International Coastal Management

STOCKTON BEACH

EROSION REVIEW

Prepared for

Stockton Community Group (SCG)

By

International Coastal Management

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EXECUTIVE SUMMARY

The Stockton Embayment is a very complex coastal system that has had many studies undertaken by previous consultants. These studies have attempted to document, understand and model the historical and on-going coastal processes and changes to the beach. This report includes a summary and critical assessment of the insights gathered from the conclusions made by these previous studies.

On-going Erosion at Stockton Beach

It is clearly the case, and agreed to by each of the previous studies, that long-term coastal erosion and landward re-alignment of the shoreline has been occurring along Stockton Beach to at least about midway along Stockton Bight. This erosion has been occurring from the upper beach face and out to the offshore seabed up to a water depth of 20m, resulting in the on-going deepening of the offshore seabed profile. It is also clear that this erosion is ultimately the result of a severe nett deficit of sand supply to the Stockton Beach system (i.e., more sand is lost from the system than is being brought in to replenish it).

Each of the studies agree that the interruption of the sand supply and resulting starvation of sand to Stockton Beach is most significantly due to the changes to the harbour entrance and port, including:

- Construction of the breakwaters
- Capital dredging to deepen the entrance channel
- On-going maintenance dredging
- Reduction of beach compatible sediments from the river

These changes represent a physical barrier preventing the natural longshore transport of sand that was historically supplying Stockton Beach and the Stockton Embayment, which Bluecoast (2020) estimated was about 100,000m^3/year prior to human impacts. It should be noted that the present sand budget model developed by Bluecoast (2020) assumes that no sand is naturally bypassing the entrance to supply Stockton Beach.

Given the cessation of the historic sand supply to Stockton Beach, the on-going long-term erosion that has been occurring is not considered to be cyclical in nature, and rather should be expected to continue, and most likely worsen as the remaining sources of sand become depleted. This worsening has been observed in recent changes to the seabed profile by Bluecoast (2020) and would be expected as a result of larger waves be able to pass over the deeper eroded seabed. Projected sea level rise and other impacts due to climate change would also be expected to exacerbate the magnitude of the erosion. Erosion impacts to date due to sea level rise and climate change are difficult to separate from the other causal factors of erosion at Stockton Beach, but are not considered to be significant compared to the major impacts due to changes to the entrance.

Relative Performance of Adjacent Beaches:

In contrast to the erosion occurring at Stockton Beach, the adjacent Nobby's Beach and northern region of Stockton Bight have observed nett growth in sand volumes.

- For Nobby's Beach, the construction of the southern breakwater resulted in the trapping of sediment prior to entering the entrance channel, causing a build-up of sand at Nobby's Beach and formation of a sand lobe. This build-up of sand also suggests sand continues to be supplied to Nobby's Beach from the South.
- For northern Stockton Bight, on-going nett northward longshore transport continues to supply it with sand shifted north from the southern portion of Stockton Bight, including Stockton Beach.

Stockton Beach Coastal Processes and Sediment Pathways

The coastal processes occurring across the Stockton Embayment and habour entrance have been well studied by the previous consultants, in particular:

- Shifting Sands at Stockton Beach. Umwelt & SMEC, 2002
- Stockton Beach Coastal Processes Study. DHI, 2006
- Stockton Bight Sand Movement Study. Bluecoast 2020

DHI (2006) and Bluecoast (2020) both presented conceptual models that attempt to represent and predict what is occurring at Stockton Beach.

- The model developed by DHI (2006) is a 2-dimensional numerical model that is based on inputting site environmental conditions, including wave, tide and bathymetric data, to calculate the currents, waves and subsequent movement of sand across Stockton Beach and the harbour entrance. Predictions regarding erosion and accumulation of sand were then made on the basis of the how sand was expected to be transported.
    - o <u>Use known environmental conditions to predict coastal processes and resulting changes to the seabed and beach</u>
- The conceptual model developed by Bluecoast (2020) was based on a volumetric analysis of historical survey data of the beach an offshore seabed profile. Changes to these profiles over time were analysed in the context of site environmental conditions to quantify the movement of sand volumes using a sand budget approach. (Use known
    - o <u>Use known changes to the seabed and beach to infer coastal processes in the context of environmental conditions</u>

Although each of these studies agreed that sand is ultimately being eroded and lost from Stockton Beach, the system is complex and there is likely to be different transport paths and rates corresponding to different weather patterns. As a result, modelling is difficult and there is some disagreement as to exactly how the sand is being eroded and where the eroded sand is being transported to.

Both studies agreed that Stockton Beach is generally influenced by a nett northerly transport of sediment that is driven by frequent south-easterly swell conditions, and that episodically, a net southward sediment transport direction can occur as a result of infrequent north-easterly and easterly swell conditions. However, the models diverge on the coastal processes occurring at the southern end of Stockton Beach.

- The numerical model by DHI (2006) indicated the existence of a counterclockwise re-circulation pattern that was produced by the sheltering effect of the breakwaters. This pattern resulted in a nodal point where the longshore transport direction split, driving sediment both northward to Stockton Bight and southward to the breakwater where it may accumulate.
- The expected impacts of the circulation pattern (accumulation of sand against the breakwater) were not apparent in the subsequent volumetric analysis of seabed and beach survey by Bluecoast (2020) and as an explanation for the observations, they postulated that the erosion is being driven largely by a nett northward longshore drift occurring along the entire extent of Stockton Beach. This is in contrast to the predictions of the 2-dimensional numerical modelling by DHI (2006).

If the predictions by the DHI (2006) model were valid and southerly transport is occurring, but sand is not observed to be accumulating over time, it then becomes a question of where is the eroded sand being transported to? Umwelt & SMEC (2002) claimed that historic survey strongly suggested there was a transport of sand from the nearshore area of Stockton Beach into the entrance channel from the north via a drainage path north of the tip of the northern breakwater.

- The DHI (2006) model indicated that a volume of about 3,500m^3/year of sand was being lost around the tip of the breakwater and into the entrance channel and acknowledged that localised scour at the breakwater could occur. However, they did not agree with Umwelt & SMEC (2002) regarding a drainage pathway from the nearshore. It should be noted that any sediment transported from the beach and nearshore area out to the breakwater would be expected to be lost or re-circulated under the predictions of the DHI (2006) model.
- Bluecoast (2020) also acknowledged the possibility of sand being lost into the entrance channel, where it is then dispersed by ebb and flood tides but discounted it on the grounds that dredge survey data did not support it.

Transport and loss of sediment into the entrance channel, in addition to re-circulation of sediment at the nodal point where it may then be transported north through longshore transport, may provide an alternative explanation that reconcile the predictions by DHI (2006) and the volumetric analysis by Bluecoast (2020). However, further research into the localised coastal processes north of the breakwater, offshore and along Stockton Beach is required to confirm the validity of each explanation.

Beach Nourishment and the Need for Action

In recent years, dredged port sands have been placed offshore of Stockton Beach to help supply sand and offset the sand deficit. Even with this, estimates by Bluecoast (2020) suggest that the rate of sand lost from Stockton Beach is about 112,000m^3/year. Without action, the nett deficit of sand supply to Stockton Beach and on-going long-term erosion is expected to continue, and likely progressively worsen.

- Limited options to manage the erosion have been investigated, including increasing the volume of beach nourishment to reduce or balance the deficit of sand supply.
- An assessment of the available practical options to manage the on-going erosion needs to be considered.
- Given the clear interaction of the harbour infrastructure with the coastal processes, the port, including both the owner and lease holder, needs to be involved with any proposed solution.
- Solutions need to be practical and robust to account for the variability and uncertainty in the complex coastal processes and conceptual models developed in previous studies.

In addition to considering robust and practical solutions that can account for the uncertainty in the DHI (2006) and Bluecoast (2020) conceptual models, a clear understanding of the sediment transport directions and where eroded sand is being lost to for southern Stockton Beach and around the northern breakwater is critical for the design of any solution to manage the long-term erosion, in particular for nourishment programs, groynes and seawalls.

1. INTRODUCTION

Stockton Beach is located to the north of the entrance of Newcastle Harbour, NSW and has a long history of erosion.

With the headland to the south (updrift) and the works associated with the port – training walls and large scale dredging (capital and maintenance) of a deep channel - the coastal processes and timeframes are complex.

This report is a concise high-level summary of what past work has been documented about the erosion and coastal processes at Stockton Beach. Specifically, the report is focused on the reports provided by the client to ICM (listed in section 2) and what causal factors (natural and antropogenic) are at play making Stockton Beach more susceptible than nearby beaches to beachline fluctuations and severe erosion events that impact on the coastal community. Thus, identifying the factual causes and potential solutions is important.

This is a high-level summary report citing key evidence, conclusions and insights from past studies. This work does not include new studies – it is intended to be a technical assessment of "what we know" today.

Figure 1: Location of Stockton Beach, Newcastle, NSW (Source: Google Earth 1/10/2016)

2. PREVIOUS REPORTS AND PAPERS

The following is a timeline of the previous relevant reports, papers and key studies that have been developed specifically examining the coastal processes, erosion and beach management of Stockton Beach.

