Government of South Australia
Department for Environment and Water

IMPACT ASSESSMENT (PHASE 2) OF MOVING SAND FROM ADELAIDE'S NORTHERN BEACHES

Prepared by Salients and Coastal Environment
for the Department for Environment and Water

9th July 2021

Salients

Coastal Environment

Impact Assessment (Phase 2) of Moving Sand from Adelaide's Northern Beaches

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1 Introduction

1.1 Scope of This Assessment

Salients and Coastal Environment were jointly engaged by the Coast and Marine Branch of the Department for Environment and Water (DEW), to:

- Review background information relating to a proposed extension to sand transfer infrastructure along the northern beaches of metropolitan Adelaide and to provide an independent review on coastal engineering and some environmental aspects of the project.
- To revisit, assess and discuss the assessment of surveyed beach profiles undertaken by others, including extension of the assessment to include more recent survey profiles.
- To provide a (mostly) qualitative impact assessment discussing likely impacts on sand movement and other ecological and social impacts.
- To assess and advise on the strategies that might be adopted to mitigate any risks associated with Phase 2 of the beach nourishment as proposed.

Our study has relied on existing information and data as provided by DEW. This includes historic beach profiles through the relevant area from West Beach boat harbour to North Haven.

We have reviewed reports relevant to the present day understanding of the beach behaviour. The most relevant reports were:

"Adelaide's Living Beaches. A strategy for 2005 to 2025" Department for Environment and Heritage, December 2005.

"*West Beach Coastal Processes Modelling. Assessment of Coastal Management Options*" DHI, August 2018.

"*Impact Assessment of Moving Sand from Adelaide's Northern Beaches – Phase 1 Assessment: 2020-2021 Sand Movement*" Report by Water Technology, December 2020.

To fully understand these reports it was necessary to refer to several other (mainly earlier) reports on the area. All reports used are listed in the reference list to this report.

1.2 Summary of Proposed Pipeline Extension

The current assessment is concerned primarily with "Phase 2" of the overall project, involving the construction and subsequent operation of a sand pipeline extending from areas within Adelaide's northern beaches where sand is accreting over time, to the areas further south, such as West Beach, which are now eroding. Section 1.4 provides more discussion on the interim measures being undertaken as "Phase 1" of the project.

DHI (2018) estimated an ongoing annual sand deficit of around 100,000m^3/year as the main cause of present day erosion at West Beach. They also estimated a cumulative total deficit in this section of the beach, since construction of the boat harbour in the late 1990s, to be 500,000m^3 and advised that the deficit was increasing over time following cessation of mass beach nourishment which occurred up until the late 1990s. With the absence of mass beach nourishment, northerly sand transport past the Patawalonga entrance and West Beach boat harbour has reduced. In the absence of substantial beach nourishment, DHI advised that West Beach will continue to erode, and that the erosion will likely extend further along the beach past the Torrens entrance towards Henley and Grange.

The advantages of a permanent pipeline are primarily that it will enable a quicker response to erosion problems as they occur, reduce ongoing costs, reduce the impact on resident and beach users and provide flexibility in responding to beach management issues.

At the time of writing, the final pipeline route had not yet been determined. However, a preliminary online map for engagement with the project's community reference group[1] indicated the following route:

West Beach to Henley Beach South: The pipeline is to commence from the existing pipeline just to the south of the Torrens River and will be buried beneath the sand underneath the Torrens River and the dunes of South Henley Beach, before crossing to be within the road reserve (footpath) around Lexington Road.

Henley Beach South to Henley Beach: North of Lexington Road, the route continues beneath the footpath, before crossing to be below the road pavement of the Esplanade, to the north of South St. The pipeline route continues below the grassed reserve landward of Henley Beach Jetty, and then below the western footpath of the Esplanade.

Henley Beach to Terminus St, Grange: To the north of Marlborough Street, the route continues below the pedestrian accessway on the seaward side of properties along

[1] https://sagov-env.maps.arcgis.com/apps/webappviewer/index.html?id=9a0bc7fd2b364b3db8cf2afae1fa8aa5 Accessed 06/07/2021.

Seaview Road, crossing to sit below the landward edge of the dunes some 100m south of Reedie St. The route continues below the rear end of the dunes, underneath Grange Jetty until it reaches Terminus St, where it crosses the dunes to continue northwards below the beach berm.

Grange to West Lakes: The route continues for some distance through Grange and past Tennyson, except where it diverges to pick up a proposed pumping station/discharge point at the end of Moredun Street, until it again crosses in front of properties along Cormorant Court, West Lakes, to sit to the rear of the dunes, northwards to Third Avenue.

West Lakes to Semaphore Breakwater: To the north of Third Avenue, the route continues below the eastern footpath of the Esplanade for one block before crossing again to sit below the dunes to the rear of the beach. The route remains below the rear of the dunes, continuing north to its proposed termination point, in the lee of the Semaphore Breakwater, at Bower Road.

Formalised sand collection points were indicated at the following locations:

- End of Bower Road, Semaphore.
- End of Terminus Street, Grange.

New discharge locations were indicated at the following locations:

- Mirani Court Reserve, West Lakes.
- Moredun Street Beach Reserve, Tennyson.
- South of Lexington Road, Henley Beach South
- An additional discharge point in the Rockingham Dunes (from the existing pipeline).

Pumping stations are proposed at the following locations:

- Bower Road, Semaphore.
- Mirani Court, West Lakes.
- Moredun Street, Tennyson.
- Terminus Street, Grange.
- South of Henley Beach Road.

1.3 Key Concerns

It is understood from DEW's community engagement processes that concerns have been expressed about the longer-term impacts of the proposed sand pumping system, particularly near the intake locations where sand is being removed from the beach. Those concerns generally relate to perceptions that there could be:

- A loss of usable beach width and potential reduction in the width of dunes.
- Impacts on recreational use of the beach.
- Aesthetic impacts.
- A smaller buffer against erosion during storms.

Other concerns revolve around the actual methods of construction and their impact on the dunes, parkland and beach front infrastructure, plus whether the strategy will prove effective in the long term with ongoing sea level rise and a reduction of sand coming into the system from the south. Construction related impacts will be addressed as part of the development assessment process.

1.4 Phase 1 Works

The Phase 1 works covered operations in 2019/20 (121,000m^3) and 2020/21 (110,000m^3) include the immediate movement of some 120,000m^3 of sand from between Semaphore Park and Largs Bay to renourish West Beach to the north of the boat harbour. The sand is being sourced from the beaches and then trucked from the Semaphore Surf Club exit to West Beach. The works are shown schematically in Figure 1. Relocation from Adelaide's northern beaches to its southern beaches in this manner has occurred form many years.

The Phase 1 works were being executed during preparation of the present report, as a precursor to the proposed Phase 2 pipeline construction.

The Phase 1 works were required as an interim measure before the Phase 2 pipeline construction, and to refine the collection methods (depths of scraping, location of extraction). The works also provided an opportunity to monitor the impact of sand sourcing and placement.

Concerns reported regarding interim replenishment program included:

- Concerns of residents that the removal of large quantities of sand from the beaches to the north will erode and/or make those coastal sections vulnerable.
- Concerns that the interim replenishment program will become an accepted management approach.

- The interim replenishment program does not add sand to the beach system and is a stop gap measure only.
- That controls on the rate and frequency of removal may prove ineffective in preventing the condition of beach from degrading.
- Impacts of trucking will damage beach infauna and flora with unacceptable environmental consequences.
- Concerns as to the rate of beach recovery at the source location.

