline recession into the former Pleistocene barrier as sea levels fell and redevelopment of the wide Holocene barrier evident today along Bilinga-Tugun, Palm Beach, Burleigh and north from Mermaid Beach around 8,000 to 5,000 years ago (BMT WBM, 2017).

Since the late 19th century, the coastline has seen substantial change as a result of human activities. Human activities in the Project Area include construction of river training walls, groynes, seawall, sand mining, sand supply as beach nourishment and sand relocation activities, including operation of the TSB’s sand bypassing system. For a detailed timeline of these human activities, reference should be made to BMT WBM (2017).

2.3 Natural Sand Transport Mechanisms

Sand is transported through the STIS Project Area by the combined action of waves, currents and wind within the context of shoreline shape, alignment and bathymetry. Waves have three key effects on sand transport in the nearshore zone, namely:

- **Wave Breaking** - As waves break they generate radiation stresses, which may drive longshore currents (particularly within and immediately outside the surfzone);
- **Wave Motion** – The waves’ orbital motion may impose shear stresses on the seabed, which may mobilise and put into suspension the seabed sediment. The asymmetry of wave orbital motion in shallower water causes a differential in the forcing on the bed sediments that is stronger towards the shoreline, resulting in an onshore mass transport of sand; and
- **Undertow** - Waves can cause a bottom return current and rip currents in the surfzone which can result in cross-shore transport.

Currents generated by waves, tide, wind and the East Australian Current provide the primary mechanism for the transport of the sand that has been mobilised and put into suspension by wave/current action.

In simple terms, sand transport at a typical beach location may be regarded as involving longshore and cross-shore sand movement processes. These act concurrently and interact together.

2.3.1 Longshore Sand Transport

Waves approaching the shoreline from an oblique angle generate a current alongshore which, in conjunction with the wave action, transports sediment. Depending on the prevailing wave direction, the alongshore sediment transport may be directed either north or south along the coast. On the northern NSW and south-east Queensland beaches, the net alongshore sediment transport is directed to the north, due to the predominant south easterly wave climate relative to the general north to south orientation of the coastline. The rate of longshore transport tends to be the highest during the summer and early autumn months, as during these months wave energy levels are typically the highest.

Alongshore sediment transport (also commonly referred to as littoral drift) occurs predominantly in the mid to outer surfzone (or inner nearshore zone), diminishing in strength with distance offshore into deeper water. In some circumstances, winds, tides and the East Australian Current may also contribute to longshore currents, and may dominate the currents outside of the surfzone.

Along the majority of the Project Area, the wave-driven alongshore current is the dominant current with respect to overall sediment transport regime along the coastline. As a result, along most locations, the majority of the longshore sand transport occurs in water depths of less than 4 metres. Notwithstanding this, wind-driven currents and the East Australian Current have a significant influence on the longshore transport regime in the deeper parts of Point Danger, Duranbah and Letitia Spit, particularly in water depths of greater than 8 metres.

Wave effects on longshore transport are complex due to the variability of wave conditions, the dependency on the ever-changing beach profile geometry and the complex effects of headlands, man-made structures and coastal inlets on both the waves itself and the wave-driven currents.

2.3.2 Cross shore Sand Transport

Sand is transported across the nearshore beach profile by wave action. Cross-shore sand transport may be in the offshore direction during beach erosion events or onshore during normal swell conditions. Transport in these two directions appears to occur in distinct modes, with quite disparate time scales.

Onshore sediment transport essentially takes place along the direction of wave propagation, and occurs typically in “wave-like” motions whereby ripples are formed and individual packets of sand move towards (and merge onto) the dry beach. Onshore transport is largely related to the effects of waves. Outside the breaker zone, the wave crests become increasingly higher and of shorter duration than the troughs as waves approach the coast and enter shallower water. As a result, the orbital velocity becomes increasingly asymmetrical, leading to a net sand transport in the direction of wave propagation. The effect of gravity (through the bed slope) opposes this tendency for onshore movement of sand.

Within the breaker zone, the breaking of waves drives an onshore-directed mass transport which is concentrated around the water surface. The onshore-directed mass transport induces an offshore-directed return flow which is concentrated near the bottom of the water column. This so-called undertow is relatively strong in magnitude and located in an area in close proximity to the seabed, where sediment loads are typically the highest. The undertow can be substantial during storms, and can carry a considerable amount of suspended sediment offshore.

Rip currents are strong, localised seaward directed currents that are generated by longshore variations in wave setup. Rip currents tend to occur wherever there is variability in bathymetry or around structures, likes groynes and training walls. These lateral escape currents are usually quite narrow, but can become more common, wider and faster when breaking waves are large and powerful. High offshore-directed flows in rip currents can be a hazard for swimmers and can transport significant amounts of sand offshore.

2.4 Wave Climate

The regional wave climate is a dominant factor in the coastal processes affecting the Project Area. The deep-water wave climate of the northern NSW / southern Queensland coast comprises a highly variable wind wave climate superimposed on a persistent long period, moderate to high energy south to south-easterly swell.

Typically, the swell offshore may range up to 3-4m significant wave height with periods in the range 7 to 15 seconds. Prevailing wind waves are incident from a wider range of directions, consistent with the wind climate for the region, and range from small short period local ‘sea’ conditions to large storm and cyclone waves in excess of 6-7m significant wave height.

As part of the TRESBP, a directional wave recording buoy was established offshore from Letitia Spit in 20-30m of water depth, which has recorded local wave conditions since January 1995.

Table 2-1 and Table 2-2 present wave parameter statistics, based on wave recordings during the period between March 1995 and March 2017. Table 2-1 shows the frequency of occurrence FOR NOT in terms of significant wave height and peak wave direction, and Table 2-2 in terms of significant wave height and spectral peak wave period.

In addition, wave measurement data from an offshore location near Point Lookout (Brisbane Offshore) was sourced from the Queensland Department of Science, Information Technology and Innovation. Basic wave parameter statistics for this location, derived from wave recordings during the period between March 1997 and March 2017, are presented in Table 2-3 and Table 2-4.

The ambient wave climate tables illustrate the predominance of the southeasterly offshore wave direction, meaning that most of the time (>80% of time) waves approach the Tweed Heads wave buoy from a downcoast direction. Modal wave heights at the Tweed Heads wave buoy are 0.5-2.0m with spectral peak periods predominantly (~65%) in the range 7-12 seconds.

Table 2-1 and Table 2-2 show that waves with a significant wave height in excess of 7.5m have been observed at the Tweed Heads wave recorder. The highest recorded (hourly) significant wave height at Tweed Heads during the 22 year monitoring period was 7.52m and was recorded on 3rd May 1996. During the May 1996 event, large north-easterly waves were experienced for a 4-day period with the recorded significant wave height exceeding 5m for a period of approximately 28 hours (See also Figure 2-2). The maximum wave height recorded during this event was 13.1m.

There is seasonal variability in the wave climate with the summer and autumn months being the most energetic. Large wave events (events with a maximum significant wave height of greater than 5m) predominantly occur during the summer and autumn months, and rarely occur during spring or winter. During the winter months, the wave climate is mostly influenced by swell. Consequently, the average peak wave period is larger during these months and the energy-weighted wave direction is more southerly (ie. moved in a clockwise direction), compared to the other seasons.

Table 2-1 Wave Height and Direction Occurrence Frequency – Tweed Heads Wave Buoy (%)

		Peak Wave Direction (degrees TN)																	
		0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	
Hs (m)		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	TOTAL
0	0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.3%	0.2%	0.0%	0.0%	0.0%		0.0%	1.2%
0.5	1	0.0%	0.1%	0.6%	1.1%	1.0%	0.7%	1.1%	2.0%	3.8%	5.7%	6.2%	6.5%	4.8%	1.3%	0.1%	0.0%	0.0%	0.0%	35.0%
1	1.5	0.0%	0.1%	0.7%	1.2%	0.8%	0.5%	1.4%	3.8%	6.4%	7.3%	6.5%	6.4%	4.7%	1.4%	0.1%	0.0%	0.0%	0.0%	41.3%
1.5	2	0.0%	0.0%	0.1%	0.2%	0.1%	0.1%	0.6%	2.1%	2.8%	2.8%	2.5%	2.2%	1.4%	0.3%	0.0%				15.2%
2	2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.3%	0.8%	1.0%	1.1%	0.8%	0.6%	0.2%	0.0%	0.0%			0.0%	5.0%
2.5	3			0.0%	0.0%	0.0%	0.0%	0.1%	0.4%	0.4%	0.3%	0.2%	0.1%	0.0%	0.0%					1.4%
3	3.5					0.0%	0.0%	0.1%	0.2%	0.2%	0.1%	0.0%	0.0%							0.6%
3.5	4					0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%								0.2%
4	4.5					0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%								0.1%
4.5	5						0.0%	0.0%	0.0%	0.0%	0.0%									0.1%
5	5.5					0.0%	0.0%	0.0%	0.0%	0.0%	0.0%									0.0%
5.5	6						0.0%	0.0%	0.0%	0.0%										0.0%
6	6.5						0.0%	0.0%	0.0%											0.0%
6.5	7						0.0%	0.0%	0.0%											0.0%
7	7.5							0.0%	0.0%											0.0%
	>7.5							0.0%												0.0%
	Grand To	0.0%	0.3%	1.4%	2.4%	1.9%	1.5%	3.8%	9.5%	14.8%	17.5%	16.4%	16.0%	11.3%	3.0%	0.2%	0.0%	0.0%	0.0%	100%

Table 2-2 Wave Height and Peak Period Occurrence Frequency – Tweed Heads Wave Buoy (%)

		Peak Wave Period (s)																				
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
Hs (m)		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	>21	TOTAL
0	0.5	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%
0.5	1	0.0%	0.4%	1.6%	2.4%	3.1%	4.3%	4.6%	5.3%	5.5%	3.2%	2.6%	1.1%	0.5%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	35.0%
1	1.5		0.0%	0.8%	2.4%	3.5%	5.8%	6.7%	6.5%	6.8%	3.9%	2.9%	1.2%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	41.3%
1.5	2			0.0%	0.2%	0.9%	2.0%	3.0%	2.9%	2.6%	1.6%	1.2%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%		0.0%		15.2%
2	2.5				0.0%	0.1%	0.4%	0.9%	1.0%	1.0%	0.6%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%				5.0%
2.5	3					0.0%	0.1%	0.2%	0.3%	0.4%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%					1.4%
3	3.5						0.0%	0.0%	0.1%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%						0.6%
3.5	4							0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%						0.2%
4	4.5							0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%								0.1%
4.5	5								0.0%	0.0%	0.0%	0.0%	0.0%	0.0%								0.1%
5	5.5								0.0%	0.0%	0.0%	0.0%	0.0%	0.0%								0.0%
5.5	6								0.0%	0.0%	0.0%	0.0%	0.0%									0.0%
6	6.5									0.0%	0.0%	0.0%	0.0%									0.0%
6.5	7										0.0%	0.0%	0.0%									0.0%
7	7.5										0.0%	0.0%	0.0%									0.0%
	>7.5											0.0%										0.0%
	TOTAL	0.0%	0.4%	2.4%	5.0%	7.6%	12.7%	15.7%	16.3%	16.8%	9.9%	7.8%	3.1%	1.4%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	100%

Table 2-3 Wave Height and Direction Occurrence Frequency – Brisbane Offshore Wave Buoy (%)

Hs (m)		Peak Wave Direction (degrees TN)																
		N	NNE	NE	WNE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0	0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%									0.1%
0.5	1	0.5%	0.7%	0.6%	1.5%	3.0%	3.8%	4.6%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15.7%
1	1.5	1.3%	1.2%	0.8%	4.4%	7.4%	6.6%	10.2%	2.7%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	35.0%
1.5	2	0.5%	0.3%	0.2%	2.9%	5.2%	4.6%	7.8%	2.9%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	24.6%
2	2.5	0.1%	0.0%	0.1%	1.3%	2.5%	2.6%	4.8%	2.3%	0.1%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	13.7%
2.5	3	0.0%	0.0%	0.0%	0.5%	1.1%	1.1%	2.2%	1.2%	0.0%							0.0%	6.2%
3	3.5	0.0%		0.0%	0.2%	0.4%	0.4%	1.0%	0.6%	0.0%		0.0%						2.7%
3.5	4			0.0%	0.1%	0.2%	0.2%	0.4%	0.2%	0.0%								1.1%
4	4.5			0.0%	0.1%	0.2%	0.1%	0.1%	0.1%	0.0%				0.0%				0.5%
4.5	5			0.0%	0.0%	0.1%	0.0%	0.0%	0.0%									0.2%
5	5.5			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%									0.1%
5.5	6			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%									0.0%
6	6.5			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%									0.0%
6.5	7			0.0%	0.0%	0.0%	0.0%	0.0%										0.0%
	> 7.0			0.0%		0.0%	0.0%							0.0%				0.0%
	TOTAL	2.5%	2.2%	1.8%	11.1%	20.1%	19.6%	31.1%	11.0%	0.3%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.1%	100%

Table 2-4 Wave Height and Peak Period Occurrence Frequency – Brisbane Offshore Wave Buoy (%)