2002

- Shifting Sands at Stockton Beach (Umwelt & SMEC, 2002). This report reviewed earlier studies:
  - Newcastle Harbour Investigation (PWD, 1963)
  - Newcastle Harbour Hydrographic Survey (Manley, 1963)
  - Littoral Drift in the Vicinity of Newcastle Harbour (Boleyn and Campbell, 1966)
  - Newcastle Harbour Siltation Investigation (PWD, 1969)
  - Environmental Impact Statement Deeping of Newcastle Harbour (MSB, 1976)
  - Feasibility Study on Nourishment of Stockton Beach (Department of Public Works, 1978)
  - Between Wind and Water (Coltheart, 1997)
  - Newcastle Coastline Hazard Definition Study (WBM, 1998)

2003

- Newcastle Coastline Management Study (Umwelt, 2003)

2006

- Stockton Beach Coastal Processes Study Final Report (Stage 1 – Sediment Transport Analysis and Description of On-going Processes) (DHI, 2006)
- A State-of-the-Art Modelling Approach to Assess Coastal Processes at Stockton Beach (Savioli, 2007)

2010

- Selection of the Preferred Management Option for Stockton Beach – Application of 2D Coastal Processes Modelling (Allery, 2010)

2012

- Stockton Beach Sand Scoping and Funding Feasibility Study (WorleyParsons, 2012)
- Stockton Beach Sand Nourishment Scoping Study (Nielsen et al., 2011)

2014

- Newcastle Coastal Zone Hazards Study Final Report (BMT WBM, 2014a)(a)
- Newcastle Coastal Zone Management Study Final Report (BMT WBM, 2014b)(b)

2017

- DHA Stockton Rifle Range Stockton Beach Coastal Engineering Assessment (BMT WBM, 2016)

2018

- Newcastle Coastal Zone Management Plan – Stockton (City of Newcastle, 2018)
- Stockton Coastal Management Synthesis Report (Royal HaskoningDHV, 2018)

2020

- Stockton Bight Sand Movement Study (Bluecoast, 2020)
- Stockton Coastal Management Program (Royal HaskoningDHV, 2020)

3. HIGH LEVEL SUMMARY

The following section outlines a high-level summary of the conclusions and insights drawn from the previous documentation of Stockton Beach.

Shifting Sands at Stockton Beach, 2002. Umwelt & SMEC

The purpose of Umwelt & SMEC 2002 was to develop a greater understanding of the coastal processes and movement of sand at Stockton Beach and the changes that have occurred since the commencement of construction of the Macquarie Pier in 1812. The report includes:

- review of previous literature on coastal processes and hazards
- timeline of substantial infrastructure and developmental changes
- assessment of historical bathymetric survey, erosion and accretion data
- development of a set of 3D time series models of the bed profile of Stockton Beach and the channel entrance to Newcastle Harbour to enable observation of changes in sand volume and sand profiles over time.
- Modelling of cross-shore storm related erosion

Report Conclusions

Based on the literature review, analysis of available hydrosurvey data and the time-series modelling, the following conclusions were made by Umwelt & SMEC (2002):

- Changes to Sand Volume and Seabed Profiles
  - Estimated more than 10 million m^3 of sand was lost from an area off the Stockton Beach system since construction of the Southern Breakwater in 1812 to 2002. This does not include material that has been removed or lost from the entrance channel and the seabed immediately to the east.
  - Substantial changes have occurred to the bed profile, water depth and sand volume off Stockton Beach up to approximately 1,700 meters offshore and to a water depth of 20 meters. This includes a lowering of the bed elevation by 4 to 7 meters at approximately 800 to 900 meters offshore.
  - These observed changes to the seabed profile are progressive rather than cyclic, with an average loss rate of approximately 370,000 m^3/year between 1988 and 2001.
  - An erosion scour zone was identified at the tip of the Northern Breakwater, with this area appearing to trigger a removal of sand from the Stockton Beach System. Transport of sand from Stockton Beach into the entrance channel is supported strongly by a close analysis of a detailed hydrosurvey, which clearly exhibits a drainage pathway from the nearshore area of Stockton Beach to the entrance channel.
  - The observed changes to the seabed profile have occurred over the same time period as the extensive changes to the entrance to the Newcastle Harbour, including:
    - Construction and extension of the Southern Breakwater between 1812 and 1875
    - Construction of the Northern Breakwater between 1898 and 1912
    - Dredging of approximately 133 million m^3 from Newcastle Harbour and its entrance between 1857 and 1989.
    - Deepening of the harbour entrance from 8 meters to 11 meters between 1962 and 1967.

- Causes of Geomorphological Change
  - Umwelt & SMEC (2002) stated that from an analysis of historic hydrosurvey, the beach system appeared to be approaching a new equilibrium by about the late 1950s.
    - This apparent new equilibrium was disturbed between the late 1950s and late 1980s, with sand loss rates between 1988 and 2000 five time the average rate of loss between 1921 and 2000.
    - This erosion rate started to slow down after 1995, indicating the beach system maybe approaching a new, considerably deeper equilibrium.

  - The report identified that detailed hydrodynamic and nearshore wave transformation modelling would be required to develop a clearer understanding of the complex coastal processes relevant to foreshore change at Stockton Beach.

  - Umwelt & SMEC postulated that the major cause of change to the nearshore and foreshore zone of Stockton Beach can be related to the changes made to the configuration of the Hunter River estuary entrance, stating the following conclusions:
    1. Construction of the seawall in 1898 did not impact on erosion rates along Stockton Beach.
    2. Construction of the Southern Breakwater and subsequent deepening of the entrance channel has cut off any littoral drift transport from south of the entrance to Stockton Beach (estimated to be average 30,000m^3/year).
       - Prior to the breakwater, the ruling depths of 5m to 7m on the entrance bar would have been sufficient to bypass littoral drift to Stockton Beach.
    3. Construction of the Southern Breakwater altered the tidal discharge characteristics of the inlet, which affected nearshore shoals and bars and resulted in the progradation of the southern end of Stockton Beach and lowering of the seabed offshore.
    4. Dredging of the entrance channel created a potential sediment sink for the deposition of littoral drift material carried to the channel from the surrounding seabed under wave and flood tidal current action.
    5. The Northern Breakwater accelerated the flood tide flow at its tip, resulting in scouring of a deep channel and directing sediment transport into the entrance channel from the north (Stockton Beach side). This scour hole deepened by more than 3 meters following the deepening of the entrance channel in 1962 - 1967 & 1979 - 1983. This effect, in conjunction with the increased tidal exchange volumes also has the potential to cause an acceleration of sediment drawdown from Stockton Beach.
    6. Dredging of the entrance channel to a depth of about 18m has removed the river entrance bar, resulting in water depths too deep to allow any littoral drift supply to Stockton Beach from the south, thereby cutting off historical natural sand supply. Approximately 5.7 million m^3 of sand would have been supplied to Stockton Beach system from southern littoral drift if the Southern Breakwater had not been constructed and the channel deepened.

- Impacts of Geomorphological Change on Foreshore Erosion
  - Umwelt & SMEC stated that their numerical modelling of the cross-shore beach erosion processes showed there had been an increase in subaerial beach storm erosion potential along the Stockton Beach foreshore, with a strong indication that this had accelerated between 1990 to 2000 by a magnitude of 2 to 2.5, and that this increasing risk of storm erosion could be attributed to the progressive deepening of the seabed offshore of Stockton beach.

- Based on wave transformation analysis by Umwelt & SMEC, by 2002 the offshore storm wave height had increased by approximately 2 meters (or 30% to 50%) since 1899, with potential beach erosion from a design storm being approximately 5 to 6 times greater in 2000 than in 1950.
- Umwelt & SMEC (2002) concluded that the current trend of nearshore recession experienced at Stockton Beach is progressive rather than cyclic, with erosivity of the foreshore likely to increase with time.

- Final Recommendation
  - The report identified that additional detailed studies were required in order to understand the impacts of further channel deepening, and to develop appropriate mitigation measures.

Newcastle Coastline Management Study, 2003. Umwelt Environmental Consultants.

The purpose of this document was to identify options relevant to the environmental planning and sustainable management of the Newcastle coastal area. The outcomes of this study would then be used to inform the development of the Newcastle Coastal Management Plan (bounded by the Glenrock lagoon and the southern boundary of the Rifle Range at Fern Bay).

Coastal Processes and Hazards

The coastal processes and hazards identified within this report were based on the findings of the Shifting Sands at Stockton Beach Coastal Processes Study (Umwelt & SMEC, 2002), and reiterated the conclusion that the entrance breakwaters have had a major influence on the adjacent coastal alignments, as a result of:

- Interference of nearshore wave transformation processes, resulting in progradation of the southern shoreline and recession of the beach line further to the north.
- Impacts associated with the breakwaters, resulting in greater wave energy impacting the Stockton foreshore, change in the angle of incidence and changes to the rates of sediment transport.
- Impacts associated with the deepening of the entrance channel, resulting in a restriction of the supply of sand through longshore transport across the entrance bar and onto the Stockton Beach, and creation of a sediment sink for littoral sand.

Umwelt (2003) also listed the following causal factors of erosion, in addition to those already outlined in Umwelt & SMEC (2002):

- Direct loss of beach material as a result of aeolian sand transport inland due to onshore winds.
- Rising sea levels contributing to additional beach recession.
- Increased ‘storminess’ as a result of climate change.
- Long-term weather cycles, such as the El Nino Southern Oscillation. However, the report makes no direct claim to what impact this may have on Stockton Beach.

As part of the literature review, the Umwelt (2003) stated that previous erosion studies on Stockton Beach, including PWD (1977), WBM (1998) and DLWC (1995) had identified that they are generally contradictory in their interpretation of historical shoreline changes and their prognosis of future trends at Stockton Beach. The report stated previous studies recognised that the breakwaters at the Hunter River entrance have had a major influence on the shoreline configuration at Stockton Beach. However, it was not concluded by PWD (1977) or by WBM (1998) that the impacts of the breakwater constructed are completed.

Future Sea Level Rise

Umwelt (2003) identified that previous work by WBM (1998) included an allowance for recession as a result of sea level rise.

- The report concluded that it can be expected that the high-than-average erosion rates at Stockton Beach are likely to increase at an accelerating rate under large wave activity and the threat to development at Stockton Beach will increase with time.
- The report does not quantify the level of new risk associated with the accelerating erosion.

Stockton Beach Coastal Processes Study Final Report (Stage 1 – Sediment Transport Analysis and Description of On-going Processes), 2006. DHI Water & Environment.

This coastal study was undertaken in response to the findings of the Newcastle Coastline Management Study (Umwelt, 2003) and provided a detailed qualitative and quantitative analysis of the coastal erosion processes of Stockton Beach. The study included data collection and analysis, development of a 2-dimensional numerical model and identification of on-going beach erosion trends. The outcomes of this study were used in the development of the Newcastle Coastline Management Plan Revision.

Process Study Findings

A detailed analysis of the sediment transport conditions at Stockton Beach was carried out at a range of time scales.