Figure 1 Scope and Nature of "Phase 1" works[2]

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[2] From: https://www.environment.sa.gov.au/topics/coasts/managing-adelaides-beaches/adelaide-beach-works#carting-semaphore-west-beach-henley-beach, accessed 17/05/2021

2 Snapshot of Coastal Processes Understanding

DEW regularly surveys beach profiles along the Adelaide coast. There is now a reliable, and invaluable, long term survey dataset of beach profiles dating back about 50 years. The data have been used to inform beach management and validate modelling and coastal management decision making, including the Holdfast Shores development and the West Beach boat harbour design and construction over 20 years ago.

The *Adelaide's Living Beaches* report (Department for Environment and Heritage, 2005) was adopted in 2005 with the intention of implementing a process-based approach to managing the city coastline. This was effectively an upgrade of the management approach at the time to be more structured and to reduce costs through efficiency.

Adelaide's metropolitan coastline from Kingston Park to North Haven was divided into 7 beach cells, largely bounded by artificial works that had affected the natural sand movement along the coast. Each of the cells was to be managed separately with sand recycling and/or minor replenishment. In addition, the strategy included enhanced structural protection of some sections of the coast where significant assets were deemed at immediate risk. The individual cells and the net potential alongshore sand transport rate assessed at the time are shown in Figure 2. It is worth noting that no reduction in the potential transport rate was indicated to the north of the Patawalonga entrance nor at West Beach boat harbour in Figure 2. In this region the modelled potential transport was shown as "uncertain".

The report assessed the potential sand transport rate as reducing from a maximum value of 50,000m^3 to 100,000m^3/year at Kingston Park and Brighton to 0m^3/year at North Haven. The net sand transport rate was steady (or reducing slightly) across the West Beach cell from the West Beach boat harbour to the Torrens River outlet, suggesting a stable beach with a net sand transport rate of around 50,000m^3/year. The overall sand transport curve, assuming a sufficient sand supply was available, suggests a stable to accreting shoreline through the Adelaide beaches as the sand transport rates decrease. Areas of maximum accretion were assessed south of the Patawalonga entrance and extending from north of Semaphore to North Haven.

The sediment transport processes at West Beach were reassessed by DHI (2018), incorporating improved modelling techniques and a longer data set of detailed beach behaviour data. Their conclusions, based principally on the available beach change data were:

- There has been negligible natural sand bypassing around the West Beach boat harbour since its construction.

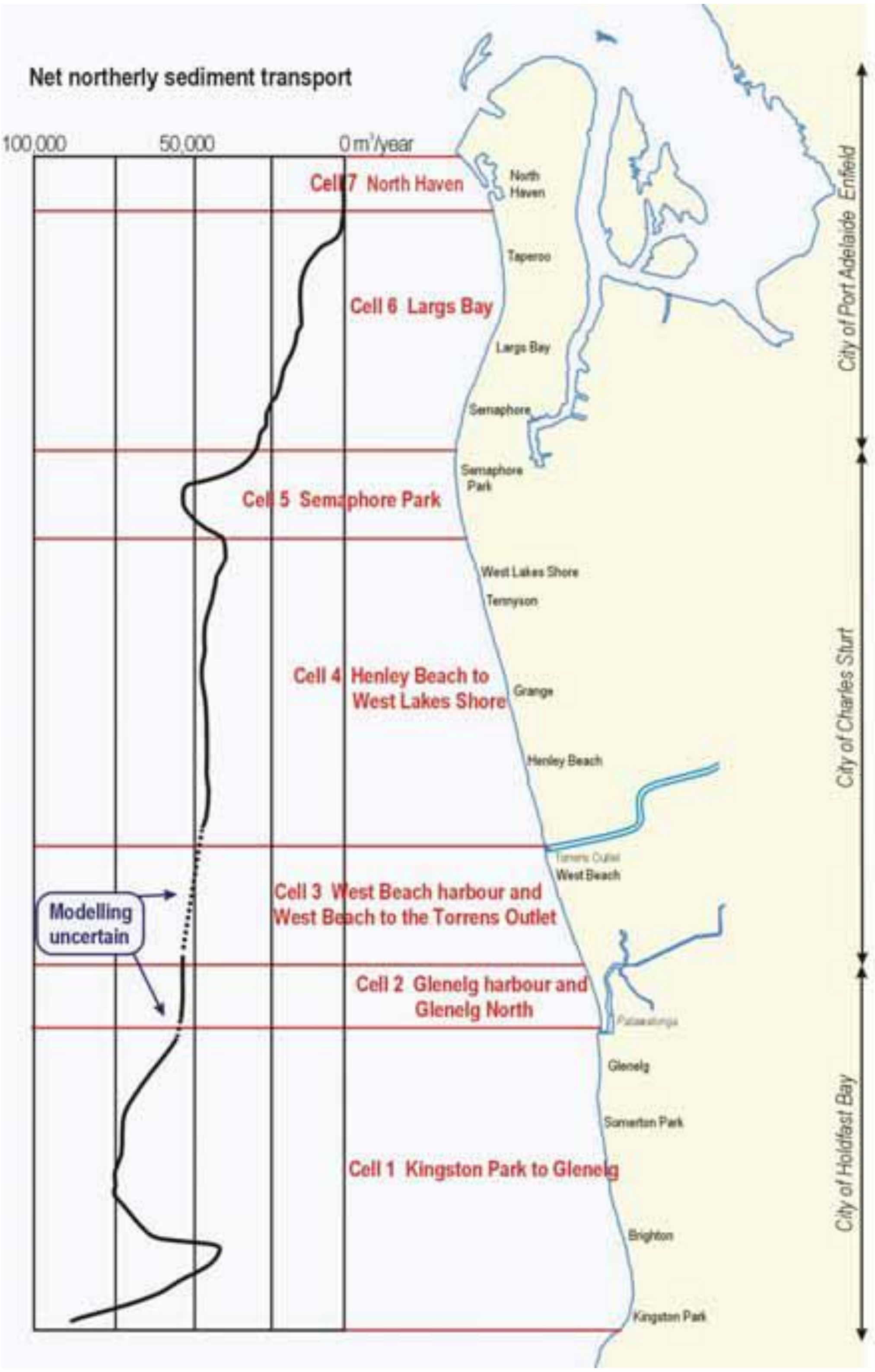

Figure 2 The Rationale for Adelaide Beach Management showing Alongshore Sand Transport Rates and the Location of Individual Beach Cells, Adapted from (Department for Environment and Heritage, 2005)

- There are minimal losses of sand offshore, with the predominant movement of sand being alongshore, to the north, under wave action.
- The estimated annual rate of alongshore sand movement through the West Beach cell is between 50,000 to 150,000m^3/year.
- The West Beach sediment cell has lost around 500,000m^3 of sand since the late 1990s and this loss rate has accelerated since approximately 2011. Sand erosion is occurring from the West Beach cell, and to a lesser extent within the Henley Beach cell, with that sand eventually accumulating in the northern most sediment cells at the end of the alongshore drift system at North Haven.

3 Assessment by Others

3.1 Available Monitoring Data

Files containing beach profile data were provided by DEW. The data comprised 38 profiles collected between 1975 and 2021, covering the area from West Beach to North Haven. The profiles are predominantly spaced around 500–800m apart, with the exception of the more closely spaced profiles along West Beach, and begin at fixed survey marks which are shown in Figure 3 for profiles from North Haven to the Torrens Outlet (beach management cells 4 to 7), and in Figure 4 for profiles south of the Torrens Outlet to the West Beach Harbour (cell 3).