Hs (m)		Peak Wave Period (s)																				
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	>21	TOTAL
0	0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%						0.1%
0.5	1	0.0%	0.3%	0.7%	0.9%	1.1%	2.0%	2.4%	2.5%	2.2%	1.2%	1.3%	0.7%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15.7%
1	1.5		0.1%	1.1%	2.5%	2.3%	4.5%	6.4%	6.1%	5.2%	2.8%	2.3%	1.1%	0.5%	0.1%	0.0%	0.0%	0.0%	0.0%			35.0%
1.5	2		0.0%	0.1%	1.1%	2.0%	3.2%	4.6%	4.3%	4.0%	2.3%	1.8%	0.9%	0.4%	0.1%	0.0%	0.0%	0.0%				24.6%
2	2.5				0.1%	0.9%	2.2%	2.8%	2.5%	2.1%	1.3%	1.1%	0.5%	0.2%	0.0%	0.0%	0.0%					13.7%
2.5	3				0.0%	0.1%	0.8%	1.4%	1.3%	1.0%	0.7%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%					6.2%
3	3.5				0.0%	0.0%	0.1%	0.6%	0.6%	0.5%	0.4%	0.3%	0.1%	0.1%	0.0%	0.0%	0.0%					2.7%
3.5	4					0.0%	0.0%	0.1%	0.2%	0.3%	0.2%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%					1.1%
4	4.5						0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%						0.5%
4.5	5						0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%						0.2%
5	5.5							0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%							0.1%
5.5	6							0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%							0.0%
6	6.5								0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%							0.0%
6.5	7								0.0%	0.0%	0.0%	0.0%										0.0%
	>7.0									0.0%	0.0%	0.0%										0.0%
	TOTAL	0.0%	0.4%	1.8%	4.6%	6.5%	12.9%	18.3%	17.6%	15.5%	9.0%	7.6%	3.7%	1.6%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	100%

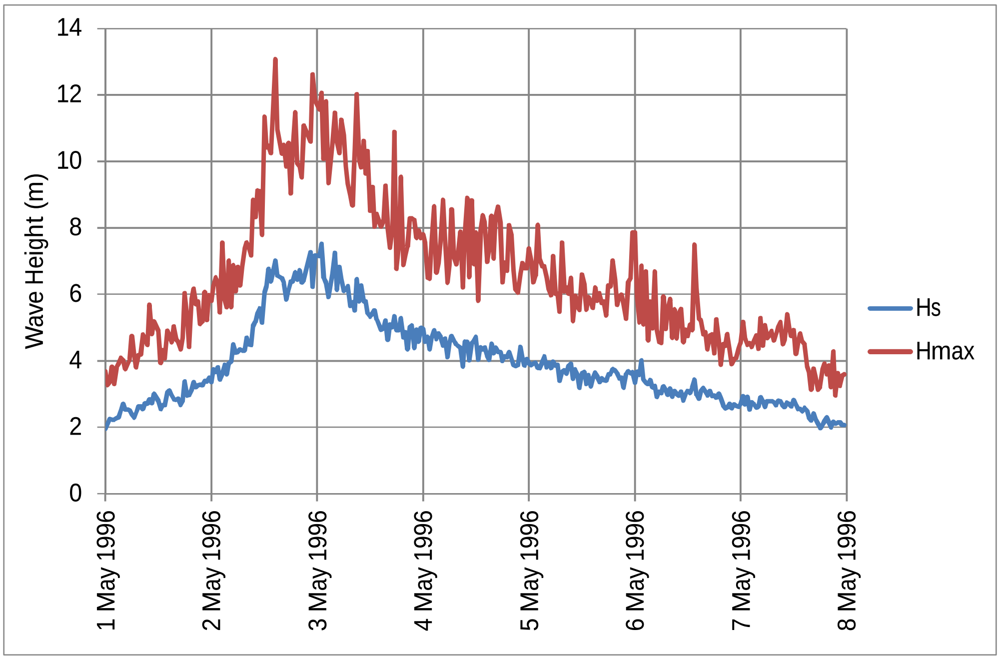

Figure 2-2 Recorded Wave Height during the May 1996 event

2.5 Currents

Nearshore currents are important because of their significant influence on longshore sand transport. The nearshore current regime within the Project Area is controlled by a complex interaction of meteorological conditions, tides, shelf/ocean currents and waves. In general terms, the following factors contribute to the generation of the overall current pattern in the Project Area:

- breaking waves,
- winds,
- tides; and
- the East Australian Current.

The relative influence of each of these components will vary throughout the study area and is strongly influenced by the water depth and the proximity of bathymetric features such as reefs, headlands, islands and river entrances.

2.5.1 Wave-driven currents

Wave-driven longshore currents are generated when waves break in front of the shoreline under an angle. The speed and nature of the longshore current is dependent on the height and angle of the breaking wave together with the bathymetric features.

Under most conditions, the speed of the wave-driven longshore current along the STIS shoreline is up to about 1m/s, either upcoast or downcoast depending on the wave angle and occurs in a zone of up to about 2-3 metres water depth (Hyder et al., 1997). During storms, larger longshore currents may be generated, with flow velocities up to about 1.5-2.0m/s may occur out to depths of about 8-10m along the open beaches. Adjacent to headlands (Point Danger) and around structures (notably the Tweed River training walls) even higher flow velocities may be expected to occur locally.

2.5.2 Wind-induced currents

As wind blows over the water surface, they exert stresses on the water surface, which may not only generate waves but can also drive shore-parallel currents.

Measurements of the currents at a location off Point Danger, at about 8m water depth (HaskoningDHV, 2017)) indicate that under ambient conditions wind typically generates a nearshore current of about 0.2m/s at this location. It is expected that during storms, larger currents will be generated, probably in the order of up to about 0.5m/s along most of the coastline.

2.5.3 Tidal Currents

The tide in the STIS region is classified as semi diurnal with significant diurnal inequalities, with two high tides and two low tides per day that are generally at different levels (i.e. the two high tide levels are different in any one day).

The tidal wave propagates more or less east to west, with little longshore components except the north facing beaches between Point Danger and Coolangatta. In most of the Project Area, tidal currents are generally of low speed (<0.1 m/s) except within the direct zone of influence of the Tweed River entrance.

The nature and magnitude of the tidal currents over the entrance bar depends on the bar bathymetry which changes continuously. Generally, the tidal current pattern at the entrance bar is radial inflow over a large part of the entrance during the flooding tide and a concentrated ebb jet directed seaward during the ebbing tide. The ebb jet may be deflected to the north or south under the influence of winds, waves, the East Australian Current and the local bar/channel configuration. Ebb flow velocities are typically about 1.0-1.5m/s through the entrance and may reach up to about 1.5m/s over the entrance bar during larger spring tides (Hyder et al, 1997, Helyer et al., 2011).

Flood tide currents tend to enter the river more or less radially and consequently peak flow velocities over the bar during flood tides are substantially lower than the peak flow velocities during ebbing. Peak flood flow velocities over the bar will be dependent on the configuration of the entrance bar. Measurements in 2009 and 2010 by Helyer et al. (2011) when the entrance was relatively open suggest that peak flood flow velocities on the entrance bar may remain below 0.3m/s. In a more silted configuration, with a fully developed bar across the entrance, peak flood flow velocities over the bar will be significantly higher.

2.5.4 East Australian Current

The East Australian Current (EAC) has a significant influence on the nearshore currents in the study area, particularly outside the surfzone along the NSW shoreline (ie. Point Danger, the Tweed River entrance, Lititia Spit and Fingal).

Flow measurements (Helyer et al., 2011, HaskoningDHV, 2017) indicate that in the nearshore off Point Danger, at depths of greater 6m, there is a general southeasterly nearshore flow with a typical flow velocity of 0.3-0.4m/s. The headland at Point Danger tends to deflect the current, and generate clockwise circulation cells within the Letitia embayment. These circulation cells may in turn interact with tidal currents from the Tweed River entrance, and influence the sand transport around the jetty and river training walls.

2.6 Sediment Budget and Longshore Sediment Supply

Sand volume changes and longshore sand transport processes within the study region have been investigated in considerable detail over the past 40-50 years. Previous investigations include: Delft Hydraulics (1970), Roelvink & Murray (1992), Hyder et al. (1997), Patterson (1999), BMT WBM (2011, 2013, 2016, 2017).

These investigations indicate that there is a continuous northerly alongshore transport of sand. The latest Long Term Average (LTA) sediment transport analysis report (BMT WBM, 2016) suggests that the long term average net sand transport rate within the Project Area is about 550,000 m^3 per year. This study also highlighted that during the period 1995 to 2015 the average net transport of sand into the system by longshore transport past Fingal has on average been about 71,000 m^3 per year higher than the sand outflow rate at Currumbin (574,000m^3/year vs. 503,000m^3/year).

Recent sediment budget analyses by BMT WBM (2017) indicate that the system has gained approximately 9.2M m^3 of additional sand since 1962 of which approximately 6.2M m^3 can be attributed to beach nourishment activities at Kirra during the 1980s and 1990s. This leaves approximately 3.0M m^3 of additional sand, equivalent to an average rate of 56,000m^3/year, that cannot be attributed to the direct effects of man-made sand imports into the system. The vast majority of the sand volume gain has occurred within the littoral zone of the beaches to north of the Kirra Point groyne (notably North Kirra and Bilinga), and the ebb delta and lower estuary of the Tweed River.

There is substantial annual variability in the inflow of sand past Fingal. Littoral transport modelling by BMT WBM (2016) suggests that the net annual sediment transport rate past Fingal has varied between 1995 and 2015 between about 300,000m^3 (in 2014) and about 1,000,000m^3 (in 2004). This differs from the sediment transport regime out of the system at Currumbin, which shows much less annual variability.

Sand transport past Fingal Head occurs primarily through periodic sand ‘slugs’. Sand from Dreamtime Beach will only travel around the headland when significant quantities of sand accumulate around the headland and substantial southerly waves occur. When these sand slugs move around the headland, these pulses of sand manifest themselves as substantial sand waves that eventually attach to the beach. Figure 2-3 presents an example of the progression of such sand slug around Fingal Head in May 2016.

Figure 2-3 Sand slug evident at southern part of Letitia Spit in May 2016

3. Quantified Conceptual Sediment Transport Model

3.1 Introduction

A series of quantified conceptual sediment transport models have been developed based on the synthesis of previous investigations and existing datasets. The conceptual sediment transport models present the key mechanisms and pathways for sand transport through the geomorphic compartments of the STIS Project Area.

According to their coastal process environment and geomorphic features, the Project Area has been divided into seven coastal compartments. The spatial extent of each compartment is shown in Figure 3-1. The offshore boundary of all compartments is the -20mAHD depth contour, beyond which it is expected that there would be no significant sand movement.

Features of each compartment are outlined in Table 3-1 below:

Table 3-1 STIS Project Area Coastal (Geomorphic) Compartment Overview

Compartment Name	Key features
Letitia Spit & Fingal Head	This compartment extends from the northern end of Dreamtime Beach to the southern Tweed River training wall, and includes Letitia Spit, a 3.6km long east-north-east facing beach. The TSB sand bypassing jetty is located approximately 220m south of the training wall, at a location where the Tweed River entrance bar merges into the littoral zone of Letitia Spit.
Tweed River entrance	This compartment includes, the entrance to the Tweed River, the Tweed River entrance bar and Duranbah beach.
Tweed Estuary	This compartment comprises the lower Tweed River estuary. It includes the river channel between the training walls, the main Tweed River channel system and the tidal broadwaters of Terranora and Cobaki, as far as it morphologically interacts with the other compartments of the STIS Project Area.
Point Danger to Snapper Rocks	The compartment extends from Point Danger to Snapper Rocks. It contains the Snapper Rocks East outlet, the primary discharge location for sand pumped by the TSB bypassing jetty.
Coolangatta-Kirra Embayment	This compartment extends from Snapper Rock to Tugun, and includes the beaches of Little Marley's, Rainbow Bay, Coolangatta, Kirra, North Kirra and Billinga. The sand transport regime through this compartment is a mixture of littoral transport and cross-embayment sand transport outside the littoral zone.
Tugun & Currumbin	This compartment is the most northern unit and extends from Billinga to the Currumbin Rock groyne in the north.

To assist with the development of the conceptual sediment transport models, the main sediment transport mechanisms and pathways under a range of key environmental conditions have been identified and assessed. The environmental conditions assessed are summarised in Table 3-2. Sediment transport mechanisms and pathways are presented graphically in Figure 3-2 to Figure 3-6, and described in detail in the sections below as appropriate.

Table 3-2 Description of Environmental Conditions

Scenario Name	Description
Modal SE Swell	This scenario represents the predominant ambient wave conditions at the site, comprising of waves with a significant wave height approximately in the range of approximately 0.5 to 2m and an offshore peak direction from the south easterly directional sector
SE Storm Event	This scenario represents a typical storm condition where waves would be typically greater than a significant wave height of 3m and come from a south easterly direction.
Typical NE Wave	This scenario represents a condition that is reasonably common during spring when local winds generate northeasterly waves. Peak wave periods of this scenario are typically in the range of 4 to 7 seconds and a significant wave height in the range of approximately 0.5 to 1.5m.
NE Storm Event	This scenario represents a storm condition where substantial waves come from the north east. These storms are relatively infrequent and often associated with a tropical cyclone or East Coast Low.
Catchment Flood Event	This scenario represents the conditions during a major catchment flood event.