- Short Term Processes
  - Processes were based on dune erosion models and modelled wave conditions in the Stockton nearshore areas and applied to the most severe storm events observed in the Newcastle areas since 1974.
  - Short-term predictions showed an increase in dune erosion risk from south to north for the most frequent events from the south east.
  - East to north east storm events also produced severe erosion but more evenly along the beach.
  - Shoreline retreat of up to 24.5m was identified (at the northern Council boundary).

- Medium and Long-term Processes (1992 – 2004)
  - Infrequent north east and easterly events produced an episodic southerly net transport.
  - The frequent SE swell conditions produced a net northerly transport.
  - A medium-term, inter-annual or decadal fluctuation was observed between 1994 – 1999.

- Long-term Analysis
  - A comparison of the 2D analysis of the littoral transport processes (1992 to 2004) to the historical data for the period between 1866 and 2000 was undertaken by DHI (2006), with the following results:
    1. From 1992 to 2004 – Estimated 55,000m^3/year net northward sand transport (Fort Wallace).
    2. From 1866 to 2004 – Estimated 20,000 to 30,000m^3/year net northward transport (Fort Wallace).
       - The difference between this and the 1992-2004 value was attributed by DHI (2006) to be the result of wave variability.
    3. The port structures were found to be redirecting the southerly sediment transport (estimated to be about 33,000m^3/year) into the deep offshore areas thereby obstructing the bypassing mechanism at the Hunter River entrance.

4. No sediment bypassing is predicted into the southern end of Stockton Beach.
5. The river is not a significant source of sediment in the Stockton area. Suspended sediment delivered to the sea during floods is too fine to be retained on the beach, with coarser catchment sands and gravels trapped further upstream of the estuary.
6. South easterly waves were found to diffract around the port breakwaters and produce a predicted nodal/neutral point at the northern end of the Mitchell St seawall. The sediment transport was predicted to split into two directions at this point. The model predicted that this was the major eroding stretch in Stockton Beach (Figure 2).
7. An increasing northward sediment transport occurs north of the Mitchell St seawall, with the area north of the seawall eroding as a result.
8. The limited wave setup occurring in the sheltered area north of the northern breakwater is inducing an anticlockwise eddy. This eddy is driving local current along the shoreline to the area immediately north of the breakwater and inducing slight accretion in this area.
9. Easterly and north-easterly waves were predicted to refract and produce a uniform southward longshore transport and sediment accumulation immediately north of the northern breakwater.
10. A wave focussing mechanism was predicted north of the Mitchell St seawall. The focussing area is located from the treatment ponds to the southern end of Fern Bay and is expected to exacerbate erosion in the area.
11. Nobby's Head generates a deposition zone north of the southern breakwater, both in the navigation channel and at Horseshoe Beach.
12. The area north of Fern Bay is expected to be in equilibrium as the beach orientation reaches the equilibrium angle
13. The drainage pathway indicated in (Umwelt & SMEC, 2002) to propagate from the tip of the northern breakwater back towards Stockton Beach was not supported by the conclusions of DHI (2006), however, their 2D model did predict a transport of sediment offshore and into the entrance channel (about 3,500m^3/year) and DHI (2006) did acknowledge the potential for scour around the tip of the breakwater channel. This suggests that DHI (2006) were aware of and did acknowledge that sand could be lost from the tip of the breakwater and into the channel, but that this loss was localised and did not extend back to the Stockton Beach nearshore. It should be noted that under the predications of the 2D model, any sediment dispersed or transported to the tip of the breakwater would then be expected to be scoured into the entrance channel, offshore, or re-circulated back towards the nodal point where it may be transported north.

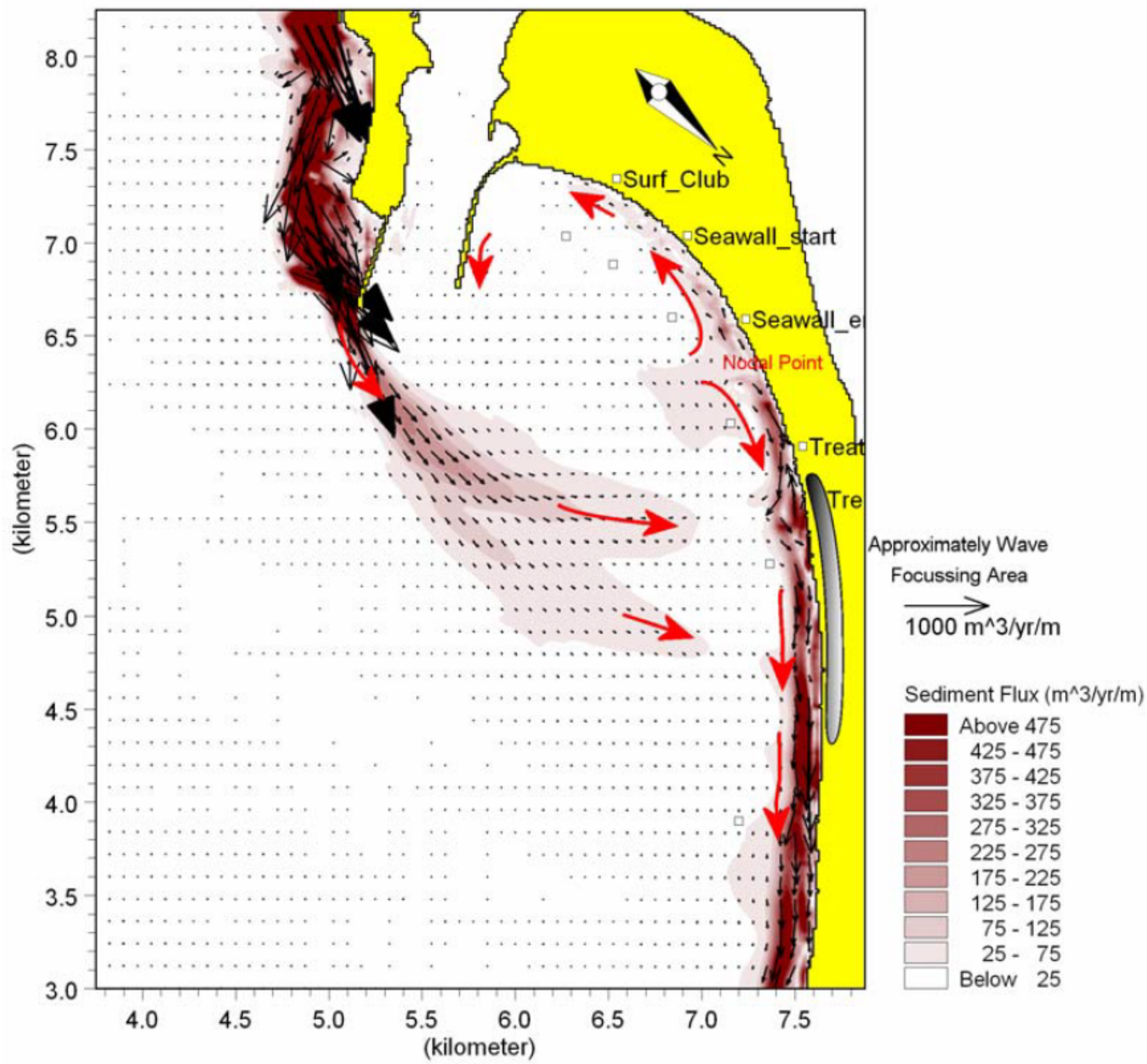

Figure 2: The predicted sediment transport mechanisms at Stockton based on the typical yearly conditions from 1992 to 2005. (DHI, 2006)

A State-of-the-Art Modelling Approach to Assess Coastal Processes at Stockton Beach, 2007. DHI Water & Environment.

This document is a presentation of the modelling approach used as part of the Stockton Beach Coastal Processes Study Final Report (Stage 1 – Sediment Transport Analysis and Description of On-going Processes) by DHI, (2006). No new conclusion were drawing within this presentation regarding causal factors of erosion at Stockton Beach.

Selection of the Preferred Management Option for Stockton Beach – Application of 2D Coastal Processes Modelling, 2010. DHI Water & Environment., Craig, Allery.

This paper presented the approach to understanding the complex coastal processes at Stockton Beach and the selection of the preferred long-term management option. The approach was underpinned by the outcomes of the 2D coastal process modelling develop as part of the Stockton Beach Coastal Processes Study (DHI, 2006), and the Stockton Beach Coastal Zone Management Study (DHI, 2009). No new conclusions with regards to causal factors of erosion at Stockton Beach were identified.

Stockton Beach Sand Scoping and Funding Feasibility Study, 2012. Worley Parsons.

This report is a scoping study for the nourishment of Stockton Beach with the objective to identify potential sources of sand, methods for extraction and placement, develop a cost estimate for a nourishment option, recommend the preferred option for nourishment and identify any potential funding opportunities for beach nourishment activities. A review of previous documentation of coastal processes studies at Stockton beach was undertaken to develop a conceptual model of the main sedimentary processes (Figure 3). This was largely based on the previous 2-dimensional modelling by DHI (DHI, 2006) and other previous reports, including MHL (1977), WBM (1998), Umwelt & SMEC (2002), Umwelt (2003) and PBP (2004).

Worely Parsons (2012) stated the following fundamental characteristics of this conceptual model:

- Considerable movement of sediment within Stockton Bight compartment is evident. This includes onshore and offshore movements.
- Stockton Beach longshore transport leads to regular shifting of sand from one end of the beach to the other in association with decadal oscillation changes in dominant wave directions.
- Net northward littoral drift transport of 33,000m^3/year past Nobby's Head, as estimated by DHI, 2006.
  - Approximately 26,000m^3/year of this is likely to be deposited at the offshore sand lobe.
  - Remaining 7,000m^3/year bypassing Nobby's Head (Umwelt, 2002).
  - Of the 7,000m^3/year bypassing Nobby's Head, an amount of this is likely to be deposited within the entrance of the Hunter River, with the remainder bypassing the northern breakwater.
  - Sediment deposited into the entrance channel at a depth of over 18m is unlikely to naturally bypass the northern breakwater.
  - Sediment that does bypass the northern breakwater at the river entrance is transported further north.
- A null point is located near the Mitchell Street seawall, at which longshore transport processes split:
  - South of the seawall – net transport is directed south toward the northern breakwater.
  - North of the seawall – net transport is directed north towards Anna Bay.
- Net southward sediment transport is episodic and caused by more infrequent north-east and easterly events. The report states that this indicates little overall net change.