The profiles typically extend to around 1km offshore but extend up to 2 to 5km offshore at some locations in more recent years. Most profiles have been surveyed annually, typically within the first three months of the year. However, there are notable exceptions and particular years when data are not available. The date ranges of available survey data for the profiles in each management cell are tabulated in Appendix A .

From Figure 3 and Figure 4, spatial distribution of profiles can be seen to vary significantly along the coast. The profiles provide a complete but variable coverage of the coastline of interest to this study. The variable spacing of the profiles is based on known past issues with erosion. As discussed below, this causes some issues when dates are missing and/or profiles available for a certain date are too widely spaced.

Despite occasional limitations, the data set remains invaluable to managing Adelaide's metropolitan beaches and collection should continue.

Figure 3: Beach Profile Locations - North Haven to the Torrens Outlet

0 0.5 1 1.5 2 2.5 km
APPROX SCALE

Adelaide Northern Beaches Impact Assessment

REV	DRAWN	CHECK
A	EN	DJW

Salients

GIS File: "Z:\BusinessShare\Them\Projects\P00121_AdelaideNorthernBeachesImpactAssessmentPhase1\GIS\BeachProfiles.qgz"

Figure 4: Beach Profile Locations - Torrens Outlet to West Beach Harbour

0 0.15 0.3 0.45 km
APPROX SCALE

Adelaide Northern Beaches Impact Assessment

REV	DRAWN	CHECK
A	EN	DJW

Salients

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3.2 Previous Analyses

Prior to updating and interpreting the analysis of these profiles to include the past few years, we have reviewed key reports, as provided by DEW, which outline previous work undertaken to examine ongoing loss of sand from Adelaide's beaches and overall patterns of alongshore transport, accumulation of sand and erosion.

Three documents have been reviewed, namely:

- *Adelaide's Living Beaches. A Strategy for 2005 to 2025. Technical Report* (Department for Environment and Heritage, 2005).
- *West Beach Coastal Processes Modelling. Assessment of Coastal Management Options* (DHI, 2018).
- *Impact Assessment of Moving Sand from Adelaide's Northern Beaches - Phase 1 Assessment: 2020-21 Sand Movement* (Water Technology, 2020).

An introduction to the key findings was provided in Section 2. The key findings from these reports, particularly in relation to the comparison of the surveyed coastal profiles to interpret erosion and accumulation of sand at different locations along coast, are described in turn in the following sections.

3.2.1 Department for Environment and Heritage, 2005

This technical report associated with the *"Adelaide's Living Beaches"* project (the ALB report) was provided by DEW to the study team for background review. We understand it to be a comprehensive summary of the analysis completed by 2005 and scientific understanding of Adelaide's beaches at the time.

At the outset, the report notes that Adelaide's coastline has been highly managed, at least since 1973. If Adelaide's beaches are not actively managed, they will begin to disappear. The predominant direction of sand transport along the beaches is from south to north. Subsequent management of that sand by 'recycling' the sand accumulating at the northern ends of the beach system (Semaphore to North Haven) by transporting it back and placing it on more southerly beaches is a common management strategy adopted by the South Australian government.

In addition, management of Adelaide's beaches had historically involved nourishment using sand dredged from offshore areas not part of the alongshore sand transport system of the metropolitan beaches of Adelaide.

The strategy proposed was noted as being flexible to meet the needs of sand lost from different areas due to alongshore transport or during storms. The strategy had been reviewed several times and found to be appropriate, although historical offshore sources of sand had been 'exhausted' by the late 1990s and the loss of this sand source seems to have had a marked effect on the beaches in the past two decades.

Alongside ongoing replenishment and recycling of sand, and construction of coastal structures, the *ALB* strategy includes an aim to:

> "*Maintain the necessary sand dune buffer along the metropolitan coast to provide protection for two 1 in 100-year average return interval storms*" (including an allowance for one metre of future sea level rise)
>
> and
>
> *"Sand dune volumes and beach widths were to be used as management performance indicators."*

The ALB report noted that the principal ways to analyse profile data was to calculate the volume of sand down to a certain depth. Storm erosion values are commonly expressed as a volume of sand lost above 1.0m AHD. Beach widths normally consider the width of the dry sandy beach (down to -0.152m AHD, which is the neap high water mark).

The *ALB* strategy divided Adelaide's metropolitan beaches (from Kingston Park to North Haven) into seven separate 'cells' (see Figure 2). For this assessment, we are interested in the five northernmost cells, stretching from West Beach Harbour to North Haven as follows:

- Cell 3: West Beach Boat Ramp and Harbour to the Torrens Outlet
- Cell 4: Torrens Outlet to West Lakes, including Henley Beach South, Henley Beach, Grange, Tennyson and West Lakes
- Cell 5: Semaphore Park, around which the shoreline direction changes from a south westerly to north westerly facing orientation.
- Cell 6: Largs Bay, Including Semaphore, Largs and Taperoo
- Call 7: North Haven, including the area to the north of North Haven Marina and the breakwater for the Port of Adelaide.

The ALB report notes that there are limited natural external sources of sand to the beach system (e.g., from rivers and creeks, or onshore transport, by waves, from offshore). Accordingly, sand which erodes from one location is transported alongshore where it may accumulate or subsequently move further alongshore.

While the dominant natural sand movement is alongshore from south to north, waves can also move sand both offshore and onshore, during and following storms. The ALB report notes that the extent of significant offshore-onshore transport is understood to be at around -5m AHD.

Once sand is on the dry part of the beach, wind can lift and carry sand further landwards, building up the sand dunes that exist behind the beach. The subsequent establishment of vegetation helps to further stabilise those dunes and impedes further landward movement of the sand by wind.

In Adelaide, herbs and grasses help to colonise and trap sand within the foredune above around 2m AHD. However, tides and storm surge can undercut the foredune or exceed 2m AHD, removing vegetation from the dune. The process of dune building is long term while the storm erosion/inundation reversing those gains may occur in a very short period.

Vegetation establishes more permanently at heights of greater than 3m AHD. These higher parts of the dune can still be reached by storm tides or undermined if the shoreline recedes far enough.

The ALB report presents a variety of different analysis methods for the surveyed profiles. We note the earlier requirement for "*sand dune volumes*" and "*beach widths*" to be used as key management performance indicators. Considering the reports discussed in more detail below, we note that subsequent analyses seem to have diverged from this. The beach volume/width is a measure at a point in time of the cumulative impact of all coastal processes and anthropogenic activities on the beach state. These two indicators make a great deal of sense:

- *Beach width*, say between mean neap high water and the start of the dune (at around ~2m AHD) is a good indicator of the available space on the beach for use by the public.
- *Sand dune volume* is a sensible measure of the available 'store' of sand available to meet storm demand at a given location. Sand scraped from the beach as part of recycling/relocation activities (either by subsequent trucking or pumping via pipeline) will reduce the sand volume present across the beach face and berm at the 'borrow site'. However, standard operation practices for these operations avoid any excavation from the dune itself. This means that the volume stored in the dune remains as a buffer against storms and the intention is to leave enough sand to buffer against two 1 in 100-year storms. The ALB report indicated that a design dune buffer volume (above 1.0m AHD) of 80m^3/m was adopted at the time compared to the maximum modelled erosion from eight severe historical storms at several locations as follows:
    - West Beach Dunes: 35m^3/m
    - Tennyson: 23m^3/m
    - Tennyson Dunes: 20m^3/m
    - Semaphore Park: 18m^3/m

- Semaphore Jetty: 13m³/m

Examples of analyses of use to management are presented below:

- Figure 5 shows a variety of volume change analyses completed during an earlier report by the state government's Coastal Management Branch. This is useful in understanding where the erosion has been more severe and helps to potentially predict how areas may be expected to evolve in future. However, additional analyses are required to assess whether, for example, there remains an adequate storm buffer to withstand erosion.
- Figure 6, which shows how much beach width has changed over time along the Adelaide coastline. Again, it is useful in looking at past patterns and to project change into the future but does not identify critical locations where beach width is less than a required target value for management.