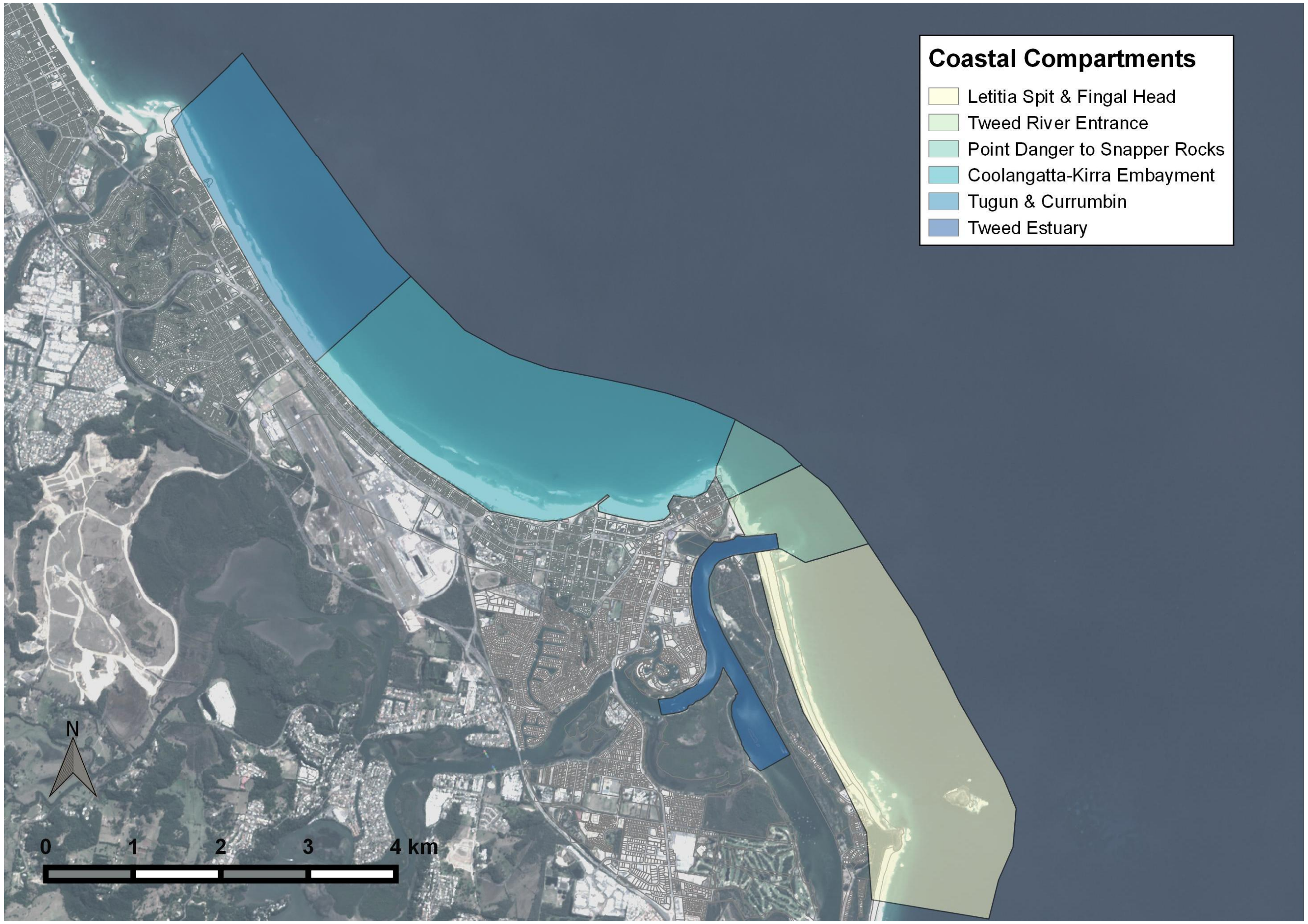

Figure 3-1 Geomorphic compartments of the STIS Project Area

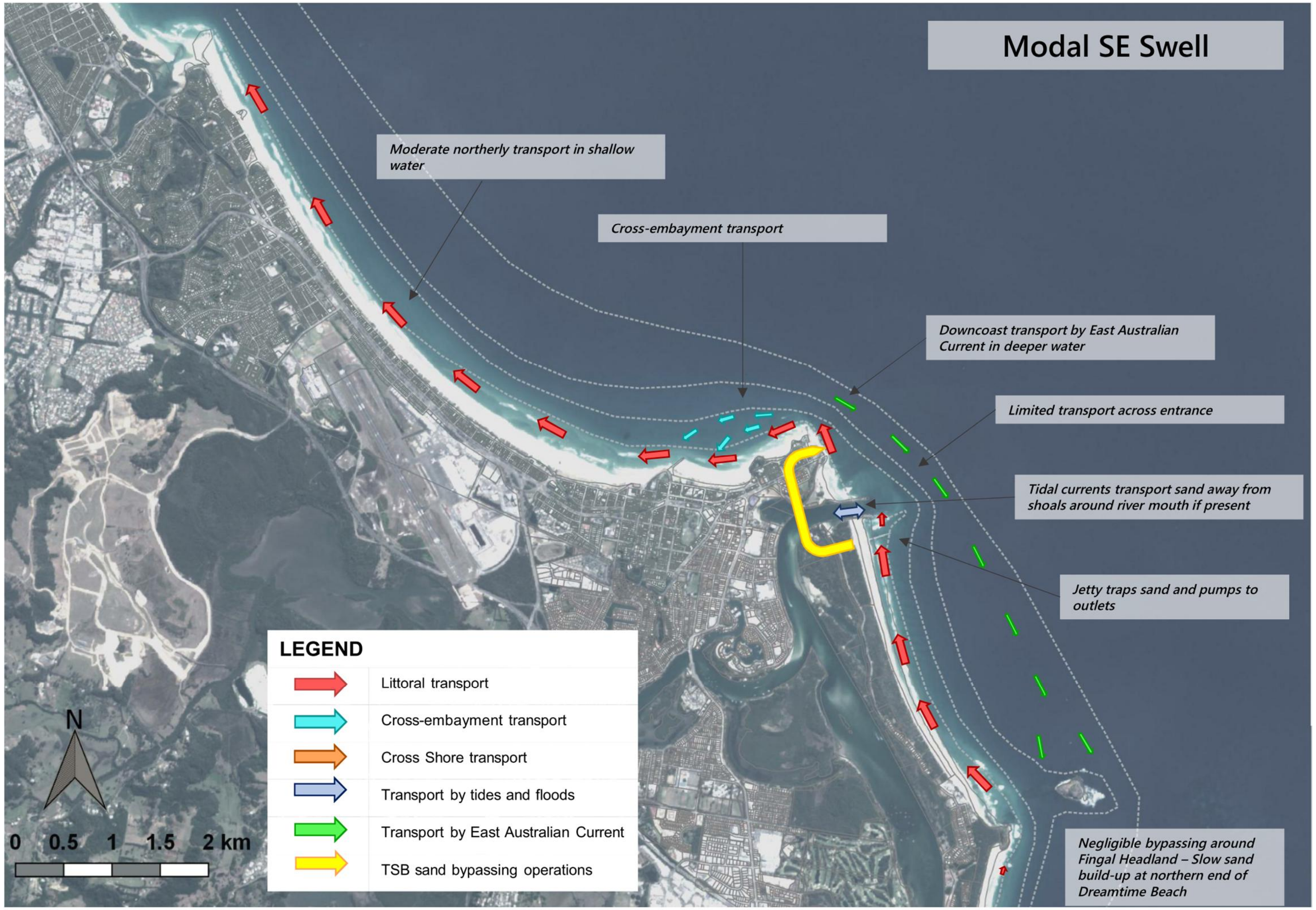

Figure 3-2 Main sediment transport mechanisms and pathways - 'Modal SE Swell' scenario

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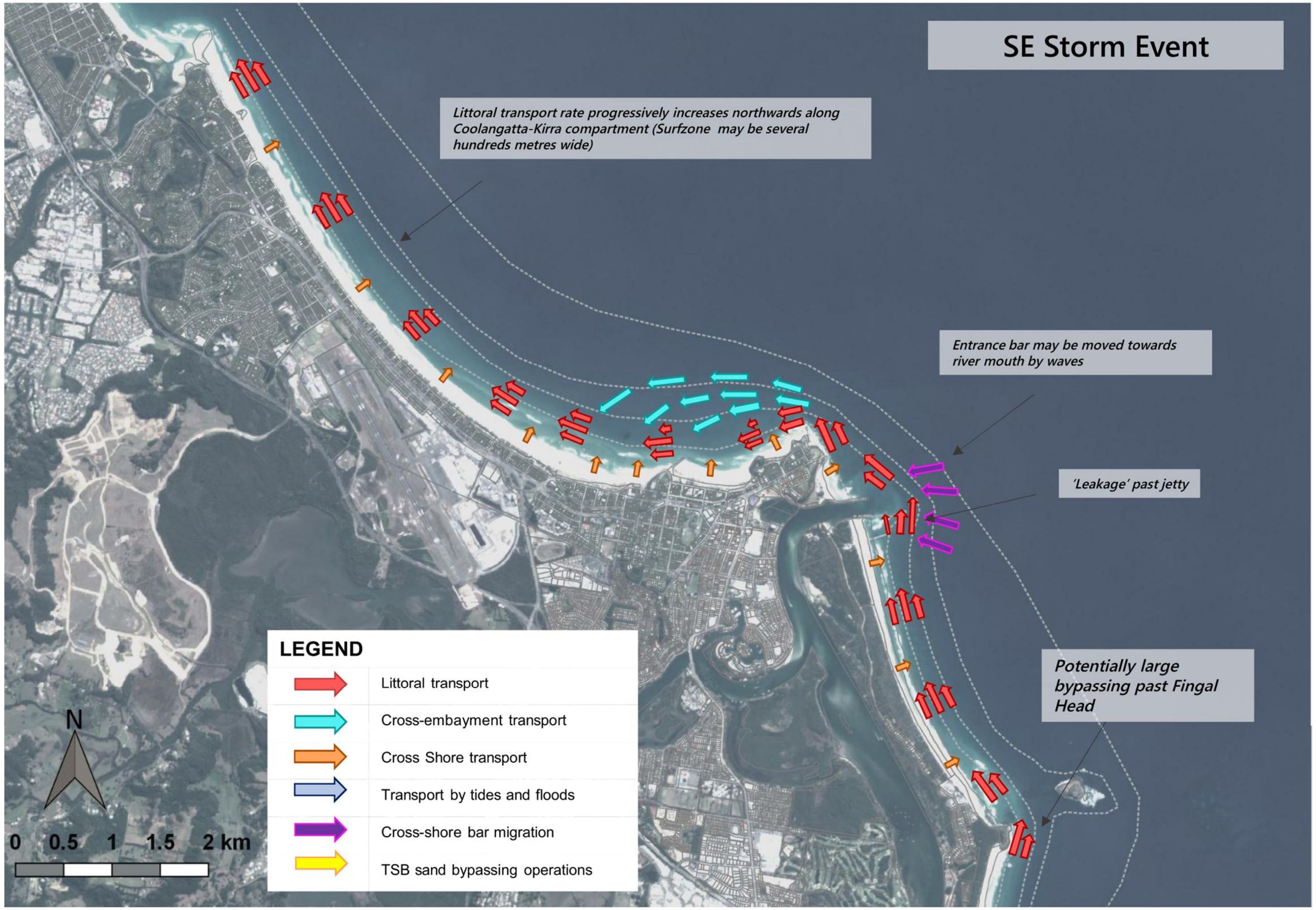

Figure 3-3 Main sediment transport mechanisms and pathways - 'SE Storm waves' scenario