- Net northward sediment transport is due to the more frequent south-east swell conditions and is estimated to range from 20,000m^3 to 55,000m^3/year in the area north of the Mitchell Street seawall and sewage ponds.
- Aeolian transport of up to 300,000m^3 is lost from the system, which equates to 1 to 5m/year beach recession (MHW, 1977).

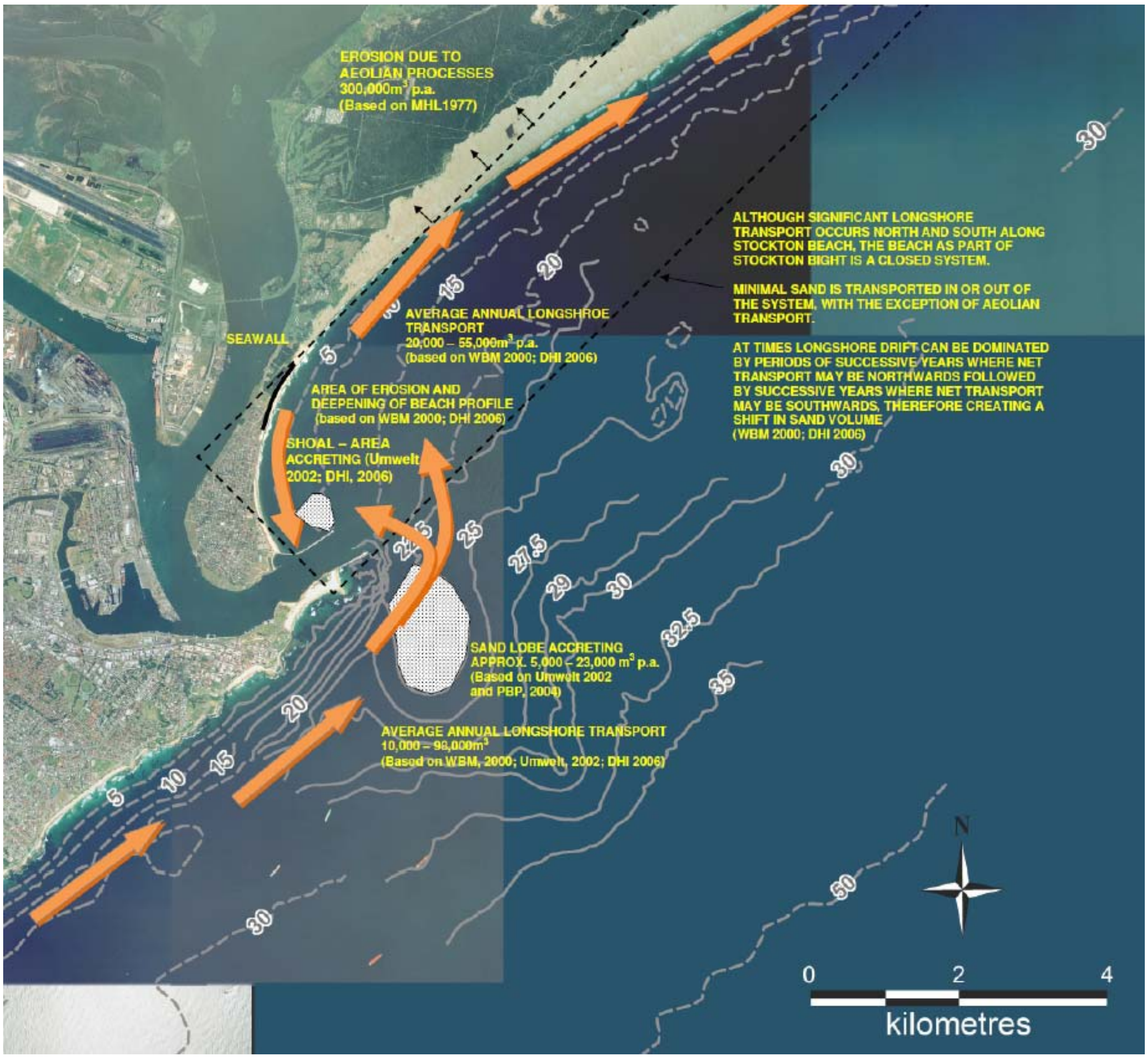

Figure 3: Conceptual sediment processes model developed as part of the Stockton Beach Sand Scoping Study (Worely Parsons, 2012)

Stockton Beach Sand Nourishment Scoping Study, 2012. Lex, Nielsen et al.

This paper was developed as a synthesis of the Stockton Beach Sand Nourishment Scoping and Feasibility Study (WorleyParsons, 2012), reiterating the same findings as that study. No new conclusions were drawn regarding causal factors of erosion at Stockton Beach.

Newcastle Coastal Zone Hazards Study Final Report, 2014. BMT WBM.(a)

This report presented a summary of the coastal processes operating on the Newcastle Coastline, including Stockton Beach, and the methodology and outcomes for the definition of coastal hazards impacting the study area.

BMT WBM (2014) reiterated many of the findings of previous studies, including Umwelt & SMEC (2002) and DHI (2006) regarding the coastal processes at Stockton Beach:

- Natural northerly longshore transport has been captured by the Macquarie Pier and southern breakwater to form Nobby's Beach.
- Stockton Beach is experiencing ongoing recession due to the interruption of northerly longshore sediment supply by the harbour breakwaters.
- The southern most end of Stockton Beach has a slight accretionary trend due to the sheltering of the beach from the dominant south easterly swell by the northern breakwater.
- A sediment transport nodal point exists at the northern end of the seawall where the supply direction splits into southerly and northerly directions.
- Northern Stockton Beach becomes more exposed to offshore swell and without sediment supply from the south, this shoreline is experiencing on-going recession measured at about 1m / year.

The report makes the following statement with regards to the likely impacts due to sea level rise:

- The harbour breakwaters will continue to impede the northerly transport of sediment.
- Ongoing recession at Stockton Beach is likely to continue with sea level rise impacts likely to add to this recession.
- Recession at Stockton Beach is partially constrained by the existing rock seawall, but if the seawall is breached as a result of sea level rise, the recession extents would be considerably larger at this area.

Newcastle Coastal Zone Management Study Final Report, 2014. BMT WBM.(b)

This report outlined and evaluated the management options for treating the risk from coastal hazards along the Newcastle Local Government Area and is informed by the summary provided in the Newcastle Coastal Zone Hazards Study (BMT WBM, 2014a)(a).

No new conclusions or statements with regards to coastal processes and causal factors for erosion at Stockton Beach are outlined in this report.

DHA Stockton Rifle Range Stockton Beach Coastal Engineering Assessment, 2017. BMT WBM.

This report provided an assessment of the coastal hazards to be expected by 2100 that may impact the proposed Stockton Rifle Range site, approximately 4km north of the Mitchell Street seawall.

- The beach at the Rifle Range Site does not appear to exhibit any signs of erosion and was found to not presently be greatly affected by the ongoing recession due to the harbour breakwaters.

A literature review of previous coastal processes studies was undertaken by BMT WBM (2017) as part of this assessment to understand the history and causal factors of erosion at Stockton Beach. The review included the following investigations:

- Newcastle Coastline Hazards Definition Study (WBM, 2000)
- Shifting Sands at Stockton Beach (Umwelt & SMEC, 2002)
- Stockton Beach Coastal Processes Study (DHI, 2006)
- Stockton Beach Coastal Processes Study Addendum – Revised Coastal Erosion Hazard Lines 2011 (DHI, 2011).

The literature review reiterated many of the causal factors identified in reports previously summarised, including the following key statements and conclusions:

- Northerly littoral drift has been impeded from passing the Hunter River entrance and supplying Stockton Beach by the southern and northern entrance breakwaters.
- Littoral drift past the entrance breakwaters has not been able to be re-established as a result of the regular dredging of the channel to a depth of 18m.
- Any fluvial sand supply from the Hunter River to Stockton Beach has also ceased due to entrance dredging.

The report made the following statements regarding shoreline retreat:

- The shoreline retreat is estimated to about -0.8m/year at Stockton Centre, Fort Wallace and the Stockton Rifle Range Site (DHI, 2011).
- Erosion of the beach has previously threatened the following:
  - Central section of the beach along Mitchell Street
  - Stockton Beach Surf Life Saving Club and Pavilion
  - The wastewater treatment ponds, one of which has been lost to erosion with the next most seaward pond now under threat.
- With regard to future recession due to sea level rise, the report states that the beach is predicted to retreat by 28m for a sea level rise of 0.4m, and by 68m for a sea level rise of 0.9m. This data is based on the estimates by DHI, 2011.

The report made the following statements regarding nourishment history at Stockton Beach:

- Approximately 130,000m^3 of sand was dredged from the Harbour entrance (August 2009) and placed off Stockton Beach as nourishment. The placement was generally agreed to be a success.
- Small volumes of suitable dredged material (~5,000m^3 each) have been placed at Stockton Beach by the Port's maintenance dredger. However, this has not fully replicated the lost regional sand supply of up to 30,000m^3/year into Stockton Beach. As such, recession is expected to be on-going.

Newcastle Coastal Zone Management Plan – Stockton, 2018. City of Newcastle.

This document was the Draft Coastal Zone Management Plan for Stockton Beach and formed the first part of the on-going assessment and management of coastal hazards and community use of the coastal environment at Stockton Beach. The purpose of this plan was to present the coastal management actions for the short (1-2 year) and medium (1-5 year) term that would then be brought forward into the Coastal Management Program.

The report includes a background of the existing coastal hazards identified at Stockton Beach, based on the findings of the previous studies, including:

- Stockton Beach Coastal Engineering Advice, Public Works Department 1985
- Stockton Beach Coastal Engineering Advice Addendum, Public Works Department 1987
- Stockton Beach Coastline Hazard Study, Department of Land and Water Conservation 1995
- Newcastle Coastline Hazard Definition Study, WBM 1998
- Shifting Sands at Stockton Beach, Umwelt & SMEC 2002
- Stockton Beach Coastal Processes Study Stage 1, DHI 2006

The findings of these reports are reiterated with no new conclusions or statements made with regards to coastal processes or causal factors for erosion at Stockton Beach.