In comparison, the calculation of alongshore transport rates, as may be determined by modelling completed by Coastal Engineering Solutions are presented in Figure 7.

Alongshore transport rates are perhaps less useful from a responsive management perspective but provide some additional engineering insight relating to the underlying driving processes. If alongshore transport rates reduce in a downdrift direction (northerly in the case of Adelaide's beaches), depositional processes would be expected to dominate. Conversely, if they increase in the downdrift direction, erosion is expected to dominate.

Net alongshore transport rates change from year to year, depending on wave and current conditions, and as the alignment of the shoreline adjusts. For example, if a beach rotates to be more perpendicular to the typical wave climate, generally transport rates will reduce. The rate estimates are sensitive to assumptions regarding calibration parameters and not necessarily time-based measurements. These parameters are generally calibrated to a limited period and may not reflect the actual values at a particular future point in time.

The underlying conditions may vary over time as the beach evolves and sea level changes (e.g., grain size, inshore wave angle, breaking wave height etc). Mental gymnastics are required to effectively interpret charts of alongshore transport to appreciate the real-world measures that need to be addressed for management (e.g., beach width or ongoing changes to the volume of sand on the beach (including changes that occur underwater).

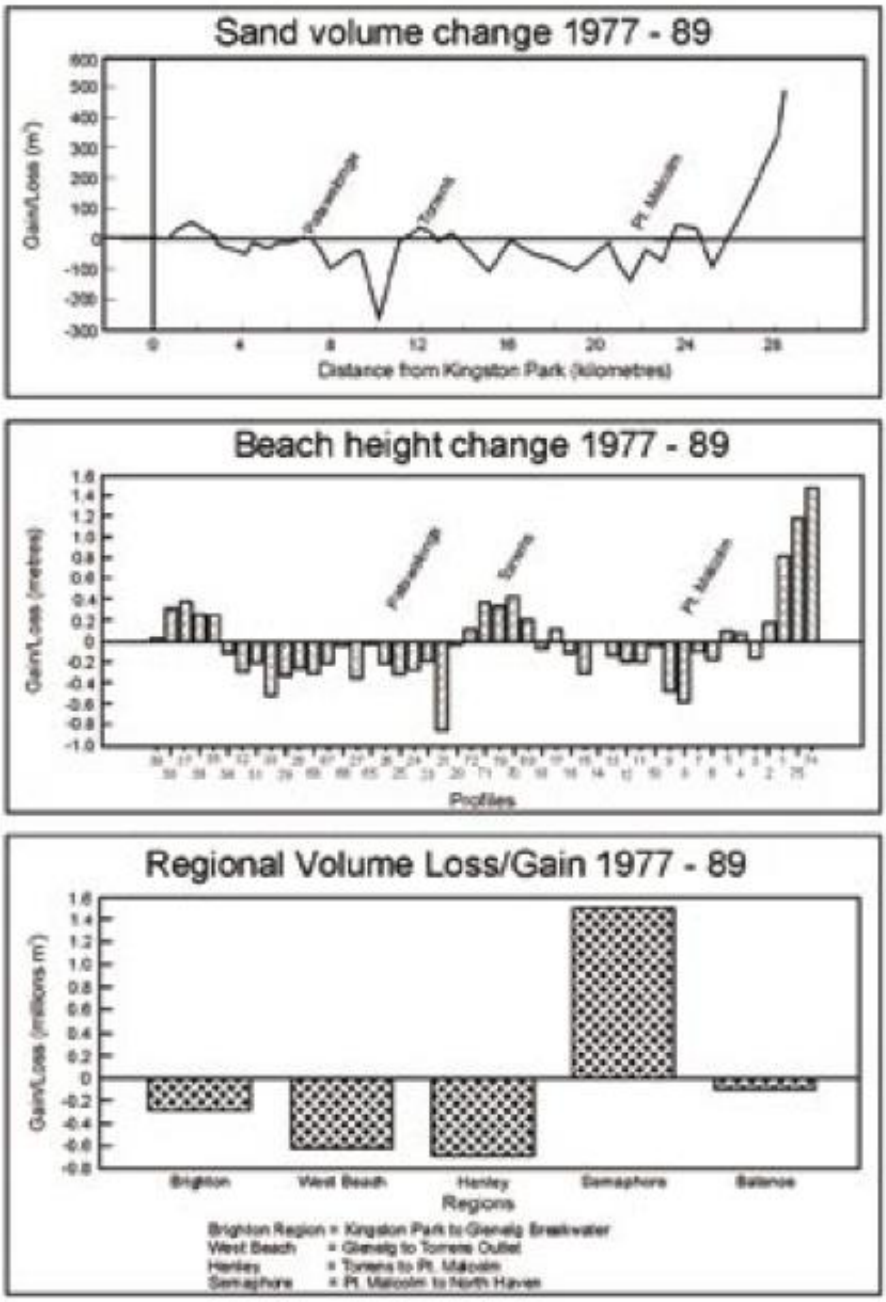

Figure 5 Example of Volume Change Analyses: 1977 - 1989 (from Department for Environment and Heritage, 2005)[3]

[3] Sourced from an earlier report by Coastal Management Branch 1992, *Review of Alternatives for the Adelaide Metropolitan Beach Replenishment Strategy, Department of Environment and Planning, Adelaide*