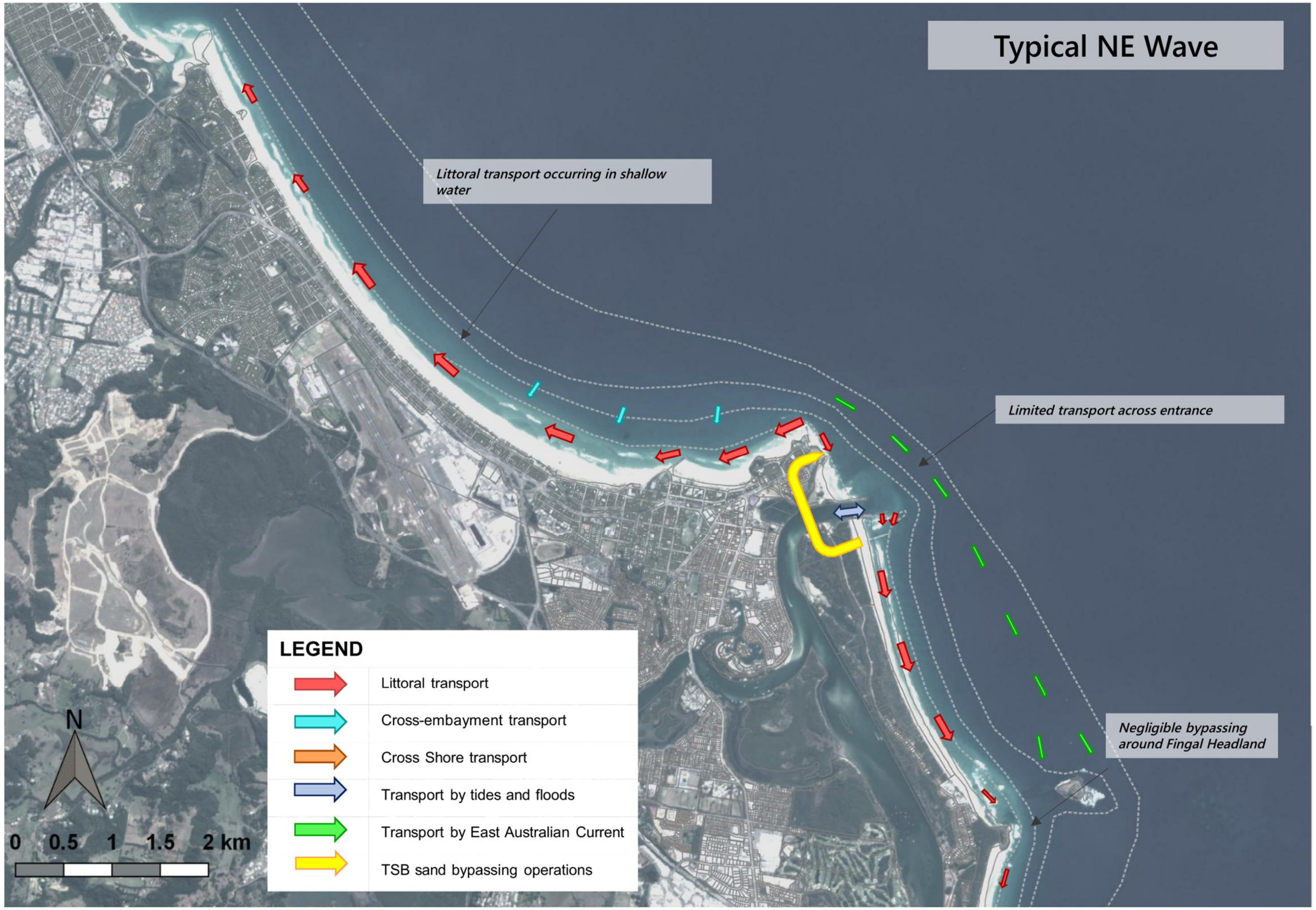

Figure 3-4 Main sediment transport mechanisms and pathways - 'Typical NE Wave scenario

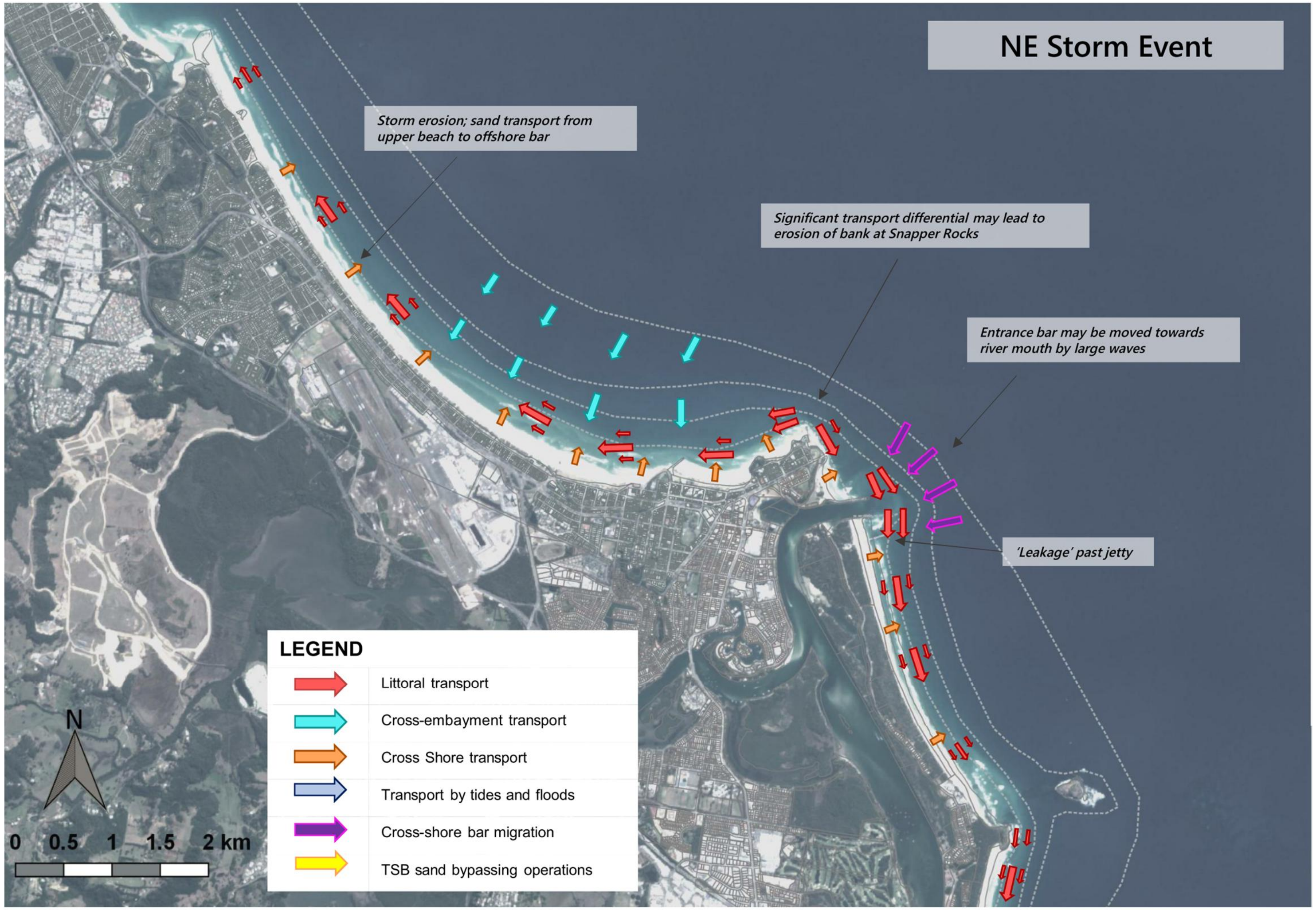

Figure 3-5 Main sediment transport mechanisms and pathways - 'NE Storm waves' scenario

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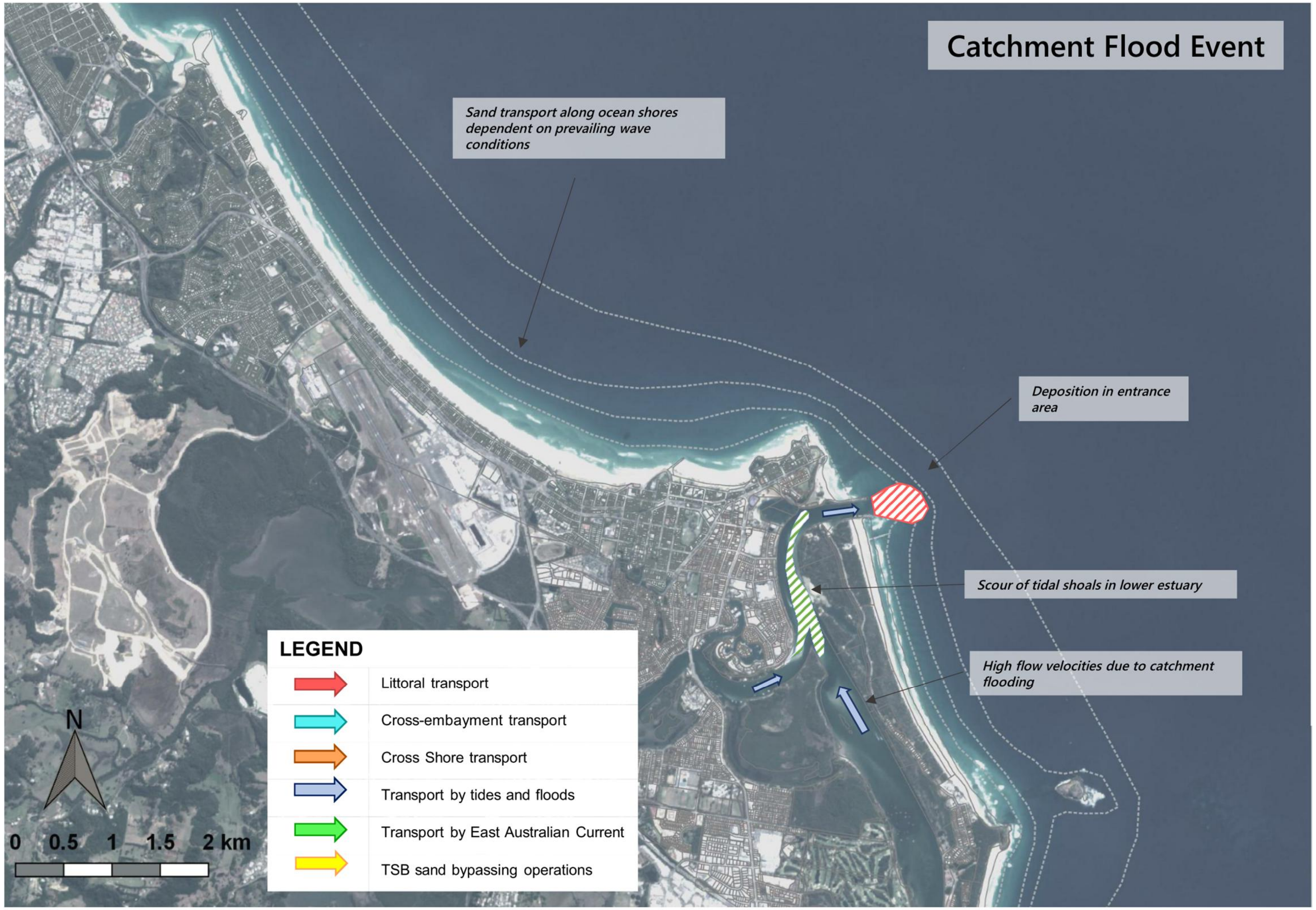

Figure 3-6 Main sediment transport mechanisms and pathways - ‘Catchment Flood event’ conditions

3.2 Letitia Spit & Fingal Head

Sand supply to Letitia Spit occurs past Fingal Head and tends to occur mostly as episodic 'slugs' of relatively large quantities of sand over a short period of time.

The periods of strong sand transport past the headland are usually associated with storm events with high waves, and will only occur when significant quantities of sand have accumulated at the northern end of Dreamtime Beach and are available to be carried around the headland by littoral transport processes. When prevailing waves cause a persistent sand transport away from the headland on both sides (ie. southward on the southern beach and northward to the north), the area immediately south and east of the headland tends to become eroded and bed rock may become exposed throughout the littoral zone of the northern end of Dreamtime Beach. When this occurs, sand transport past the headland can only resume if sufficient sand has returned to the southern side of the headland. As a result, there is considerable variability in the annual sand transport past Fingal Head. The average sand transport into Letitia Spit has been approximately 574,000 m^3 per year during the period 1995 and 2015, with annual lows of approximately 300,000m^3 and highs of above 1,000,000m^3/year (BMT WBM, 2016).

The sand transport pathway past the headland is expected to be exclusively located between Cook Island and Fingal Head. It is likely that some of the sand that is moved into the deeper parts between Fingal Head and Cook Island will be swept back into the Dreamtime Beach embayment by the East Australian Current, particularly if the sand slug extends onto the reefs around Cook Island where the East Australian Current frequently generates southeasterly currents above 0.5m/s (Helyer et al., 2011, Wyllie and Tomlinson, 1991).

On the southern end of Letitia Spit, sand movement generally manifests itself as sand waves that eventually attach to the beach. Often, these sand waves extend about one kilometre past the headland before becoming fully attached and can reach depths of about 8m, as illustrated by the bulge evident in the 2003 profile in Figure 3-7.

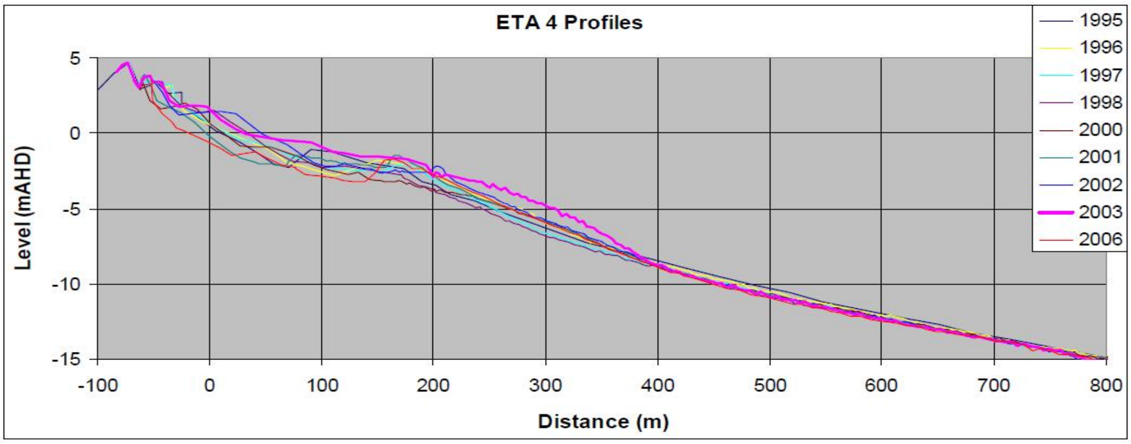

Figure 3-7 ETA 4 profile (Fingal) showing a sand 'bulge' in 2003 (Source: BMT WBM, 2011)

Away from the headland, Letitia Spit Beach usually exhibits a single or double bar system, and most of the sand transport is the result of littoral processes. Due to its wave exposure, gross longshore rates at Letitia Spit are amongst the highest along the STIS Project Area, and this beach experiences significant downcoast transport from time to time. Periods of significant downcoast (southwards) transport tend to occur mostly during spring and summer when the average wave direction is more northerly.