Stockton Coastal Management Synthesis Report, 2018. Royal HaskoningDHV.

This report outlined the development of a revised strategy for coastal management of the Stockton Bight frontage, and including the following investigations:

- An overview of coastal processes at Stockton Beach, including a review of previous studies undertaken.
- An update of coastal processes analysis that includes more recent data to provide (photogrammetry from 2011 and 2016) a revised historical beach recession rate.
- Discussion of strategy options, including a comparative assessment of short-listed options.

<u>Literature Review</u>

The review of the previous studies undertaken included the following:

- Shifting Sands at Stockton Beach (Umwelt & SMEC, 2002)
- Stockton Beach Coastal Processes Study (DHI, 2006)
- Stockton Coastline Management Study Report (DHI, 2009)
- Stockton Beach Coastal Processes Study Addendum – Revised Coastal Erosion Hazard Lines 2011 (DHI, 2011)
- Newcastle Coastal Zone Hazards Study (BMT WBM, 2014)

As part of the overview and review of the previous studies the report acknowledged that all of the previous studies indicated that Stockton Beach has been experiencing ongoing recession as a result of the interruption of the natural northerly littoral drift at the Newcastle Harbour and entrance channel, and that this situation has been evolving since completion of the Macquarie Pier in 1836. No new conclusions with regards to the causal factors for erosion at Stockton Beach were presented by the report.

<u>Gap Analysis</u>

In response to the review of previous studies, the report highlighted a number of 'gaps' in the understanding of coastal processes and available data, with the following recommended:

- Additional field-based investigations, including:
  - Subaqueous sediment sampling
  - Updated bathymetric survey
  - Sand tracer studies of placed dredged material to verify the suggested sediment transport regime.
- An improved understanding of the medium-term rotational behaviour of the beach.
- Review of the existing hazard lines, based on following:
  - Short term storm demand to include empirically measured data in conjunction with the previous numerical modelling.
  - Updated photogrammetry data from 2011 and 2016.

Stockton Bight Sand Movement Study, 2020. Bluecoast.

The purpose of this study was to further develop the understanding of sand movement patterns along Stockton Bight, including quantities, rates and key drivers of sediment transport. In particular, the study included new survey of the subaqueous profile along the entire sediment compartment, which was identified as a knowledge gap in the Stockton Coastal Management Study Synthesis Report (Royal HaskoningDHV, 2018).

Bluecoast (2020) aimed to be a data-driven study that mapped historical sand movements, with the key drivers of the observed sand volume changes at Stockton Beach being described based on observational data, previous literature, state-of-the-art numerical modelling and coastal knowledge.

The outcomes of this report were intended to be used to inform the Stockton Coastal Management Program (2020), the Stockton Coastal Management Plan (2021) and sound coastal management into the future.

The following previous studies were included in the literature review of coastal processes:

- Littoral drift studies at the entrance to Hunter River in 1966
- Major investigations into sand movements along Stockton Bight, PWD (1977)
- Shoreline data and historic newspaper articles, DWLC (1995)
- Shifting Sands at Stockton Beach, Umwelt & SMEC (2002)
- Stockton Beach Coastal Processes Study, DHI (2006) and associated options assessment (2009)
- Stockton Beach Coastal Hazard Study, WBM BMT (2014)

Bluecoast (2020) acknowledged that the Stockton Beach coastal area is extremely complex and a dynamic natural system with considerable sand movement. A quantified conceptual sand movement model was developed using a sand budgeting approach that was underpinned using the following data:

- 16 historical bathymetric surveys between 1866 and 2018
- Subaerial storages and beach profiles between 1953 and 2020
- satellite derived shoreline change
- LiDAR and previous studies
- Sensitivity analysis to confirm understanding of uncertainty

Bluecoast (2020) outlined the following key findings from their conceptual model and assessment of historical data (Figure 4):

- Stockton Bight shows a net longshore transport of sediment from south to north, with southern Stockton Bight and the Stockton Beach area showing a net erosive trend. It was also noted that the northern beach and dunes of Stockton Bight showed a net gain in sand volumes, with the pivot point for erosion/accretion being about mid-way along Stockton Bight.
- The greatest net northward sand transport rates were found to be adjacent to the Fort Wallace area.
- Observations by Bluecoast (2020) found a long-term deepening of the nearshore and more recent landward re-alignment of the shoreline in the southern embayment between the northern breakwater and Fort Wallace (Stockton Beach).
  - Bluecoast (2020) concluded that this is partly attributed to a significant reduction in the rate of sand bypassing the river entrance due to the construction of the breakwaters and deepening of the navigation channel. The report states that the combination of the breakwater and deep channel represent a physical barrier to natural sand movement, with no natural sand bypassing from Nobby's Beach.
  - This physical barrier to sand bypassing, and the net northward longshore transport along Stockton Beach results in the net loss of sand, or downdrift starvation, from the southern embayment of Stockton Beach.
  - The report estimated that prior to the construction of the breakwaters and deepening of the channel about 100,000m^3 of sand was bypassing the Hunter River entrance, which was the entry point of sand into the Stockton Beach system, see Figure 4.
- Since 2009, Bluecoast (2020) suggested that the sediment supply to southern Stockton Beach has been through natural onshore transport mechanisms, with the supply of this sand coming from the manual placement of dredged sand (~30,000m^3/year since 2009) and from a relic ebb-tide shoal. The report also postulated that as the relic ebb-tide delta has also been deepening, the supply of onshore sediment from this source will likely continue to decrease and result in worsening erosion at Stockton Beach.
- Bluecoast (2020) also identified a second and more persistent pattern of coastal erosion/recession observed along the northern sections of Stockton Bight that is likely inherent to coastal system. The report reasoned that the cause of this was the natural supply of marine sand to the transgressive dune sheet.

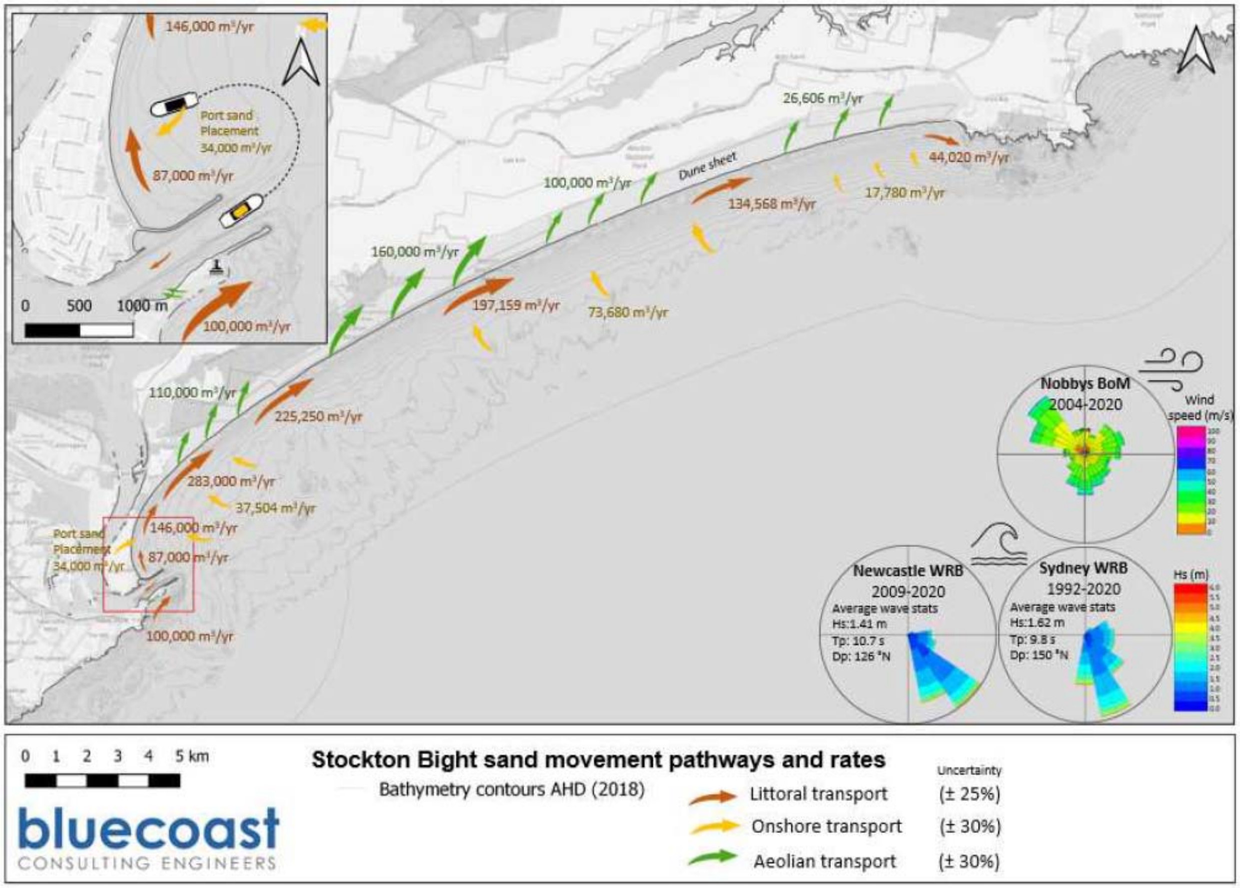

Figure 4: Conceptual sand movement model developed by Bluecoast (2020)

Sub-Aqueous Loss Assessment

The Bluecoast (2020) examined the pattern of sub-aqueous sand loss at Stockton Beach based on changes in seabed levels relative to 2018. The report made the following conclusions from the analysis:

- Analysis of the long-term sand losses supported the claim by Umwelt & SMEC (2002) of a progressively worsening erosion problem at Stockton Beach likely due to starvation of the sand supply from south of the river entrance.
- Erosion of the seabed has predominately occurred on the shallow inshore slope of the ~-8m AHD contour ad upper shoreface at water depths less than 10m (but also out to 15m), likely as a result of longshore transport and with the majority of sand lost to the north.
- Bluecoast (2020) identified that the location for the Port's sand placement operations is dispersive, with the bulk of the sand transport being onshore prior to then moving into the littoral transport system in a net northward direction. However, Bluecoast (2020) acknowledged that there may be secondary transport pathways that could be inferred from the survey data that are dependent on the prevailing wave conditions.
- There is evidence of a sediment pathway from the entrance area to the sand lobe offshore of Nobby's Head, with accretion occurring at this location. The report suggests that the sand lobe may provide a potential source of sand for beach nourishment of Stockton Beach under a 'working with nature' approach to continue the natural flow of sediment transport along the coast.