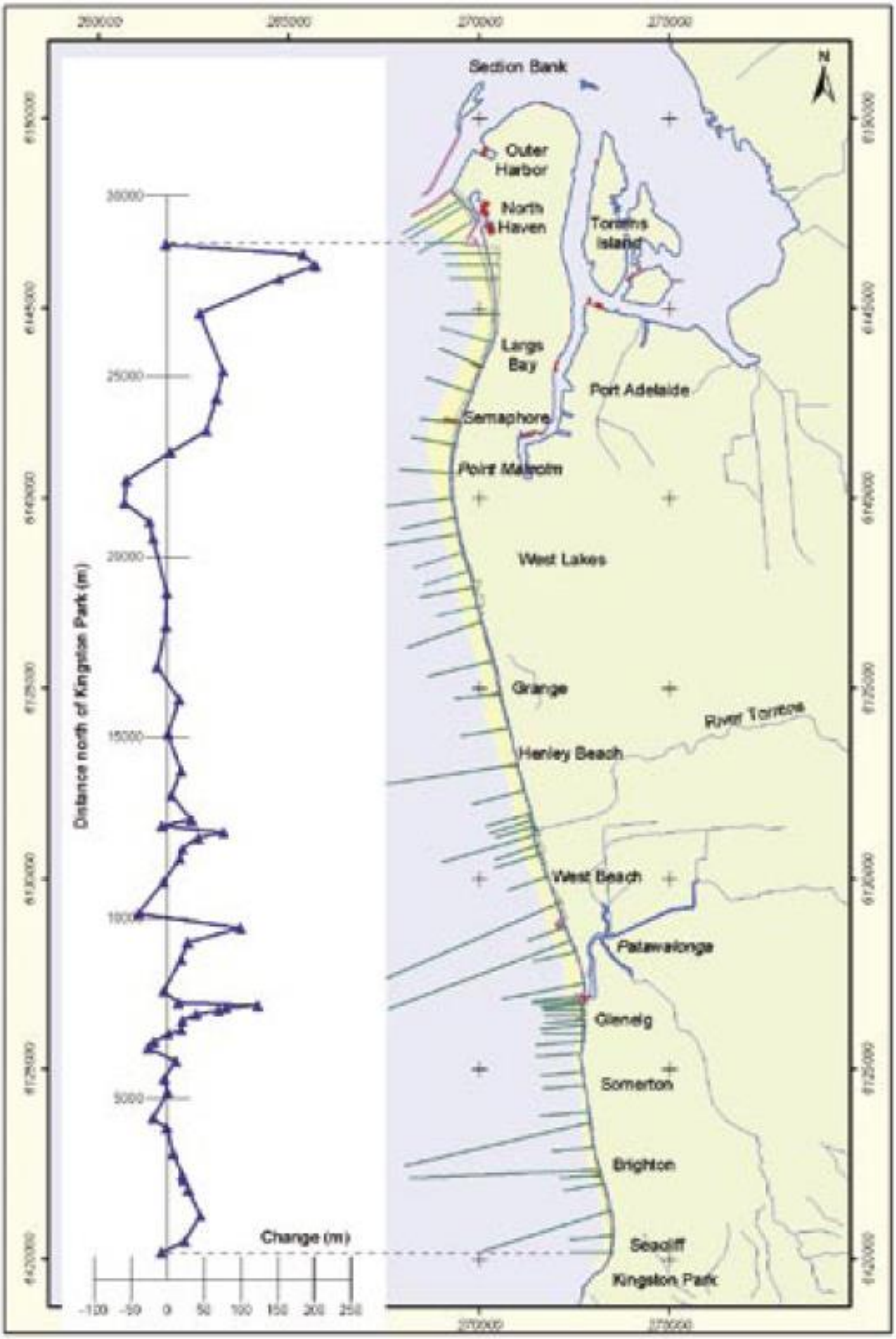

Figure 6 Example Consideration of Historical Change of Beach Width 1975-2003 (from Department for Environment and Heritage, 2005)[4]

[4] Sourced from background study: Coastal Engineering Solutions 2004, *Coastal Processes Study of Adelaide Beaches, prepared for the Department for Environment and Heritage, Adelaide.*

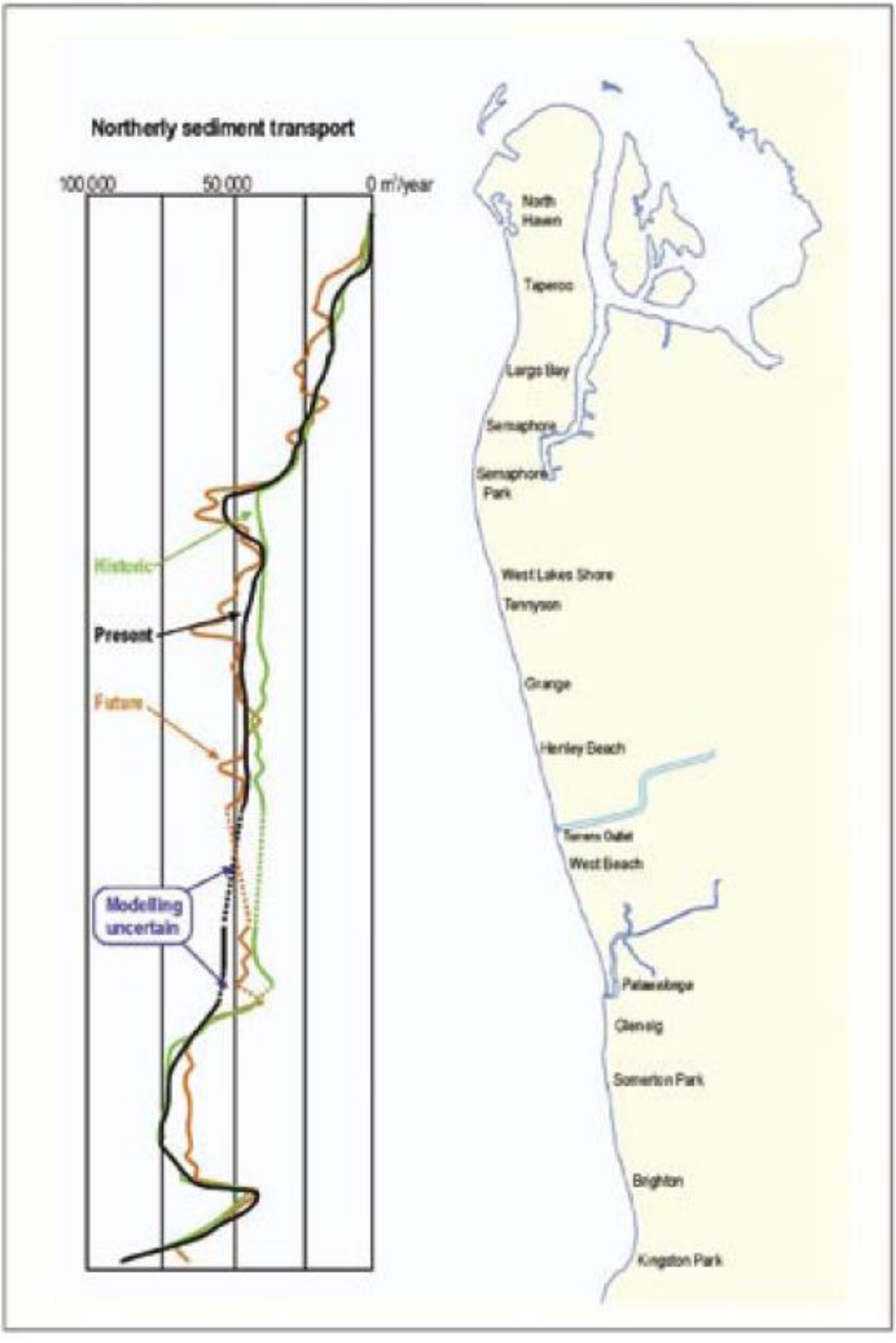

Figure 7 Example of Estimated Alongshore Sediment Transport Potential (from Department for Environment and Heritage, 2005)

3.2.2 DHI, 2018

DHI's investigation was mostly focussed on ongoing erosion of the West Beach sediment cell, stretching from the West Beach Boat Harbour to the outlet of the Torrens River. The West Beach SLSC is located around midway along this 2.4km stretch of coast, behind a rock revetment wall of some 600m length.

DHI noted that there is now limited natural sand supply from the south, and that this has been further intercepted by the construction of Holdfast Shores and the West Beach Boat Harbour (aka 'Adelaide Shores'). DHI highlighted the uncertainty in prior modelling undertaken for the ALB strategy which assessed a net alongshore transport rate of around 55,000m^3/year.

In 2012, a pipeline was commissioned to enable back passing of sand from the Torrens outlet to the southern end of West Beach. In the years preceding DHI's report (2011-2017), they advise an average of around 55,000 m^3/year was back passed by the South Australian government through this pipeline, yet the shoreline between the West Beach Boat Harbour and the West Beach SLSC continued to erode, losing around an additional 60,000 m^3/year on average while the back passing was occurring.