The vast majority of the longshore transport occurs in water depths of less than 4m; Hyder et al. (1997) estimates that approximately 73% of the gross transport sand occurs in water depths of less than 4m and approximately 91% in depths of less than 8m. At greater water depths, the East Australian Current becomes increasingly more significant, and is the dominant factor in water depths of more than 12m. Consequently, there is a net southward sand transport in water depths of more than 12m.

The sand bypassing jetty has an overall length of 450m, of which approximately 220m extend beyond the Tweed River training walls. The system has been designed to intercept the majority of the sand that is transported northwards under natural littoral processes and transport to the north of the Tweed River entrance. The ability of the bypassing jetty to intercept sand depends on the prevailing wave conditions, the shape of the slurry pit and the regional shoreline configuration. In recent years (2009-2015), the sand bypassing jetty has artificially bypassed an average 432,000m^3 of sand per year to the north of the Tweed River entrance. It thereby intercepted an estimated 70% of the net longshore transport along Letitia Spit and allowed an estimated 187,000 m^3 per year to 'leak' into the Tweed River entrance area (BMT WBM, 2017).

The exact pathways and mechanisms that cause sand leakage past the jetty are not completely understood, but it is likely that a large portion of the leakage occurs during major storm events when the littoral zone extends seaward of the jetty and the slurry pit is unlikely to trap all transport through the jetty.

The extension of the Tweed River training walls and the TRESBP bypassing operations have had a significant impact on the shoreline alignment of Letitia Spit. During the period 1962 and 1995, (the period between construction of the training walls and commencement of TRESBP Stage 1 operations), Letitia Spit experienced substantial accretion due to the construction of the training walls and the shoreline at the northern end of the beach moved seaward by some 200m. Since the start of TRESBP Stage 1 operations, and particularly during the supplementary bypassing period (2001 and 2008), the beach has experienced substantial erosion. By 2015, the sand volume within the northern part of the beach appears to have reached a state of dynamic equilibrium, but the central and southern parts appear to continue to experience a trend of erosion. Changes in the alignment of the upper beach have a direct impact on the net sand transport rate along the beach, with a counter clockwise movement resulting in increased northerly transport.

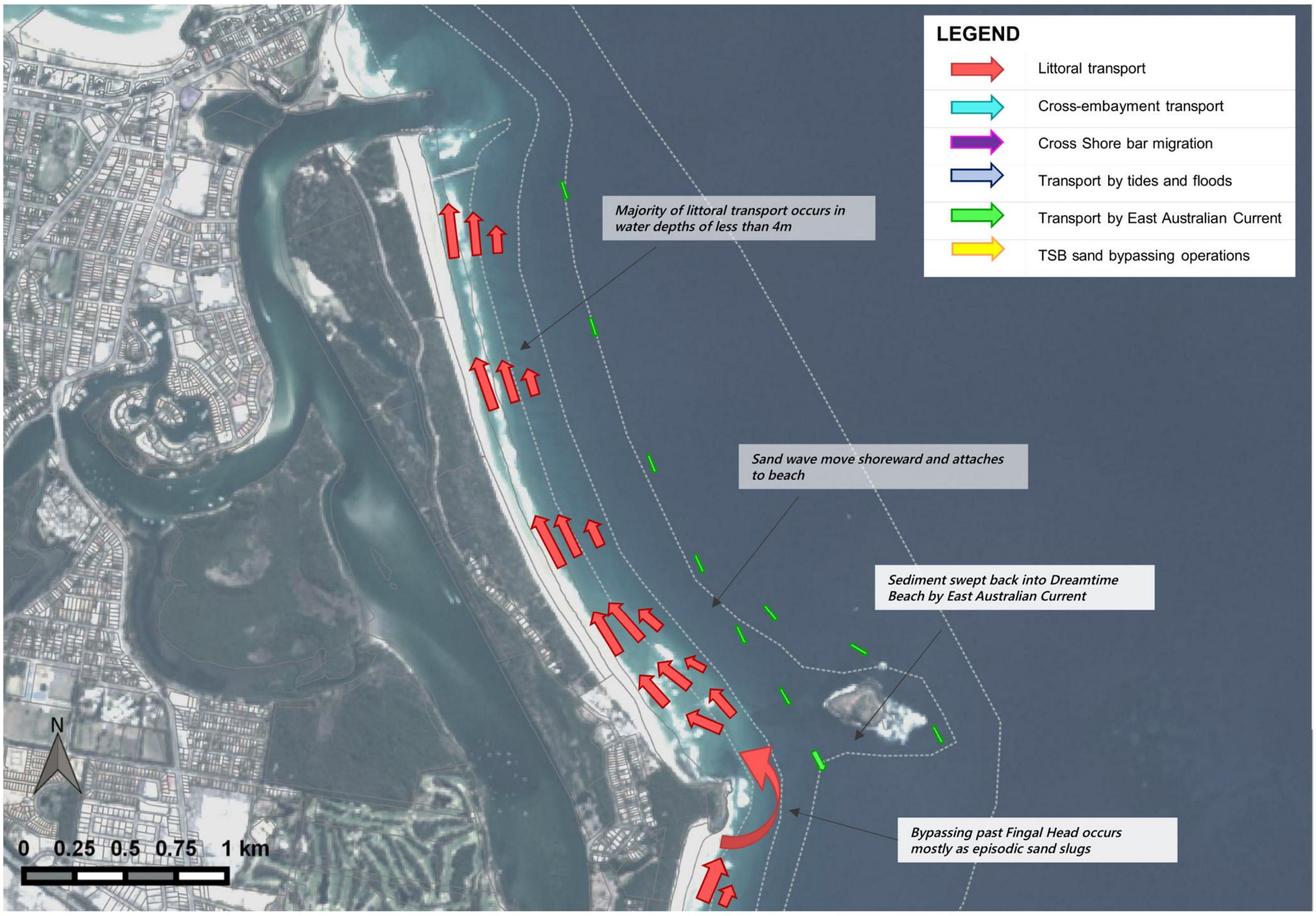

Figure 3-8 Conceptual model of sediment transport patterns through Letitia Spit & Fingal Head compartment

3.3 Tweed River Entrance

The main mechanism for natural sand transport across the entrance is bypassing via the entrance bar. It is however likely that some sand will also bypass the entrance via tidal currents in and out the river mouth. The processes influencing the movement of sand through the entrance are extremely complex. Sand transport across the entrance depends upon many interrelated factors, the most significant being:

- Longshore transport to the entrance area
- The configuration of the shoreline at the updrift side of the entrance
- The rate of sand extraction at the TSB jetty
- The configuration of the entrance, particularly the depth and shape of the entrance bar; and
- The effects of catchment runoff and tidal flows in and out the Tweed River mouth.

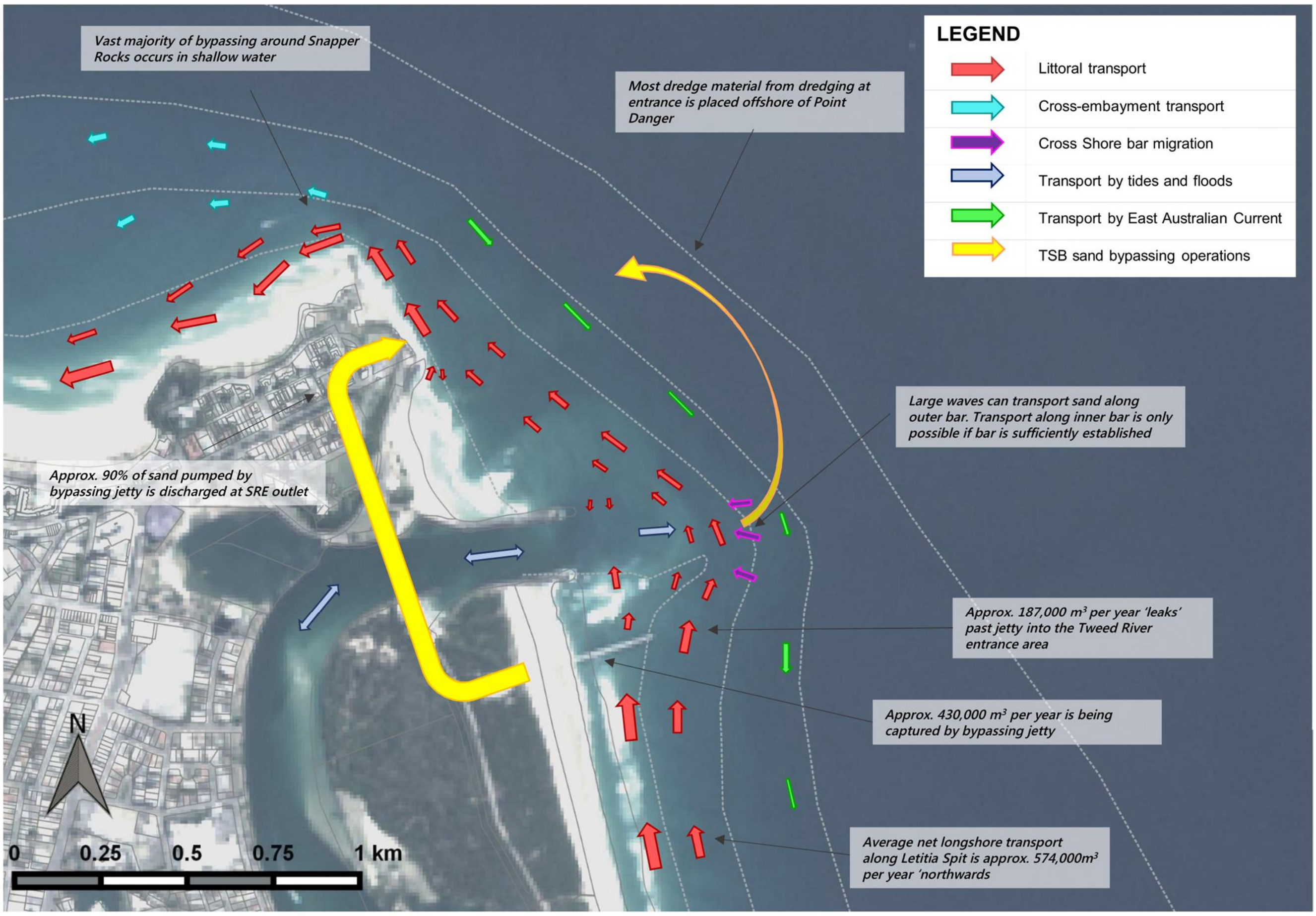

Figure 3-9 Conceptual model of sediment transport patterns at and around the Tweed River entrance

Figure 3-9 illustrates the principle of bypassing across the Tweed River entrance. Waves transport sand from the updrift shoreline towards the entrance. Some of the sand is transported from the updrift littoral zone directly to the entrance bar under the influence of waves and the persistent rip current that tends to be present at end of the downdrift beach. This sand is temporarily stored in the shoal or transported across the entrance by larger waves. Offshore of the inner bar, another sand transport pathway exists along the outer slope of the ebb delta. Transport via this pathway will almost entirely occur during east/southeasterly storms when larger waves are able to generate transport at greater depths. Once outside the principal influence of the ebb flow, waves transport the sand both landward and further downdrift, where the pathway eventually rejoins the littoral zone of the Duranbah Beach / Point Danger. The result of this is a horseshoe shaped bar system.

The dimensions of the entrance bar that will form under natural processes are predominantly determined by the quantum of sand that is being supplied to the entrance and the local wave conditions. By increasing amounts of littoral drift, the depth of the bar will decrease and its width increase. Under the recent configuration whereby most of the littoral drift is bypassing the entrance through pumping at the jetty and an estimated net volume of 187,000 m^3/year 'leaks past the jetty (BMT WBM, 2017), without dredging of the entrance, the bar tends to develop to a height of about -3 to -4mAHD and is located 300 to 400m offshore of the river mouth.

Selected hydrographic surveys of the entrance from the period 2008 – 2016, shown in Figure 3-10, illustrate the typical development of the entrance bar from a dredged configuration and without any dredging in the entrance (In 2008 the entrance area was generally dredged to about -6.5mAHD and no significant dredging was undertaken until April 2016).