Assessment of Long-term Sand Loss from Stockton Beach

An assessment of the change in the sand volume of the Stockton Beach area was undertaken by Bluecoast (2020).

- The long-term combined sand loss rate (1988 to 2020) was estimated by Bluecoast (2020) to be 112,000m^3/year, which included 100,000m^3/year from sub-aqueous losses and 12,000m^3/year from sub-aerial losses. The report stated that this rate of sand loss is significantly greater than previous estimates by DHI (2006) and has implications such as chronic and worsening erosion.
  - Since 1866, the average rate of sand loss adjacent to Stockton Beach was estimated to be approximately 76,000m^3/year, increasing to more than 100,000m^3/year since 1988.
  - Between 1985 and 2020, Bluecoast (2020) found that the sub-aerial portion of Stockton Beach (Block A, B &C) had seen an average loss rate of 12,000m^3/year.
- Bluecoast (2020) found that their estimated long-term sand loss rate was consistent with the estimate by Umwelt & SMEC (2002) and disputed the relatively low loss rates estimated by DHI (2006). Bluecoast (2020) also noted that the estimate by Umwelt & SMEC (2002) for the rate of sand loss since 1988 of 370,000m^3/year was excessive.
- Bluecoast (2020) also noted that this sand loss rate accounted for approximately 33,000m^3/year of nourishment dredged from the port entrance that had been placed in the nearshore of Stockton Beach for beneficial reuse and acknowledged that if these nourishment activities were to cease, sand loss rates would be expected to higher (about an additional 33,000m^3/year).
- The report notes that the upper beach volumes above 0m AHD have remained relatively stable since the 1950's, with a significant loss of volume occurring between 2016 and 2020.

Tidal, Fluvial and Circulation Patters

Bluecoast (2020) acknowledged that the complex currents at the site have been well documented in previous studies, including the impacts of the anthropogenic developments. The predictions of the 2-dimensional coastal processes model developed by DHI (2006) were compared against the observed erosion rates and volumetric analysis from recent survey data, with the following conclusions outlined by the report:

- Continued erosion north of the Mitchell Street seawall was supported by the Bluecoast (2020) analysis.
- Accretion along the shoreline in the area immediately north of the northern breakwater was not supported by the Bluecoast (2020) analysis.
- Sand accumulation as a result of sand bypassing north of the northern breakwater was not supported by the Bluecoast (2020) analysis.
- Based on the outcomes of their volumetric analysis of more recent survey data and their sand movement conceptual model, Bluecoast (2020) questioned the validity of the cross-embayment pathways previously predicted by the 2-dimensional numerical modelling undertaken by DHI (2006). The report recommended for the DHI (2006) 2-dimensional numerical model to be revisited based on the latest outcomes of the volumetric analysis and sand movement model by Bluecoast (2020).

Stockton Coastal Management Program, 2020. Royal HaskoningDHV., City of Newcastle.

This document is presented the long-term plan for addressing erosion, shoreline recession and other coastal hazards along Stockton's coastline (specifically between the Hunter River entrance and Meredith Street).

The document acknowledges the existing erosion and shoreline recession present at Stockton Beach, based on the preliminary findings of the Sediment Transport Study within Stockton Bight (2020).

- Sediment transport studies for the full Stockton Bight were underway at the time the program was being developed and expected to be completed in late 2020.
- Targeted analysis from the sediment transport study showed that the ongoing sand deficit rate within the Stockton CMP area is approximately 112,000m^3 / year, which the program acknowledges is significantly higher than previous estimates, and likely to increase with time.
- A probabilistic coastal hazard assessment undertaken based on the findings of the targeted sediment transport study concluded that the Stockton CMP is at high to extreme risk, with public assets at immediate threat and requiring urgent protection, and private assets at threat over the longer term.

4. SUMMARY AND OBSERVATIONS

A high-level summary of previous studies and reports documenting the coastal processes and erosion at Stockton Beach has been undertaken.

The following is the most recent list of the key anthropogenic influences on the coastal processes at Stockton Beach (Bluecoast, 2020):

- 1818
  - Construction commences of the Macquarie Pier, linking Nobby's Head to the mainland.
- 1848
  - Macquarie Pier completed
- 1859
  - Continuous dredging commences to remove mud, sand and surface rock from the Newcastle Harbour and Hunter River entrance
- 1861
  - Commencement of construction of the Private Point breakwater at the tip of Stockton peninsula. Work completed by 1866
- 1875
  - First breakwater extension beyond Nobby's Head. Work completed by 1883.
  - Extension to Private Point breakwater. Work completed by 1896.
- 1898
  - Work commenced on the northern breakwater.
- 1941
  - Dredging of the entrance and harbour increased depths to about 7.5 meters.
- 1952
  - Approximately 1.5 million cubic meters of sediment dredged from the entrance channel.
- 1955
  - Approximately 3.5 million tonnes of sediment dredged from Newcastle Harbour and the lower reaches of the Hunter River.
- 1962
  - Approximately 450,000m^3 of rock and 620,000m^3 of sediment was dredged and largely disposed offshore. Some dredged sand was placed on Stockton Beach via pipeline.
- 1977
  - The Newcastle Harbour approach is deepened to 17.7m, and harbour channels deepened to 15.2m. Works were completed by 1983 and included the removal of about 2 million cubic meters of rock and over 8 million cubic meters of sediment. Dredged material was disposed offshore.
- 1989
  - Rock seawall at Mitchell Street was constructed protecting approximately 600m of shoreward assets in the southern Stockton embayment.
  - "Temporary" geotextile sandbag wall also constructed at the Surf Life Saving Club.
- 2005
  - Maintenance dredging of 153,000m^3 of sand was dredged from the harbour entrance and disposed offshore.
- 2016
  - Rock seawall was constructed at the Surf Life Saving Club protecting approximately 145m of shoreline in the southern Stockton embayment. *(ICM note: this replaced previous "temporary"geobag wall constructed in the 1980's)*

The following key conclusions and insights have been put forward by the past documentation, specifically with regards to the causal factors driving erosion at Stockton Beach.

1. Stockton Beach has been experiencing long-term and on-going seabed erosion and deepening.
    - The offshore seabed profile off Stockton Beach has undergone substantial erosion and deepening since the 1800's (Umwelt & SMEC 2002; DHI, 2006 & Bluecoast, 2020). There is a steady long-term and on-going trend of sand volume loss, deepening of the offshore seabed profile and landward re-alignment of the Stockton Beach shoreline (Umwelt & SMEC, 2002 & Bluecoast, 2020).
    - The majority of the seabed erosion has been observed within the sub-aqueous portion of the beach profile at water depths less than 10m (Bluecoast, 2020). However, deepening of the offshore profile has been observed up to a water depth of 20 meters (Umwelt & SMEC, 2002).
    - The northern section of the Stockton Bight coastline have observed a net gain in sand volumes, with the pivot point for erosion/accretion being about mid-way along Stockton Bight (Bluecoast, 2020).

2. Erosion of Stockton Beach and deepening of the offshore seabed profile is progressively worsening.
    - Umwelt and SMEC (2002) found that the erosion of Stockton Beach and deepening of the offshore seabed profile is progressively worsening. Although this statement was disputed by DHI (2006), Bluecoast (2020) have supported the conclusion of a progressively worsening erosion problem at Stockton Beach, based on their more recent volumetric analysis of long-term sand losses.

3. The majority of sand eroded from Stockton Beach is lost from that section of beach through longshore sediment transport to the north along Stockton Bight.
    - While Stockton Beach is largely influenced by a nett northerly transport of sediment along the Newcastle Coastline that is driven by frequent south-easterly swell conditions. (Umwelt & SMEC, 2002; DHI, 2006; Bluecoast, 2020), episodically, a net southerly sediment transport direction can occur as a result of infrequent north-easterly and easterly swell conditions (DHI, 2006; Bluecoast, 2020).
    - Numerical modelling by DHI (2006) indicated the existence of a counterclockwise re-circulation pattern produced by the sheltering of the breakwaters, and a nodal point where the longshore transport direction reversed, driving sediment transport southward to the breakwater where it may accumulate, re-circulate or be lost into the entrance channel.
        i. The existence of this circulation patter and southward transport model was subsequently discounted by Bluecoast (2020) on the grounds that the predicted accumulation of sand due to the circulation pattern was not apparent in their volumetric analysis of recent survey data. However, they did acknowledge the possibility of sand being lost into the entrance channel and dispersed by ebb and flood tides could be an alternative explanation for the lack of accumulated sand at the southern end of Stockton Beach.
        ii. As an explanation for the observations made from the analysis of recent survey, Bluecoast (2020) postulated that the erosion is being driven largely by a nett northward longshore drift occurring along the entire extent of Stockton Beach, which is in contrast to the predictions of the 2-dimensional numerical modelling by DHI (2006).

4. The observed on-going long-term deepening of the nearshore at Stockton Beach, and landward re-alignment of the shoreline is the result of an interruption of the natural supply of sand through northward littoral drift and sand bypassing of the Hunter River entrance.