DHI further examined long term changes within the active beach system by comparing bathymetric surveys from 1990 and 2017 (between -5 and +5m AHD). They found that there had been an overall cumulative loss of around 440,000 m^3 from the West Beach cell over that time. Using alternative, but comparable analyses of the long term surveyed profile record, they calculated a loss of some 300,000 m^3 over the same period (1990 – 2017). For their analysis, they applied the following constraints on profiles:

- If a profile did not extend below -5.0m, it was excluded from the calculation.
- If a profile did not extend above 0.0m, it was excluded.
- Due to different timing of different surveys, volumes for each profile were interpolated to January 1st each year.
- Some copying of profiles in space was undertaken to better represent the actual variation in profiles. For example, where there was a discontinuity at a boat harbour.

The surveyed profiles vary somewhat substantially in the extent surveyed at different times and the timing during the year. The impact of the manipulation and exclusion of profiles from the calculation by DHI on the estimated loss of sand from West Beach remains uncertain and these changes may explain the differences between the estimates between the two methods. There may be similar 'errors' introduced in the calculated loss of 60,000 m^3/year between 2011 and 2017. We have revisited this key estimation to check for veracity in Section 4.1. The results of DHI's assessment are presented in Figure 8.

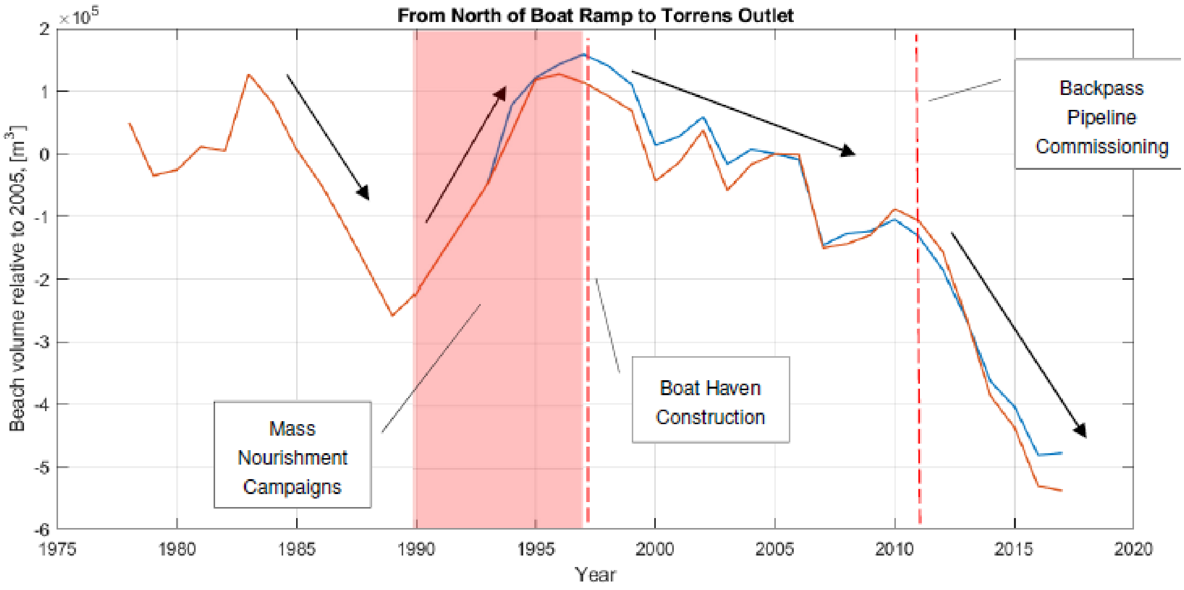

Figure 8 Calculated Change in Volume within the West Beach Cell from -5m AHD to 5m AHD (from DHI, 2018)

It is difficult to quantify and attribute the impacts of different past management strategies, although the cessation of large-scale importation of sand from offshore sites, and the construction of the West Beach Boat Harbour and the Holdfast Shores Marina during the late 1990s, seem to be key factors in the more recent observed erosion of West Beach.

Regardless, the most recent period (the last decade) is the most useful in projecting how this cell may behave in the short to medium term. DHI argue that the ongoing erosion of average 60,000m^3/year, when combined with the average annual backpassing of 55,000m^3/year, indicates a net potential alongshore transport rate of 115,000 m^3/yr. (averaged since 2011). If their analysis is adopted and, taking the assumption that there is a minimal infeed of sediment from the south, it is reasonable to expect that a deficit of around 115,000 m^3/year of sand is felt at the southern end of West Beach and that this deficit needs to be managed if the beach is to be prevented from receding/realigning. With no sand coming from south of West Beach Boat Harbour, DHI concluded that an average 100,000 m^3/year would need to be added to the southern end of West Beach to balance this loss. In future years, the average volume required may vary from this figure.

DHI also undertook broader analysis of the entire set of profiles between Brighton Yacht Club (south of the present study area of interest) and North Haven SLSC. They found that, between 2005 and 2017 an equivalent volume to that eroded from West Beach ultimately accumulated in the northern cells (cells 6 and 7).

In summary, DHI found that:

- *The mass external nourishment campaigns undertaken in the 1990s had a significant influence on the volumes of the entire littoral system, including the West Beach sediment cell.*
- *The littoral volumes on West Beach increased up to the late 1990s due to the abundant sediment supply from the updrift mass nourishments, this source of sand continue to supply updrift beaches, including West Beach, for up to for 10 years following their completion.*
- *The littoral drift increases from close to zero just north of the boat ramp to around 100,000 m^3/yr on the south end of West Beach. Most of this increase occurs south of the northern end of the existing rock wall.*
- *The sand pumping from Torrens Outlet to West Beach has significantly reduced the erosion, which would otherwise have occurred on the south end of West Beach, but it has not been large enough to mitigate the erosion completely.*
- *The sand harvesting at Torrens Outlet has likely increased the decline in littoral volumes observed on the southern section of Henley Beach sediment cell, by reducing the amount of sand reaching this section of the shoreline by 10,000 -20,000 m^3/year.*

These conclusions all seem fair based on DHI's presented analysis. Notably, DHI did not use numerical models to derive this behaviour. Instead, they have relied upon the data presented in the surveyed beach profiles. Numerical models were subsequently calibrated against a short period (2013-2015) of calculated erosion and accretion volumes along West Beach and used. DHI noted the shortcomings of the model along West Beach, particularly in and around the outlet to the Torrens River, where:

> *"The morphology … is very complex due to the interaction of the discharge from the drain during rain events with the wave driven longshore flow"*

This is true and such processes are difficult to model. As with all modelling, there are other limitations. It appears that the nearshore hydraulics were not considered as part of the model calibration, presumably because appropriate field data to calibrate against were unavailable. It remains difficult to explain the nearshore morphology at the river entrance as being due to the river discharges which are comparatively low and infrequent. Sediment supply from the river would be expected to be low. By contrast, the estimated average net transport potential at the Torrens entrance is given as around 100,000m^3 per year. It would be expected that the persistent alongshore processes would dominate the disruption from the intermittent river flows. This aspect warrants more detailed investigation.

It appears that volumes of erosion and accretion calculated from the beach profiles were used to calibrate the numerical model, meaning that, while the answers ultimately obtained from the calibration may be reasonable, the proportional influence of physical processes within the model is likely to be in error. While this is a limitation, it is not particularly unusual considering the limited data available for calibration.

Care would be needed in relying solely on the results of the model for future scenarios, where the nearshore profile, nature of sediment on the beach, or West Beach's orientation relative to incoming waves may have changed or is continuing to change.

Finally, DHI also recommended that the profile dataset be standardised and formalised to ensure it is actively used to inform ongoing management decisions along Adelaide's Metropolitan Beaches.