This figure demonstrates that the bar almost entirely develops as a prograding (advancing) spit from the south. That is, the infilling of the entrance channel is primarily driven by migration of a sand spit across the entrance. The average rate of growth of the spit was about 60,000 m^3 per year during the period 2009-2015, suggesting that in recent years most of the sand that is supplied to the entrance (approximately 187,000 m^3 per year, BMT WBM, 2017) is transported past the entrance in deeper water, offshore of the inner bar.

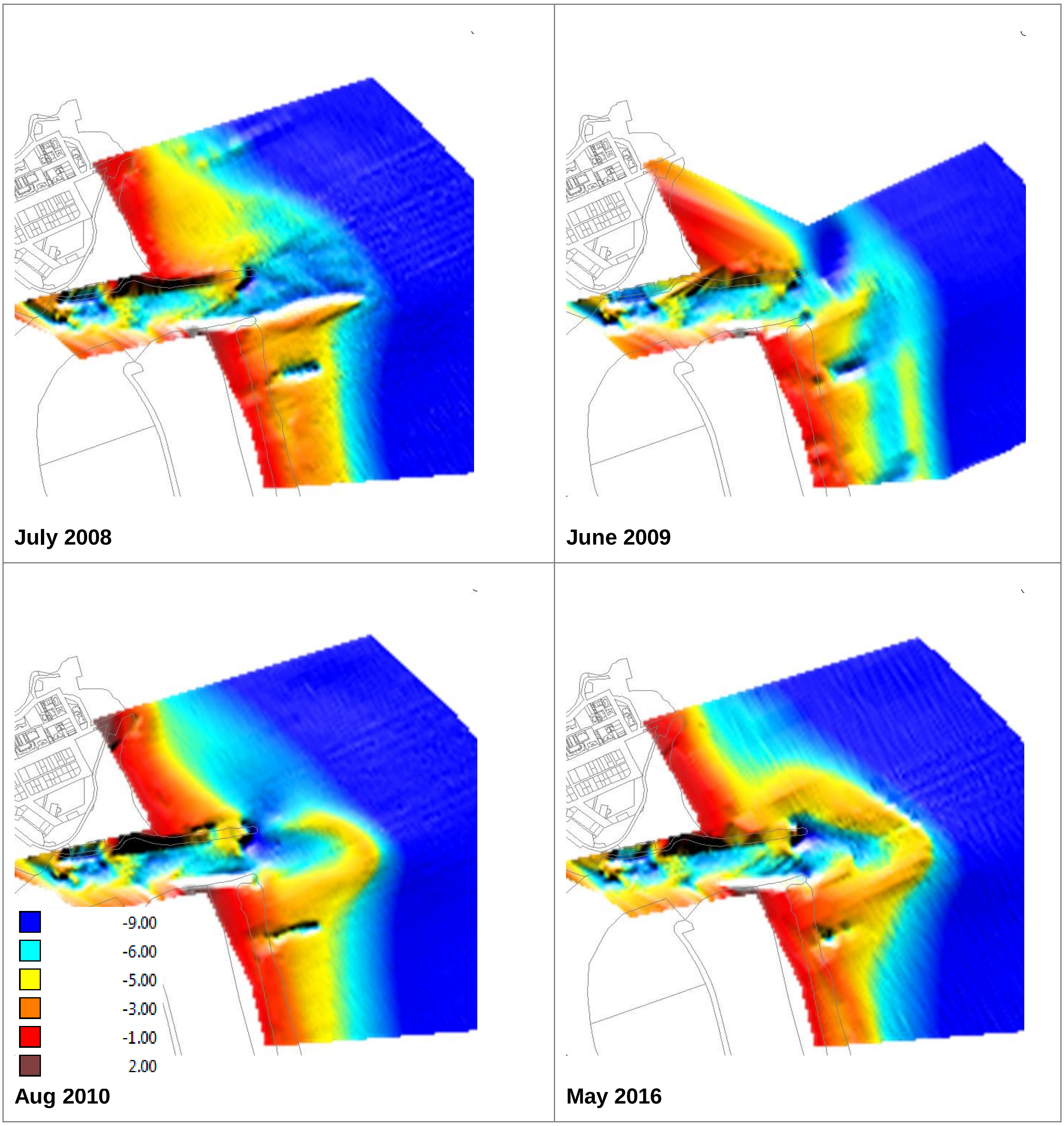

Figure 3-10 Hydrographic surveys of Tweed River entrance for period 2008 – 2016, illustrating typical entrance bar development

The Tweed River entrance bar is highly dynamic and sediment in the entrance area is constantly reworked. During severe storm events, volumes of sand in excess of 100,000m^3 can be moved from the bar into the entrance area under the influence of waves. Storm waves are capable of eroding the inner bar completely, and can lead to substantial sedimentation at the entrance. Following storm events, sand that has been deposited near the river mouth is generally moved out of this area reasonably quickly under the influence of tidal currents in and out of the estuary.

Tidal flows in and out the Tweed River mouth have thus a significant influence on the sediment transport regime of the entrance area. Generally, the tidal current patterns in the entrance area are characterised by a more or less radial inflow on the flooding tide and a concentrated ebb jet directed seaward on the ebbing tide. The nature and magnitude of the currents over the entrance bar depends on the bar configuration, and to a lesser degree on the shoal regime within the lower estuary. In particular, the peak flow currents during flood tides are sensitive to the bar configuration. When the entrance bar is fully developed, peak flow velocities during flood tides will be above 0.4m/s and will generate significant sand transport into the estuary. However, when the bar is dredged and the entrance is reasonably open, peak flow velocities over the bar may remain too weak to generate significant sand transport into the entrance.

During ebb tides, the current flows out of the entrance in a rather concentrated jet that generally remains quite defined for a distance of at least 400-600m offshore from the training walls. The ebb jet is generally flowing eastward centred around the river mouth, but may be deflected to the north or south under the influence of winds, waves, the East Australian Current or the local bar/channel bathymetry. Peak flow velocities typically reach up to about 1.5m/s over the entrance bar, and reduce in magnitude immediately seaward of the shoal. Occasionally, the ebb jet interacts with the northerly wave-driven currents along Letitia Spit and Eastern Australian Current in deeper water to generate a large-scale clockwise circulation cell on the southern side of the river. This circulation cell may strengthen the wave-driven current within the surfzone of Letitia Spit and could potentially facilitate a sand transport pathway towards the entrance area (Helyer et al., 2011).

Flood events in the Tweed River catchment can deliver substantial volumes of sand to the entrance area from the lower estuary. Hydrographic surveys of January 2017 and April 2017 suggest that more than 150,000m^3 of sand was delivered to the entrance area during the March 2017 flood event, a significant flood event with a return period of about a 1 in 20 years at Uki. Figure 3-11 shows that during this event the majority of the sand became deposited between the entrance and the bar by building a mild sloped wedge against the inner bar

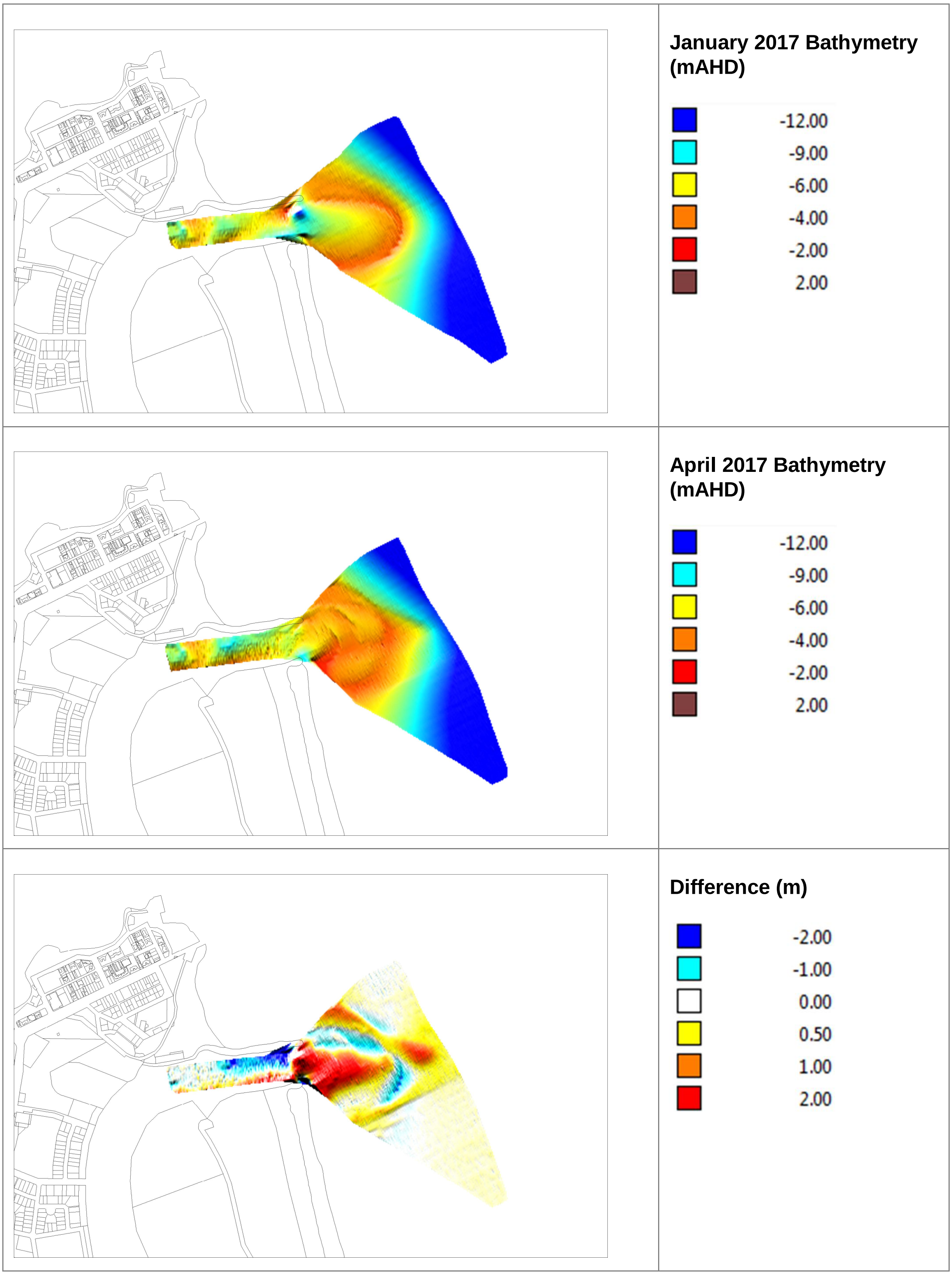

Figure 3-11 Pre- and Post-March 2017 flood event surveys, illustrating sedimentation patterns of a major flood

3.4 Tweed Estuary

Although the Tweed River is not part of the open coast, there is significant sand exchange between the lower estuary and the entrance area, and as such is of importance in the overall sediment transport regime of the STIS Project Area.

The Tweed River has a catchment of approximately 1100 km^2 that experiences a humid sub-tropical climate with a marked wet season that extends from December to April. Heavy rainfalls with falls of 250mm in 24 hours are not unprecedented in the catchment, and consequently the river experiences frequent flood flows. The river has an estuary area of approximately 22.7 km^2 (DECCW, 2010) and includes the main Tweed River channel system and the tidal broadwaters of Terranora and Cobaki, which connect to the main channel via Terranora Creek about 2km upstream of the river entrance. The main river is tidally influenced up to Murwillumbah, some 30km upstream of the river mouth. The tidal prism of the river is approximately 13.5 Mm^3 during large spring tides (OEH, 2015).

The morphology of the lower estuary is characterised by a fairly complex bathymetry of sand shoals and channels. The vast majority of the bed sediment within the lower estuary comprises marine sand and bed forms of the sediments indicate active sand transport under tidal processes. Extensive bedrock outcrops occur in the outer bend of the main channel near Jack Evans Boat Harbour, just inside of the training walls (Refer to Figure 1-1).

The lower Tweed River estuary has a strong tendency towards the establishment of a unique pattern of tidal shoals, and will generate significant net sediment fluxes in and out of the entrance in response to modifications in bed levels within the lower estuary or at the entrance. For example, Druery and Duredale (1979) indicates that the net sand influx into the lower estuary from the entrance exceeded 84,500 m^3 per year in the 1920s, as the lower estuary was adapting to the construction of the initial river training walls at the turn of the 20th century. Similarly, BMT WBM estimates that the average annual influx of sand from the entrance was about 126,000 m^3 during the period 1972 to 1983, due to the combined effects of extension of the river training walls in 1962 and major dredging works that were conducted in the lower estuary in the 1970s. Both in response to the initial training wall construction, as well as the extension in the 1960s, it took about 30 years for the shoal regime to adapt. It is estimated that the lower estuary held approximately 1.4 million m^3 more sand in 1993, compared to 1962. Since TRESBP bypassing commenced in 2001, there appears to be a trend of sand supply from the lower estuary to the entrance.

The capacity of the shoal regime to adapt to changes is associated with the configuration of the Tweed River entrance. When the entrance area is not heavily shoaled, sand transport through the training walls will reduce, and so does the ability for the lower estuary to adapt.