- Historically, the supply of sediment to the Stockton beach system was from northward sand bypassing of the Hunter River entrance from south of Nobby's Head (DHI, 2006) (Bluecoast, 2020). Prior to the construction of the breakwaters and deepening of the channel, this bypassing was estimated to be about 100,000m^3/year (Bluecoast, 2020).
- It is well documented that the on-going long-term deepening at Stockton Beach is the result of sand starvation due to the interruption of this natural northerly littoral drift and sand bypassing of the Hunter River Entrance (Umwelt & SMEC, 2002; DHI, 2006; Royal HaskoningDHV, 2018; Bluecoast 2020).
- Bluecoast (2020) reason that the construction of the harbour breakwaters and deepening of the entrance channel represent a physical barrier to natural sand bypassing of the entrance and cessation of sand supply to replenish Stockton Beach (No sand bypassing the port entrance).
- The most recent estimate by Bluecoast (2020) suggested that the long-term sand loss rate from the Stockton Beach system is about 112,000m^3 per year (starvation of sand supply).
- Bluecoast (2020) also noted that his loss rate does not discount the nourishment operations by the Port and that the sand loss rates to Stockton Beach would be expected to be higher if these nourishment activities were to cease.

5. The interruption of the northward sediment supply and sand bypassing of the Hunter River entrance (downdrift starvation) is the result of impacts from the anthropogenic changes to the river entrance, including construction of the entrance breakwaters, deepening of the entrance channel and on-going maintenance dredging of the entrance.
    - The observed changes to the seabed profile at Stockton Beach have occurred over the same time period as the extensive changes to the entrance to Newcastle Harbour (Umwelt & SMEC, 2002).
    - Natural northerly longshore transport has been captured by the Macquarie Pier and southern breakwater to form Nobby's Beach (Umwelt & SMEC 2002; DHI, 2006).
    - It was concluded by Bluecoast (2020) that the long-term deepening of the nearshore and landward re-alignment of the shoreline at Stockton Beach is partly attributed to a significant reduction in the rate of sand bypassing the river entrance due to the construction of the breakwaters and deepening of the navigation channel.
        i. The report stated that the combination of these two factors represent a physical barrier to natural sand movement, with no natural sand bypassing from Nobby's Beach.
        ii. This physical barrier to sand bypassing results in the estimated 112,000m^3/year net loss of sand (downdrift starvation) observed at Stockton Beach (Bluecoast, 2020).

    - A sediment deposition area (sand lobe) has been identified north east of the southern breakwater and Nobby's Beach, representing a sediment trap prior to entering the Stockton Beach system. (DHI, 2006; Bluecoast, 2020).
    - Any sediment bypassing Nobby's Head and the sand lobe is likely to be deposited within the entrance of the Hunter River (DHI, 2006).
    - Sediment deposited into the entrance channel at a depth of over 18m is unlikely to naturally bypass the northern breakwater (DHI, 2006; Worely Parsons, 2012).
    - Natural bypassing of the entrance channel has not been able to be re-established as a result of the regular dredging of the entrance channel to 18m (DHI, 2006; DHI, 2011; BMT WBM, 2017).
    - It was concluded by Bluecoast (2020) that the long-term deepening of the nearshore and landward re-alignment of the shoreline at Stockton Beach is partly attributed to a significant

reduction in the rate of sand bypassing the river entrance due to the construction of the breakwaters and deepening of the navigation channel.

i. The report stated that the combination of these two factors represent a physical barrier to natural sand movement, with no natural sand bypassing from Nobby's Beach.
ii. This physical barrier to sand bypassing results in the estimated 112,000m^3/year net loss of sand (downdrift starvation) observed at Stockton Beach (Bluecoast, 2020).

6. The construction of the northern breakwater, and deepening of the entrance channel, has disrupted the littoral drift and current circulation patterns influencing Stockton Beach.
   - Umwelt & SMEC (2002) claimed that historic survey strongly suggested there was a transport of sand from the nearshore area of Stockton Beach into the entrance channel from the north via a drainage path north of the tip of the northern breakwater. It was postulated that this drainage pathway formed as a result of the disruptions to the circulation patters caused by the northern breakwater.
     i. Although the conclusion made by DHI (2006) claim to not support the existence of a drainage pathway from the Stockton Beach nearshore to the tip of the northern breakwater, DHI (2006) do acknowledge that localised scouring around the tip of the breakwater was certainly possible with their 2-dimensional numerical model predicting transport of sediment around the tip of the northern breakwater and into the entrance channel to the amount of 3,500m^3 per year. This suggests that DHI (2006) do agree with Umwelt (2002) regarding there being a loss of sediment into the channel, but that it is localised to the tip of the breakwater rather than being a clear drainage pathway extending back to the nearshore of Stockton Beach. It should be noted that any sediment dispersed or transported offshore to the tip of the northern breakwater would be expected to be lost into the entrance channel or re-circulated based on the predictions by the DHI (2006) modelling.
     ii. The conceptual model of sand movement developed by Worely Parsons (2012) did not include any removal of sand via a drainage pathway.
     iii. Although Bluecoast (2020) did not indicate an erosion pathway existed from the tip of the northern breakwater and into the entrance channel, they did acknowledge the possibility of sand being transported into the deeper entrance and then dispersed by ebb and flood tides as an explanation for where the sand lost from southern Stockton Beach may be ending up.
   - Numerical modelling undertaken by DHI (2006) suggested that predominant south-easterly swell was found to be diffracting around the port breakwaters to produce a nodal point at the northern end of the seawall at Mitchell Street. At this nodal point, DHI (2006) predicted that the direction of the sediment transport would split into northerly and southerly transport directions. This southerly transport was found to occur regardless of the modelled incident wave direction, and in particular for easterly swell conditions where sediment is transported south to the breakwater and into the entrance channel.
     i. The modelling by DHI (2006) also suggested that the limited wave setup predicted in the sheltered area in the lee of the northern breakwater was inducing an anti-clockwise eddy driving local currents south along the shoreline. It was predicted that this southerly current would produce a slight accretion of sediment immediately north of the northern breakwater (DHI, 2006).

ii. Bluecoast (2020) questioned the validity of the cross-embayment sediment transport pathways predicted by DHI (2006), based on their analysis of sand volume changes using more recent survey data, with the following comparisons made:
   - The accumulation of sand as a result of sand bypassing of the entrance channel predicted by DHI (2006) was not supported by the analysis of recent survey data.
   - The accretion of sediment along the Stockton Beach shoreline immediately north of the northern breakwater was not supported by the analysis of recent survey data.
   - Continued erosion north of the seawall at Mitchell Street was found to be supported by the analysis of the recent survey data.

ii. It should be noted that this does not necessarily invalidate the DHI (2006) model, or the existence of the predicted re-circulation pattern, but rather suggests that there is no apparent accumulation of sand in recent survey as a result of a re-circulation pattern or the sediment transport pathways predicted by DHI (2006).

- Bluecoast (2020) identified that the location for the Port's sand placement operations is dispersive, with the bulk of the sand transport being onshore prior to then moving into the littoral transport system in a net northward direction. However, Bluecoast (2020) acknowledged that there may be secondary transport pathways that could be inferred from the survey data that are dependent on the prevailing wave conditions.

7. Supply of sand to Stockton Beach is a combination of beach nourishment from maintenance dredging of Newcastle Port, and a natural onshore transport mechanism.
   - Initially, the 2-dimensional modelling by DHI (2006) predicted some degree of annual averaged transport of sediment may still bypass the entrance to offshore of the Mitchell Street seawall to supply the Stockton Beach system. However, as this area is north of the predicted longshore transport nodal point, the majority of the bypassing sediment would be expected to be transported northward through longshore transport, with limited or no bypassing sediments supplying the southward transport of sediment to southern Stockton Beach and the breakwater.
     i. Bluecoast (2020) suggest in their more recent conceptual model that the depth and dredging of the entrance channel, and impacts from the breakwaters, now present a physical barrier to any sediment bypassing to supply Stockton Beach (no sand passing to Stockton).
   - Bluecoast (2020) suggest that the supply of sand to the Stockton Beach system is presently through placement of dredged port sands (averaged about 34,000m^3/year) and natural onshore transport mechanisms from the offshore seabed. The following should also be noted:
     i. Without sand bypassing of the entrance channel to supply and replenish the Stockton Beach system, the deepening of the offshore seabed would be expected to continue.
     ii. Beach nourishment from maintenance dredging of Newcastle Port does not fully replace the lost regional sand supply into Stockton Beach that was historically bypassing the entrance, estimated to be about 100,000m^3/year (BMT WMB, 2017; Bluecoast, 2020). It has been acknowledged by Bluecoast (2020) that cessation of these nourishment activities would be expected to result in greater sand loss rates and beach recession.
   - Supply of sediment to the section of beach from the northern breakwater to the Mitchell Street Seawall was predicted by the DHI (2006) model to be through an annual averaged nett southward longshore transport driven by a counterclockwise re-circulation pattern caused by the

breakwaters, with easterly and north-easterly swell conditions also driving southward sediment transport along Stockton Bight.

   i. Although this coastal model had been adopted into subsequent coastal models and management plans (Worely Parsons, 2012; BMT WBM, 2014, Royal HaskoningDHV, 2017), the validity of the numerical model was questioned by Bluecoast (2020) on the grounds that no depositional area for the southward transported sediment could be observed from their volumetric analysis of more recent survey data. Bluecoast (2020) do acknowledge the possibility that this sand may be continue being transported offshore into the deepened entrance and then either dispersed by ebb tide or flood flows or dredged and disposed offshore, not note that existing dredging records don't support this notion.
   ii. It has been suggested by Bluecoast (2020) more recently that the sediment supply to southern Stockton Beach has been through natural onshore transport mechanisms, with the supply of this sand coming from manual placement of dredged sand (~30,000m^3/year since 2009) and a relic ebb-tide shoal. However, Bluecoast (2020) also observed this relic ebb-tide shoal to be deepening, due to interruption of the northward sediment supply, and as a result the onshore supply of sand to Stockton Beach will likely continue to decrease.

8. The short-term erosion risk at Stockton Beach is increasing as a result of the deepening of the offshore profiles.
   - The extent of storm related erosion occurring at Stockton Beach increases from the south to the north as a result of the increased exposure of the beach to offshore swell (DHI, 2006; Bluecoast, 2020). However, Bluecoast (2020) stated that the alongshore distribution of this storm erosion is sensitive to the direction of the swell, with easterly and northerly storms resulting in greater storm erosion demand in the southern sections of Stockton Beach.
   - Bluecoast (2020) noted that there is difficulty in separating the short-term erosion signals from the long-term recession observed at Stockton Beach.
   - Umwelt & SMEC (2002) stated that the offshore storm wave height at Stockton Beach had increased by approximately 2 meters (from 1899 to 2000) as a result of the observed deepening of the offshore seabed profile.
   - As a consequence, Umwelt & SMEC (2002) estimated the potential design storm erosion being 5 to 6 times greater in 2000 than in 1950.