3.2.3 Water Technology, 2020

Water Technology was engaged to provide an independent review of the impacts of sourcing and trucking sand between the beaches of Adelaide proposed for the 2020/21 calendar year.

In particular, the report examined the expected impacts from relocating 120,000m^3 of sand from the northern beaches to West Beach to mitigate the ongoing erosion. The sand movement was being undertaken at the time of writing the present report, as a precursor to the importation of sand from an external source and the construction and commissioning of the pipeline from Largs Bay to West Beach.

Water Technology's report focussed on the impact of sand harvesting from three areas:

- Near Semaphore Breakwater.
- Between Semaphore and Largs Jetty.
- North of Largs Jetty.

Profile analyses therefore were limited to these areas. Furthermore, Water Technology limited their analysis of beach profile records to the period post 2010, following rock armouring of the Semaphore Breakwater. As for the West Beach compartment, analysis of the last decade appears to be the most relevant for informing ongoing management of the beaches north of the Patawalonga Entrance. Since that time, transport past the Patawalonga entrance appears to have greatly diminished (if not ceased altogether).

Water Technology relied on previous work by the Water Research Laboratory of UNSW when considering sand movement around the Semaphore Breakwater[5]. They noted that WRL had concluded that a "sustainable yield" of sand in the lee of the Breakwater would vary between 28,000m^3/year and 45,000 m^3/year. It appears that this 'sustainable yield' is less than the total potential transport through this area and

[5] WRL, 2007: Technical Review of the Semaphore Park Trial Breakwater, South Australia, Oct 2007

that approximately 33,000m^3/year would therefore naturally bypass the breakwater. While the phrasing is unclear, they note that sand harvesting campaigns in the 2018/19 and 2019/20 had exceeded the upper "sustainable yield" (taking some 80,000m^3 and 100,000m^3, respectively).

Given that sand continues to naturally pass through this area, the area leeward of the breakwater is 'leaky'. Sand which naturally bypasses the breakwater subsequently feeds the downdrift Semaphore Beach and the other beaches north to North Haven. Any removal of sand will cause some deficit of sand in the downdrift beach. Complete removal of all sand transported into the compartment leeward of the breakwater would result in groyne like behaviour, preventing the passage of sand to the downdrift beach and a net deficit resulting in ongoing erosion until the downdrift beaches north of Semaphore and within Largs Bay reach an equilibrium alignment, consistent with complete capture and relocation of all littoral transport behind Semaphore Breakwater. Accordingly, Water Technology's conclusion that harvesting campaigns should not exceed *"the natural rate of replenishment"* may be misleading.

The natural replenishment rate is ill-defined and extremely variable over time. It is feasible to source sand from here provided the volumes removed are not sufficient to initiate recession (rather than accretion or stability) of the beaches to the north, or at least to maintain any northerly recession within acceptable limits. This requires a frequent and detailed assessment of the morphology and sand volumes landward and south of the Semaphore breakwater prior to any extraction. It also requires detailed monitoring of the beach volumes north of the breakwaters following any extraction.

It is difficult to provide an informed comment on the reasoning of WRL behind establishing a "sustainable yield" from this area. We have not reviewed the original report by WRL in detail for the present assessment. Regardless, it does seem likely that the quantities of sand removed by the harvesting campaigns have contributed to downdrift erosion in recent years. Further erosion was projected by Water Technology until such time as a "new equilibrium" is established in the lee of the Breakwater.

Based on the analysis of Water Technology, the dunes between Semaphore and Largs jetties have accreted seaward by around 9m between 2010 and 2020 and by 30 to 35m to the north of Largs Jetty over the same period. However, the parameters used to define the location of the dune do not seem to have been detailed and may be difficult to define, depending on the beach state at the time of each survey.

The Semaphore and Largs jetties are themselves acting as "leaky" groynes with some build-up of sand centred around each jetty and in the sub aqueous areas adjacent. This accumulation is clear from aerial photography or satellite imagery (e.g., Google Earth). This further complicates any assessment of the impact of beach changes resulting from updrift activities.

Detailed accretion and erosion rates, as determined by Water Technology, are presented below in Table 1.

Water Technology concluded that, due to the notable historical and ongoing accretion, the beaches north of Largs Jetty were the most resilient for future sand harvesting. Given that dunes were also accreting between Semaphore and Largs jetties, sand could be harvested from that area as well. Harvesting from the area immediately north of Semaphore Breakwater was advised against, noting that erosion of this area will continue as the salient leeward of the breakwater acts like a dynamic groyne. Instead, active management of this area may be required through periodic nourishment.

Table 1 Dune Growth Characteristics 2010-2020 (reproduction of Table 2.2 from Water Technology, 2020)

Profile	Description	Average 2010 to 2020 dune growth (+) or recession (-) [front face] in m	Comment
200008	South of Semaphore breakwater	+8	Dune grew in height and overall thickness landwards and seawards.
200007	Semaphore breakwater	+13	Lower front dune established in front of existing dune.
200006	North of Semaphore breakwater	-27 (2020) -40 (2017/18/19)	Dune recession due to breakwater downdrift effects. Beach nourishment campaign undertaken in 19/20. Largest amount of recession was experienced in 2017/18/19.
200005	Semaphore Jetty	+14 (2010-2016) -7 (2016-2020) +7 (2010-2020) TOTAL	Dune grew in height 0.8m. Dune accretions 2010 to 2016 followed by dune recession 2016 to 2020. In total there is dune accretion, however, the existing trend is recession.
200004	In between Semaphore and Largs jetty	+9	Dune grew in height 1.2m.
200003	Largs Jetty	N/A	Profile excluded due to anthropogenic impacts.
200129	Approx. 700m north of Largs Jetty	+30	Steady growth, new foredune forming
200002	Approx. 1.5km north of Largs Jetty	+35	Steady growth, new foredune forming

4 Revised Assessment

The calculations behind the key findings of DHI (2018) and Water Technology (2020) have been independently tested as part of our assessment and described below.

4.1 Assessment of the Alongshore Sediment Transport Rate Estimated by DHI

As noted above, DHI calculated a net deficit of 115,000m^3/year on average at the southern end of West Beach between 2011 and 2017.

The change in volume of sand along West Beach between 2011 and 2017 was estimated using the beach profile data provided by DEW (described in Section 3.1). Cross-section areas between -5m and +5m AHD were calculated for profiles along West Beach that were surveyed in both 2011 and 2017 in an aim to replicate the numbers presented by DHI. The earliest available survey dates in each year were used, which was typically mid-January or mid-February.

The beach was divided into three sections for the volume calculation:

(i) From the Torrens outlet to the northern end of the revetment.

(ii) In front of the revetment.

(iii) From the southern end of the revetment to the boat harbour.

Only one profile within the southern section of West Beach was surveyed in both years (profile 200021). While the profile is in the middle of this beach section, the limited data is problematic for making estimates, as erosion is most keenly felt to the south of the revetment.

Similarly, only one profile was surveyed in both years for the section of beach along the revetment (profile 200020, next to the Surf Club). For these two sections, volumes were determined by multiplying the corresponding cross-section area by the length of section. The profiles used in the volume calculation and length of each section are shown in Figure 9.

For the northern section of the beach, three profiles were available, situated at approximately even intervals from south of the Torrens outlet to mid-way along that section of the beach. Profile 200020 (next to the Surf Club) was duplicated at the northern end of the revetment, and profile 200019 (south of Torrens outlet) was duplicated at the very northern end of the beach, and the volume was approximated using the trapezoidal rule. The locations of the duplicated profiles and beach are shown in Figure 9.