Major flood events in the Tweed River catchment tend to result in scouring of the estuary shoals and can result in significant volumes of sand being transported from the lower estuary to the entrance area. Following flood events, sand that has been deposited in the immediate entrance area tends to be moved away by tidal currents. As a result, some of the sand may be transported back into the estuary.

3.5 Point Danger to Snapper Rocks

The TSB sand bypassing operations have had a significant impact on the sand supply to this compartment from the Tweed River entrance. Due to the reduced natural bypassing around the Tweed River entrance, the lower beach profile of this compartment has seen significant erosion, particularly the zone between -5mAHD and -10mAHD.

At present, the vast majority of the sand through this compartment is supplied via the Snapper Rocks East outlet. This outlet, located at Point Danger, is the primary discharge location for sand pumped by the TSB bypassing jetty. Over the life of the project to date, approximately 90% of the total sand volume pumped (or 7.5M m^3) has been discharged at this location. The Snapper Rocks East outlet is a fixed pipeline release that discharges the sand as a slurry above mean sea level just off the cliff face of Point Danger.

The nearshore area around Point Danger is highly dispersive with sand placed by the pipeline usually quickly dispersing even under relatively mild metocean conditions. Discharge rates of more than 100,000m^3 per month have not been uncommon during the winter months of the initial years of sand pumping, but have rarely resulted in a lasting deposition of sand around the discharge location. Instead, the sand tends to be transported away by littoral transport processes.

Most of the sand transport along Point Danger occurs in a narrow zone in close proximity to the shoreline.

3.6 Coolangatta-Kirra Embayment

The bathymetric changes experienced over the last 50 years, outcomes of the sand tracing study (HaskoningDHV, 2017) and the nature of the wind and wave driven currents suggest that the sand transport regime through the Coolangatta-Kirra embayment occurs as both:

- Littoral zone alongshore transport, priarily driven by breaking waves and wave-driven currents; and
- Cross-embayment mass transport outside the littoral zone where the transport is mostly driven by wave asymmetry (in the direction of wave travel), wind and broader wave radiation stress gradients

Thus, conceptually, the sand transport through this compartment may be considered as following two distinct pathways, defined by somewhat different mechanisms that drive it.

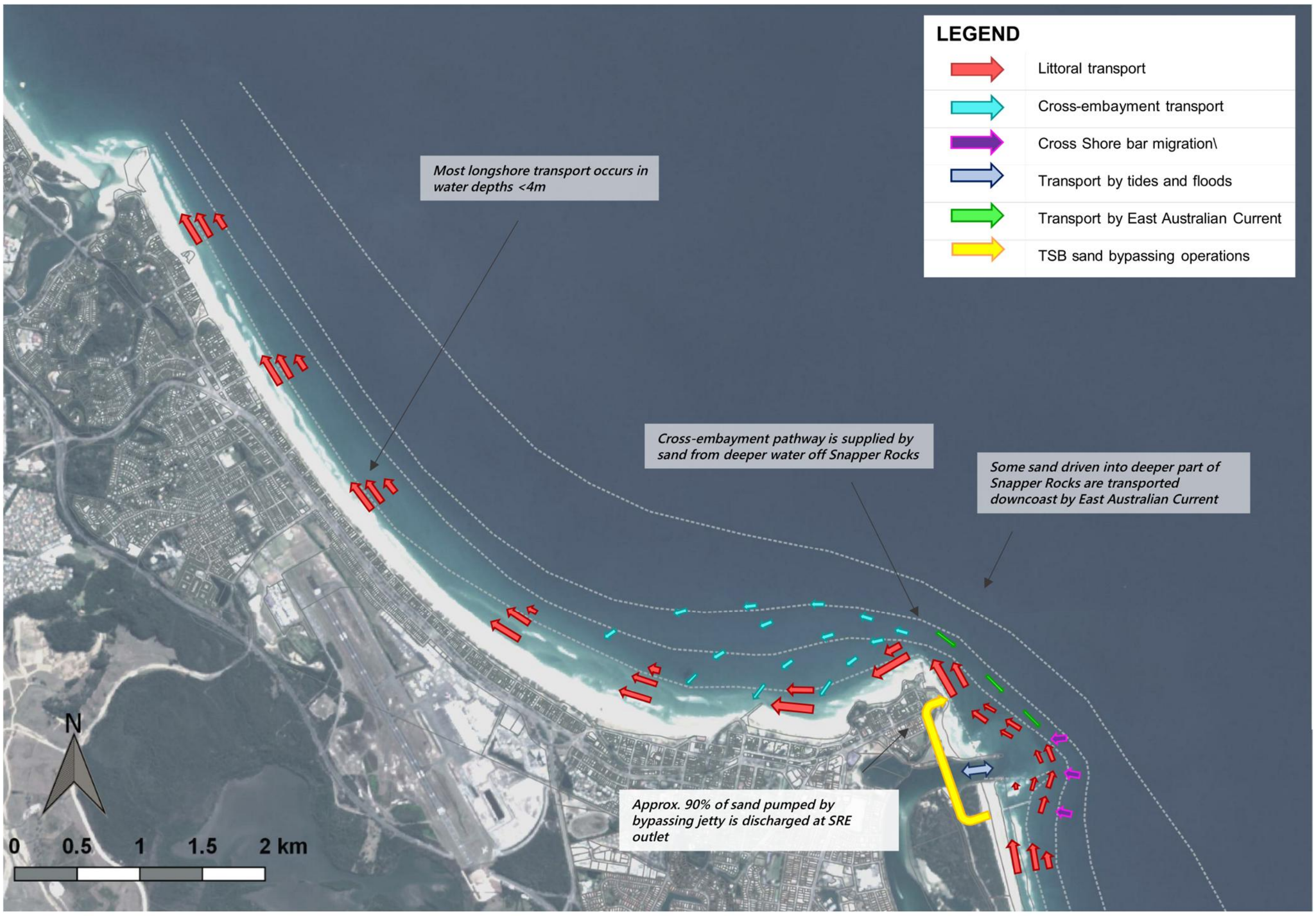

Figure 3-12 Conceptual model of sediment transport patterns through Coolangatta-Kirra embayment and Tugun-Currumbin

The littoral transport is confined to depths not much greater than the wave breakpoint depths, probably up to about 6-8m within the embayment, as demonstrated by the historic bi-modal beach profile response at Coolangatta (Refer to Figure 3-13).

The extent of cross-embayment sand transport is less clearly defined and most probably decreases progressively with depth as the influence of the waves on the bed, wave asymmetry and the strength of induced net currents decreases. A recent sand tracing study (HaskoningDHV, 2017), whereby tracing material released at a location near Point Danger was sampled on a number of occasions following its release in May 2016, found tracing material at a location approximately 800m north of Kirra Point, in about 12m of water depth (See Figure 3-14). Macdonald and Patterson (1984) suggest that the cross embayment may extend to about 15m, based on analysis of beach profile evolution at Kirra and Coolangatta following construction of the Tweed River training walls.

The proportion of sand that follows the littoral zone and the proportion that moves across the embayment as cross-embayment transport have not been quantified reliably. These will almost certainly vary with varying wave and sand transport conditions, with a higher littoral proportion of littoral transport, but lower total transport, under lower wave energy conditions.

It is likely that the sand bypassing operations have influenced the proportion of sand that follows the littoral zone and the proportion that moves across the embayment as cross embayment transport. Since commencement of TSB sand pumping in 2001, the sand transport regime around Snapper Rocks appears to have changed somewhat with more sand transport past the headland taking place in shallow water depths and less being transported through the cross-embayment sand transport pathway. This is evident from the progressive gains of the upper beach volume of Rainbow Bay and Snapper Rocks, and the progressive loss of volume in the lower beach profiles of Rainbow Bay, Snapper Rocks and Coolangatta, particularly the zone between -5m and -10mAHD. This trend of progressive sand loss from the lower beach profile appears to be ongoing, with no sign of moderating at most locations.

The proportion of sand that follows the littoral zone and the proportion that moves across the embayment will vary along the embayment shoreline, with an increasing amount of the cross-embayment component re-joining the littoral zone further north along the shoreline. The morphologic evidence indicates that the longshore sand transport becomes exclusively 'littoral' at or just south of the northern end of Bilinga Beach. The cross-embayment pathway is expected to almost entirely bypass Snapper Rocks, Rainbow Bay and Greenmount.

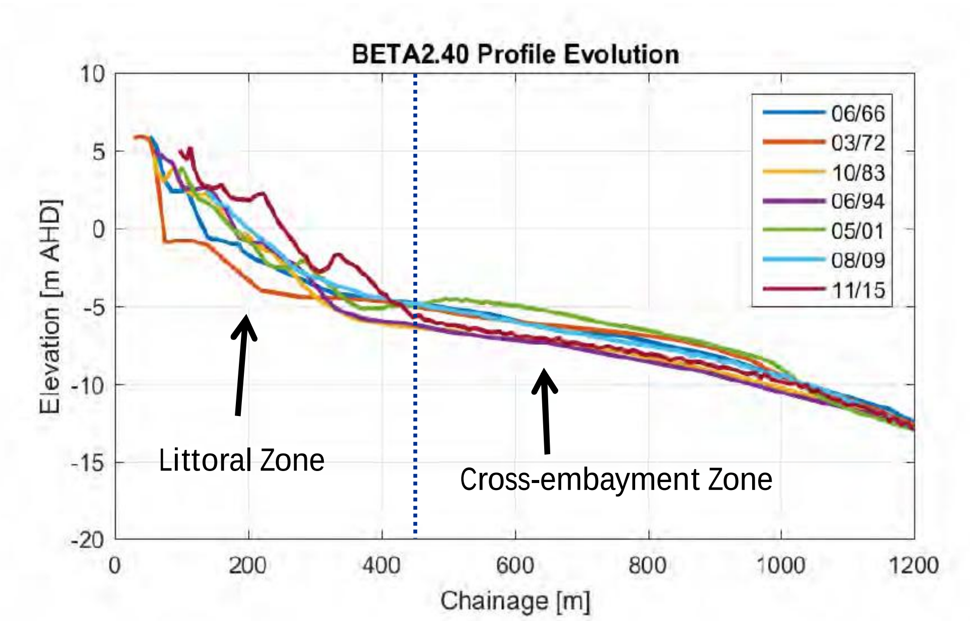

Figure 3-13 Coolangatta Beach profiles providing evidence of cross-embayment sand transport

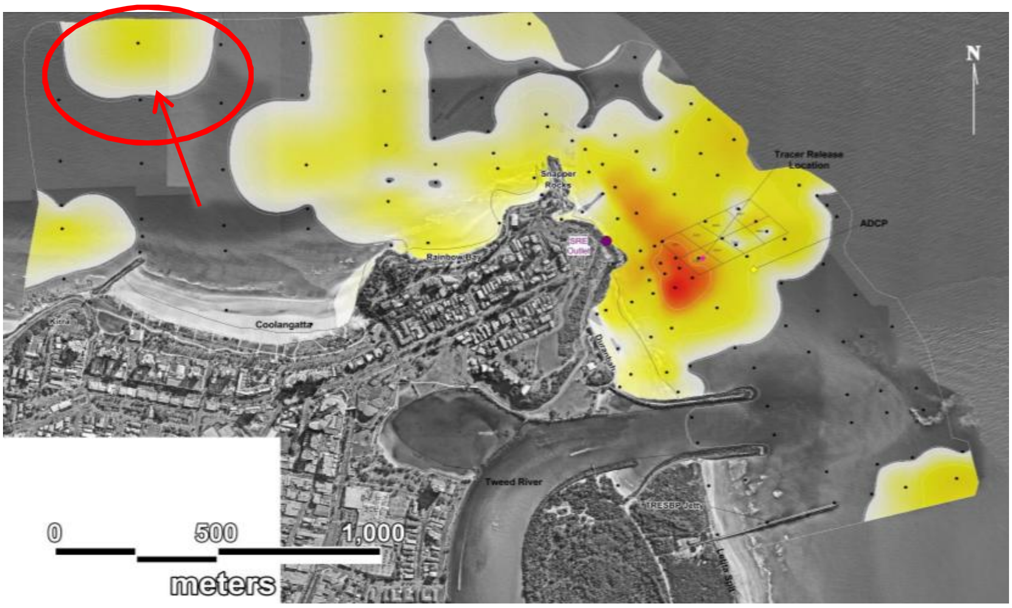

Figure 3-14 Tracer material concentrations 9 months after release (HaskoningDHV, 2017)

Rainbow Bay and Little Marley's are relatively small, north facing beaches. These beaches generally receive waves that are substantially lowered due to the influence of the headland. The width of both beaches and offshore bank conditions depend on both the prevailing wave climate and sand supply around the headland.

During the winter months, the wave climate is mostly influenced by swell, and consequently the wave direction is more southerly. Due to the more southerly waves, above average rates are being discharged by the bypassing jetty at the Snapper Rocks East Outlet, and transported northward around Snapper Rocks. Past Snapper Rocks, the transport capacity of the more southerly waves reduces, and sand temporarily accumulates in the lee of the headland. As a result, the beach width of Rainbow Bay and Little Marley's increases and the beaches often become connected by sand.