5. CONCLUSIONS

The Stockton Embayment is a very complex coastal system that has had many studies undertaken by previous consultants. These studies have attempted to document, understand and model the historical and on-going coastal processes and changes to the beach. This report includes a summary and critical assessment of the insights gathered from the conclusions made by these previous studies.

On-going Erosion at Stockton Beach

It is clearly the case, and agreed to by each of the previous studies, that long-term coastal erosion and landward re-alignment of the shoreline has been occurring along Stockton Beach to at least about midway along Stockton Bight. This erosion has been occurring from the upper beach face and out to the offshore seabed up to a water depth of 20m, resulting in the on-going deepening of the offshore seabed profile. It is also clear that this erosion is ultimately the result of a severe nett deficit of sand supply to the Stockton Beach system (i.e., more sand is lost from the system than is being brought in to replenish it).

Each of the studies agree that the interruption of the sand supply and resulting starvation of sand to Stockton Beach is most significantly due to the changes to the harbour entrance and port, including:

- Construction of the breakwaters
- Capital dredging to deepen the entrance channel
- On-going maintenance dredging
- Reduction of beach compatible sediments from the river

These changes represent a physical barrier preventing the natural longshore transport of sand that was historically supplying Stockton Beach and the Stockton Embayment, which Bluecoast (2020) estimated was about 100,000m^3/year prior to human impacts. It should be noted that the present sand budget model developed by Bluecoast (2020) assumes that no sand is naturally bypassing the entrance to supply Stockton Beach.

Given the cessation of the historic sand supply to Stockton Beach, the on-going long-term erosion that has been occurring is not considered to be cyclical in nature, and rather should be expected to continue, and most likely worsen as the remaining sources of sand become depleted. This worsening has been observed in recent changes to the seabed profile by Bluecoast (2020) and would be expected as a result of larger waves be able to pass over the deeper eroded seabed. Sea level rise and other impacts due to climate change would also be expected to exacerbate the magnitude of the erosion. Erosion impacts to date due to sea level rise and climate change are difficult to separate from the other causal factors of erosion at Stockton Beach, but are not considered to be significant compared to the major impacts due to changes to the entrance.

Relative Performance of Adjacent Beaches:

In contrast to the erosion occurring at Stockton Beach, the adjacent Nobby's Beach and northern region of Stockton Bight have observed nett growth in sand volumes.

- For Nobby's Beach, the construction of the southern breakwater resulted in the trapping of sediment prior to entering the entrance channel, causing a build-up of sand at Nobby's Beach and formation of a sand lobe. This build-up of sand also suggests sand continues to be supplied to Nobby's Beach from the South.
- For northern Stockton Bight, on-going nett northward longshore transport continues to supply it with sand shifted north from the southern portion of Stockton Bight, including Stockton Beach.

Stockton Beach Coastal Processes and Sediment Pathways

The coastal processes occurring across the Stockton Embayment and habour entrance have been well studied by the previous consultants, in particular:

- Shifting Sands at Stockton Beach. Umwelt & SMEC, 2002
- Stockton Beach Coastal Processes Study. DHI, 2006
- Stockton Bight Sand Movement Study. Bluecoast 2020

DHI (2006) and Bluecoast (2020) both presented conceptual models that attempt to represent and predict what is occurring at Stockton Beach.

- The model developed by DHI (2006) is a 2-dimensional numerical model that is based on inputting site environmental conditions, including wave, tide and bathymetric data, to calculate the currents, waves and subsequent movement of sand across Stockton Beach and the harbour entrance. Predictions regarding erosion and accumulation of sand were then made on the basis of the how sand was expected to be transported.
    - Use known environmental conditions to predict coastal processes and resulting changes to the seabed and beach
- The conceptual model developed by Bluecoast (2020) was based on a volumetric analysis of historical survey data of the beach an offshore seabed profile. Changes to these profiles over time were analysed in the context of site environmental conditions to quantify the movement of sand volumes using a sand budget approach. (Use known
    - Use known changes to the seabed and beach to infer coastal processes in the context of environmental conditions

Although each of these studies agreed that sand is ultimately being eroded and lost from Stockton Beach, there is some disagreement as to exactly how the sand is being eroded and where the eroded sand is being transported to.

Both studies agreed that Stockton Beach is generally influenced by a nett northerly transport of sediment that is driven by frequent south-easterly swell conditions, and that episodically, a net southward sediment transport direction can occur as a result of infrequent north-easterly and easterly swell conditions. However, the models diverge on the coastal processes occurring at the southern end of Stockton Beach.

- The numerical model by DHI (2006) indicated the existence of a counterclockwise re-circulation pattern that was produced by the sheltering effect of the breakwaters. This pattern resulted in a nodal point where the longshore transport direction split, driving sediment both northward to Stockton Bight and southward to the breakwater where it may accumulate.
- The expected impacts of the circulation pattern (accumulation of sand against the breakwater) were not apparent in the subsequent volumetric analysis of seabed and beach survey by Bluecoast (2020) and as an explanation for the observations, they postulated that the erosion is being driven largely by a nett northward longshore drift occurring along the entire extent of Stockton Beach. This is in contrast to the predictions of the 2-dimensional numerical modelling by DHI (2006).

If the predictions by the DHI (2006) model were valid and southerly transport is occurring, but sand is not observed to be accumulating, it then becomes a question of where is the eroded sand being transported to? Umwelt & SMEC (2002) claimed that historic survey strongly suggested there was a transport of sand from the nearshore area of Stockton Beach into the entrance channel from the north via a drainage path north of the tip of the northern breakwater.

- The DHI (2006) model indicated that a volume of about 3,500m^3/year of sand was being lost around the tip of the breakwater and into the entrance channel and acknowledged that localised scour at the breakwater could occur. However, they did not agree with Umwelt & SMEC (2002) regarding a drainage pathway from the nearshore. It should be noted that any sediment transported from the beach and nearshore area out to the breakwater would be expected to be lost or re-circulated under the predictions of the DHI (2006) model.
- Bluecoast (2020) also acknowledged the possibility of sand being lost into the entrance channel, where it is then dispersed by ebb and flood tides but discounted it on the grounds that dredge survey data did not support it.

Transport and loss of sediment into the entrance channel, in addition to re-circulation of sediment at the nodal point where it may then be transported north through longshore transport, may provide an alternative explanation that reconcile the predictions by DHI (2006) and the volumetric analysis by Bluecoast (2020). However, further research into the localised coastal processes north of the breakwater, offshore and along Stockton Beach is required to confirm the validity of each explanation.

Beach Nourishment and the Need for Action

In recent years, dredged port sands have been placed offshore of Stockton Beach to help supply sand and offset the sand deficit. Even with this, estimates by Bluecoast (2020) suggest that the rate of sand lost from Stockton Beach is about 112,000m^3/year. Without action, the nett deficit of sand supply to Stockton Beach and on-going long-term erosion is expected to continue, and likely progressively worsen.

- Limited options to manage the erosion have been investigated, including increasing the volume of beach nourishment to reduce or balance the deficit of sand supply.
- An assessment of the available practical options to manage the on-going erosion needs to be considered.
- Given the clear interaction of the harbour infrastructure with the coastal processes, the port, including both the Lease Holder and Owner, needs to be involved with any proposed solution.
- Solutions need to be practical and robust to account for the variability and uncertainty in the complex coastal processes and conceptual models developed in previous studies.

In addition to considering robust and practical solutions that can account for the uncertainty in the DHI (2006) and Bluecoast (2020) conceptual models, a clear understanding of the sediment transport direction and where eroded sand is being lost to for southern Stockton Beach and around the northern breakwater is critical for the design of any solution to manage the long-term erosion, in particular for nourishment programs, groynes and seawalls.

6. REFERENCES

Allery, C., 2010. Selection of the Preferred Management Option for Stockton Beach - Application of 2D Coastal Processes Modelling. Presented at the NSW Coastal Conference, p. 15.

Bluecoast, 2020. Sediment Transport Study within Stockton Bight.

BMT WBM, 2016. DHA Stockton Rifle Range Stockton Beach Coastal Engineering Assessment (Coastal Engineering Assessment No. R.N20693.001.00). BMT WBM, Stockton Beach.

BMT WBM, 2014a. Newcastle Coastal Zone Hazards Study Final Report.

BMT WBM, 2014b. Newcastle Coastal Zone Management Study Final Report (Coastal Management Study No. R.N2051.002.01). BMT WBM, Newcastle.

City of Newcastle, 2018. Newcastle Coastal Zone Management Plan - Stockton (Draft Management Plan No. 2018–21). City of Newcastle, Stockton.

DHI, 2006. Stockton Beach Coastal Processes Study (Sediment Transport Analysis and Description of On-going Processes No. 50258). DHI Water & Environment.

Nielsen, L., Munro, K., Panayoyou, K., Potter, M., 2011. Stockton Beach Sand Nourishment Scoping Study. Presented at the NSW Coastal Conference 2011.

Royal HaskoningDHV, 2020. Stockton Coastal Management Program (Coastal Management Plan). Royal Haskoning DHV, Stockton.

Royal HaskoningDHV, 2018. Stockton Coastal Management Synthesis Report (No. PA1417M&ARP1809061620). Royal Haskoning DHV.

Savioli, J., 2007. A State-of-the-Art Modelling Approach to Assess Coastal Processes at Stockton Beach.

Umwelt, 2003. Newcastle Coastline Management Study (Coastal Management Study No. 1411/R02/V4). Umwelt Environmental Consultants.

Umwelt & SMEC, 2002. Shifting Sands and Stockton Beach (Coastal Processes Study No. 1411/R04/V2). Umwelt Environmental Consultants.

WorleyParsons, 2012. Stockton Beach Sand Scoping and Funding Feasibility Study.