During spring, the average wave direction moves anti-clockwise, and northeasterly waves become more prevalent, accompanied by more frequent northerly winds. This means that the sand pumping rates through the bypassing jetty tend to significantly reduce and less sand is transported around Snapper Rocks. At the same time, the longshore transport capacity at Rainbow Bay and Little Marley's increases during spring and summer, which leads sand being moved away from these beaches and a general reduction in the overall beach width during these periods.

Severe northeasterly storm events are particularly unfavourable for maintenance of the sand bank immediately offshore of Snapper Rocks, as during these storms waves cause sand transport away from the headland on both sides (ie. downcoast along Frog's Beach/Point Danger and upcoast along Little Marleys/Rainbow Bay, which can result in large volumes of sand being removed from the Snapper Rocks area. Often a scour hole of several metres deep develops just offshore of the bed rock of Snapper Rocks and the bank can almost entirely disappear, with most of the sand migrating westward towards Rainbow Bay/Greenmount. Surf conditions following such an event are generally poor. It can take some years for the offshore bank to fully recover, as the recovery process relies heavily on large southeasterly waves to transport sand from the lower beach profile of Frog's Beach area into the eroded areas off Snapper Rocks.

The impact of large northeasterly wave events is illustrated in Figure 3-15 and Figure 3-16, which present the bathymetry around Snapper Rock before and after a series of storms that occurred during the autumn of 2009 and caused severe erosion along most of the Northern NSW / Gold Coast region. The most severe of these storms occurred from 19 to 25 May 2009 during which a maximum significant wave height of 5.6m was recorded at the Tweed Head wave buoy and the significant wave height remained above 4m for a period of approximately 4 days.

Figure 3-15 and Figure 3-16 show that a substantial scour hole of several metres deep developed offshore of Snapper Rocks. During the storm events, approximately 70,000m^3 of sand was eroded from the offshore sand bank.

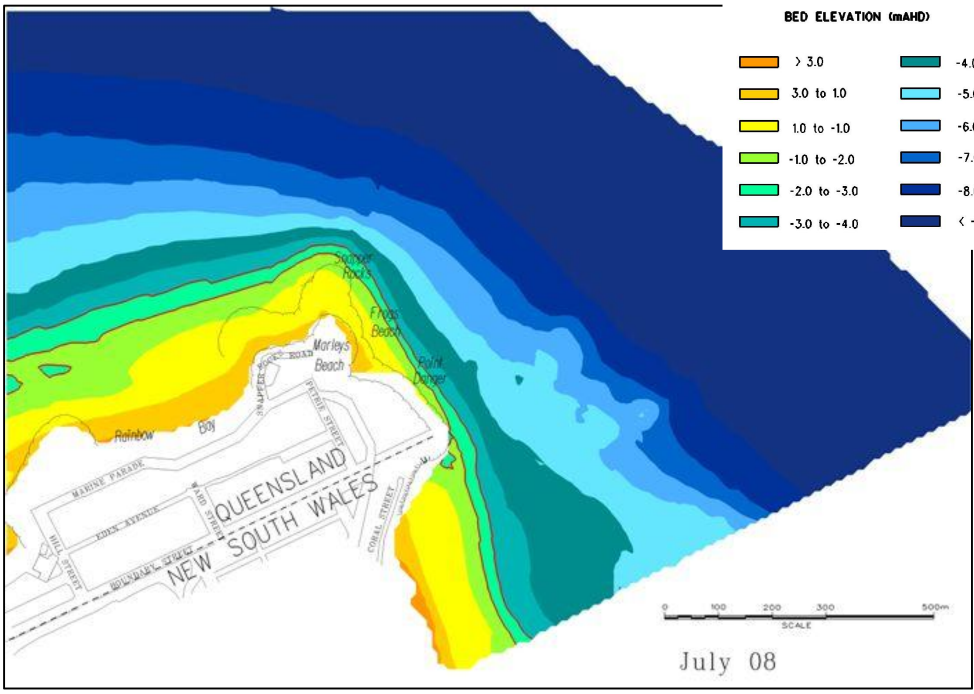

Figure 3-15 Pre- Autumn 2009 Storms Bathymetry around Snapper Rocks

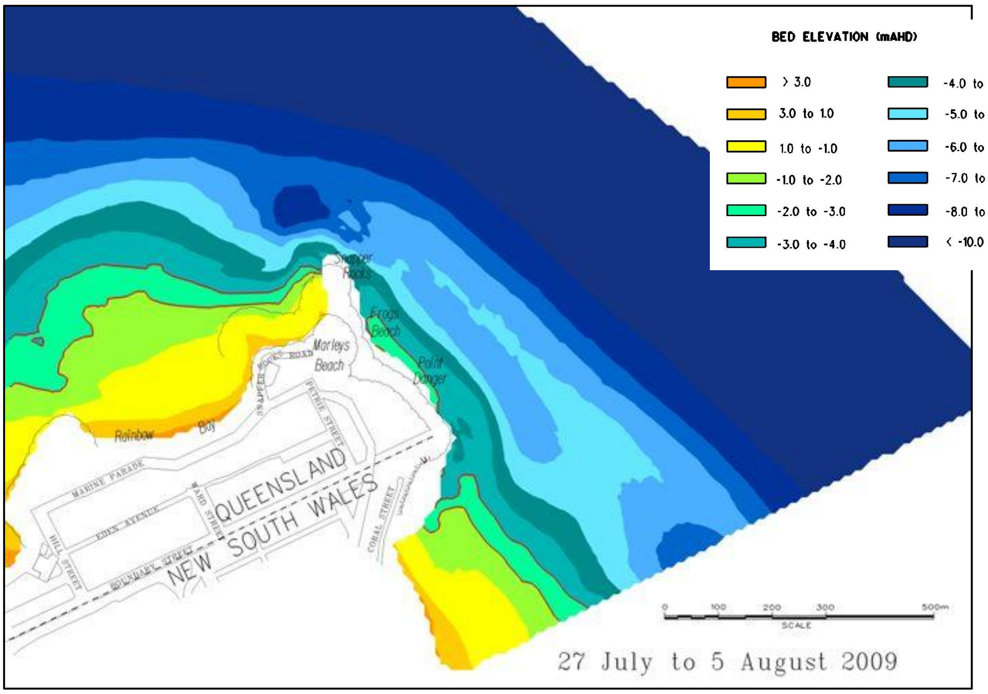

Figure 3-16 Post- Autumn 2009 Storms Bathymetry around Snapper Rocks

3.7 Tugun & Currumbin

This compartment extends from the northern end of Bilinga to Currumbin Rock in the north and encompasses Tugun and Currumbin Beach. Tugun and Currumbin form part of a somewhat larger embayment that extends from Kirra Point to Currumbin Point, and is slightly curved. The beach is separated by Elephant Rock, Flat Rock and Flat Rock Creek, a small coastal creek that drains across the beach between Elephant Rock and Flat Rock.

Currumbin Beach is fully exposed to north through easterly ocean waves, but receives protection from Snapper Rock during south-easterly and south swell conditions and, as such, the littoral sand transport processes along the entire beach remain influenced by the effects of Snapper Rocks. Even though the influence of the headland progressively reduces moving north along the shoreline, it remains significant at Currumbin Rock.

The construction of the Currumbin Rock groyne has had a significant impact on the shoreline between Currumbin Rock and Elephant Rock. Since its construction in 1973, the beach has become more stable and the upper beach has experienced significant accretion. The beach profile between Currumbin Rock and Elephant typically gained in the order of 1,000m^3/m.

Currumbin Beach usually exhibits a single or double bar system, with prevalent rip channels across the inner bars. The sand transport through this compartment occurs exclusively as littoral transport with the vast majority of the longshore transport occurring in water depths less than 4 metres, as shown in Figure 3-12.

Figure 3-17 Aerial photo of Currumbin Beach in 1970 showing rock revetment adjacent to Marine Parade

4. Knowledge Development Planning

Although considerable knowledge is available from previous scientific and engineering studies and data analyses, it is recognised that a full understanding of the processes influencing the transport of sand through the STIS does not exist. The natural physical processes of sand movement in the Project Area are variable and highly complex, and have a substantial influence on the sand bypassing operations of the TSB. In turn, the bypassing operations of the TSB affect the natural processes.

A knowledge gap analysis was undertaken to identify the critical knowledge gaps that exists in the current understanding of the sediment transport processes operating within the STIS, including the effects of TSB's sand bypassing operations; and recommend methodologies to fill these knowledge gaps. The outcomes of this knowledge gap analysis are summarised in Table 4-1.

Table 4-1 Knowledge Gap Analysis

Aspect	Knowledge Issue	Knowledge held	Knowledge Gap	Methodology to Gain Knowledge
Fingal to Currumbin sand transport differential	Recent investigations have suggested that the net transport of sand into the system at Fingal is larger than the net transport out of the system at Currumbin. The cause and validity of this apparent ongoing differential is currently unknown.	Information held by TSB to enable further investigation of this aspect includes: • Wave and longshore transport models • Historical beach profile and hydrographic surveys • Shoreline evolution model • Historical recorded wave and metocean datasets	There is uncertainty as to the cause of the differential and whether it is a result of error in the calculation of sediment transport budgets and whether it is in fact reflecting reality. Potential explanations include: • Longshore transport at Currumbin has been impacted by anthropogenic activities, both direct and indirect • Transport rates are affected by inter-decadal variability in the wave climate, which may have affected the longshore transport regime • Transport differential is due to processes that operate on geological timescale processes related to the Holocene transgression	• Determine the locations of sand volume changes and assess degree of change that can be attributed to anthropogenic actions such as groyne construction of and dredging • Investigate the sensitivity of the longshore transport at Currumbin to changes in (deepwater) bathymetry • Conduct longshore transport modelling at additional locations to validate modelled rates and provide regional context • Conduct geomorphological study to provide understanding of the ongoing effects of Holocene transgression.

Aspect	Knowledge Issue	Knowledge held	Knowledge Gap	Methodology to Gain Knowledge
Tweed Entrance Dynamics	Although the concept of the Tweed Entrance dynamics is well understood. A detailed understanding of the sensitivity of the entrance bar formation is currently not documented. The Tweed entrance dynamics is an important process which has an impact of critical operational issues such as impacts safe navigation and the TSB dredging programme	Information held by TSB to enable further investigation of this aspect includes: • Historical beach profile and hydrographic surveys • Historical recorded wave and metocean datasets • Recorded current datasets in the Tweed River entrance	The sensitivity of the entrance bar formation to flood and metocean events and different dredging campaigns is not fully understood. A better understanding of the bar dynamics could assist in improved management of the entrance dredging campaign.	• Sediment transport modelling of the entrance area to simulate transport under a range of entrance configurations and metocean and flood conditions • Conduct flow current measurements to provide insight in hydrodynamics around the jetty under a range of metocean conditions
Sand leakage through jetty	The exact pathways and mechanisms that cause sand leakage are not fully understood. ‘Leakage’ can result in significant contributions to channel deposition and entrance bar formation which can in turn impact navigability and dredge campaign volumes.	Information held by TSB to enable further investigation of this aspect includes: • Wave and longshore transport models • Historical beach profile and hydrographic surveys • Sand transport model • Historical recorded wave and metocean datasets	Pathway and mechanism of ‘leakage’ are not fully understood. Better understanding of the mechanism for sediment to bypass through and around the jetty and slurry pit could result in better planning of future operations and potential infrastructure modifications.	• Data analyse of existing information, assisted with numerical sediment transport modelling, to provide quantitative understanding of circumstances that lead to ‘sand moving past the jetty. Sediment transport model should be able to accurately represent the effects of slurry pit. • Liaise with contractor to learn from his experiences (observations of historical leakage, operational challenges, opportunities to optimise the pumping system or operations)

Aspect	Knowledge Issue	Knowledge held	Knowledge Gap	Methodology to Gain Knowledge
Sand placement operations	The lower beach profile throughout the Coolangatta-Kirra embayment appears to be subject to ongoing erosion. The effects on long-term shoreline processes are poorly understood.	Information held by TSB to enable further investigation of this aspect includes: • Wave and longshore transport models • Historical beach profile and hydrographic surveys • Shoreline evolution model • Historical recorded wave and metocean datasets	The source of ongoing erosion of the lower beach profile of the Colangatta-Kirra embayment is unknown. Further analysis would be required to identify the source of this trend, assess the nature of the impacts, and whether mitigations are required.	• Detailed analyse of previous placement operations and sand tracing study results to infer sediment pathways and rates towards Snapper Rocks. • Sand tracing study with release at deepwater location off Snapper Rocks • 2D sediment transport modelling of transport around Snapper Rocks
Transport of sand	During the “supplementary increment” period (2001-2008), the total supply to the southern Gold Coast beaches was higher than the estimated natural longterm average sand transport. This period of oversupply continues to affect the Project Area, with most of the change in recent years occurring as sand lobes between -5 and -10mAHD along Bilinga North and Tugun.	Information held by TSB to enable further investigation of this aspect includes: • Wave and longshore transport models • Historical beach profile and hydrographic surveys • Historical recorded wave and metocean datasets • Shoreline evolution model	There is uncertainty how sand will migrate from these sand lobes northwards, making prediction of adaptation timeframes difficult.	• Detailed monitoring of sand movement around sand lobes (surveys, tracing study) • 2D sediment transport modelling study of Bilinga North, Tugun and Currumbin

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