Figure 9: Profiles for Beach Volume Calculation, West Beach, 2011 - 2017

0 0.1 0.2 0.3 0.4 km
APPROX SCALE

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REV	DRAWN	CHECK
A	EN	DJW

Salients

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DHI's approach may well have differed from the calculation we present here. We note, for example, that DHI interpolated values through time to get representative cross section areas at each profile for the first day of each calendar year. It is unclear whether this means that they have temporally interpolated values for profiles that were not surveyed in a given calendar year. We have not made this adjustment, and the results presented here are not expected to directly replicate DHI's numbers.

The change in volume for each of the three beach sections was calculated. The values were then adjusted for relocated sand, which commonly involved movement of sand from the Torrens outlet to southern West Beach between 2011 and 2017. However, other sand sources and destinations were also significant. The results are shown in Table 2.

Table 2 West Beach Sand Volumes 2011-2017

Beach Compartment	Calculated Change in Volume 2011 – 2017 from profiles (m^3)	Allowance for Relocated Sand 2011-2017 (m^3)[1]	Underlying Deficit/Surplus (2011-2017)
North of SLSC Revetment	-16,900	+422,800 (i.e., removed)	405,900
Fronting SLSC revetment	-24,300	0	-24,300
South of SLSC Revetment	-91,500	-437,200 (i.e., placed)	-528,700

[1]In this column the value represents an adjustment needed to account for sand either imported or exported from this beach compartment. If net sand was added to the compartment, a negative value is required to adjust the value to represent the underlying deficit or surplus. Most of the sand relocation indicated over 2011 to 2017 represent sand moved from the "Torrens Outlet" (north of the SLSC), to the southern end of the beach, although additional sand was added to the West Beach from other locations.

Of most interest is the actual deficit of sand at the southern end, which equates to around 90,000m^3/year. By our calculations, around 90,000 m^3 of sand would have been lost from this section of beach, on average, per year, if sand were not placed on this part of the beach. This compares favourably to the 115,000m^3 deficit calculated by DHI. The difference is almost certainly related to differences in the calculation method adopted and the limited survey profiles available for both years.

Our calculations indicate that the sand relocation or recycling activities had a substantial impact in reducing the amount of erosion that would have otherwise been felt along the West Beach between 2011 and 2017.

As a test of sensitivity, we replicated the calculation considering other date ranges, varying either side of the 2011-2017 date range used by DHI (including testing years 2010, 2019 and 2021). These years for sensitivity testing were selected due to the availability of a more complete set of surveyed profiles. In addition to incorporating those profiles, an allowance was included for the additional sand that was imported to and moved within the West Beach cell in those additional years.

We found that the results of our calculations were sensitive to the year range adopted. The indicated annually averaged loss from West Beach south of the revetment, calculated for different date ranges is presented in Table 3.

Table 3 Variation of Annualised Deficits at Southern West Beach, dependent on

Date Range	Indicated Annually Averaged Deficit (south end of West Beach m^3/yr)
2011-2017	-88,000
2010-2019	-54,500
2010-2021	-49,700

Overall, we conclude that an annualised potential alongshore transport rate averaging around 100,000m^3/year is reasonably representative of the period between 2011 and 2017. However, the relatively short (6yr) period considered by DHI in assessing a rate of 115,000m^3/year may have been significantly affected by individual events, or seasonally stormy periods such as that experienced in Autumn and Winter 2016, towards the end of the 2011-2017 calculation period.

What appears to be missing from recent analyses is a robust assessment of the variability that could occur from year to year, or from season to season. With differing spacing and timing between surveyed profiles, the accuracy achievable in estimating large beach volume changes from year to year also varies. A more intensive and focussed monitoring regime would improve this accuracy.

A particularly severe year could test a pipeline designed to handle a maximum transfer capacity of 100,000 m^3 per annum, particularly noting that most of the sand loss experienced during a stormy year could arise from a single event, or a set of closely clustered events. A shortfall in the capacity provided by the designed sand transfer pipeline could be augmented by trucking additional sand, but this would cancel some of the benefits gained from having the pipeline. Alternatively, the deficit could be made up during less stormy years. Furthermore, the sand pumping system is being designed to transfer up to 150,000m^3/yr at a maximum of 30,000m^3/month. The capacity being designed is expected to suffice during all but the rarest condition. During such rare, stormy years, the system could operate for longer to cover the deficit.

4.2 Assessment of Dune Width Changes Estimated by Water Technology

To test key findings of the Water Technology (2020) assessment, we have examined dune growth and recession rates around the Semaphore Breakwater, and further north, between 2010 and 2020. The locations of the profiles included in the analysis are shown in Figure 10. Water Technology reported that they considered the movement of the "front face of the dune"; it appears that this may have been determined by inspection as their study report does not seem to indicate how the location of the front face was defined. For our assessment, we have noted the findings of the ALB report, which state that a foredune begins to establish at around 2m AHD along this coastline (see Section 3.2.1).

The location of the 2m contour, as interpolated from the surveyed profiles, was adopted as the front of the dune for our analysis. This is measurable on the ground at any point in time. The position of this contour relative to its location in January 2010 was assessed. Positive distances indicate accretion of the dune/beach location and negative distances indicate recession. The movement of the dune face at each profile in each year, relative to 2010, is listed in Table 4.

Table 4 Dune Growth / Recession 2010 – 2020 (m seaward from 2010 position)

Profile	200002	200129	200004	200005	200006	200007	200008
Location	1.5km north of Largs Jetty	700m north of Largs Jetty	Between Jetties	Semaphore Jetty	Semaphore between Jetty and Breakwater	Semaphore Breakwater	640m south of Semaphore Breakwater
2011	7.2	10.0	2.5	2.8	-2.5	0.8	-1.9
2012	15.8	14.0	2.3	2.2	-0.4	4.5	1.7
2013	18.8	17.1	1.1	9.1	-4.8	15.2	4.2
2014	25.0	18.7	1.4	8.8	-10.9	13.1	8.0
2015	24.7	22.6	1.7	3.3	-18.0	15.7	7.0
2016	32.0	21.4	0.9	2.9	-25.0	17.2	9.7
2017	27.5	28.7	-1.0	-3.8	-35.8	15.5	8.1
2018	–	–	–	-3.4	-39.1	16.0	10.8
2019	37.4	39.6	1.3	-6.5	-36.8	29.3	8.9
2020	**38.9**	**38.0**	**2.1**	**-5.0**	**-28.9**	**20.7**	**12.9**
Water Technology, 2020	**35**	**30**	**9**	**7**	**-27.0**	**10**	**8**

Figure 10: Profiles for Dune Width Assessment

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At most profiles, our assessment shows a similar trend to that of Water Technology (2020). At profiles 200007 and 200008, located at Semaphore Breakwater and around 650m south of the breakwater respectively, there has been net accretion since 2010, with the location of the dune in 2020 further seaward by around 21m and 13m, respectively. Most recession was noted to the north of the Breakwater, but south of Semaphore Jetty (profile 200006), where the dune has receded by around 29m overall between 2010 and 2020. The most marked recession occurred between 2014 and 2018.

Water Technology (2020) noted that the dune at Semaphore Jetty (profile 200005) accreted by 7m between 2010 and 2015 but has been receding since 2016. However, our assessment in Table 2 indicates overall recession since 2014, with the dune face situated 5m landward in 2020 compared to 2010. At profile 200006, which is located approximately halfway between Largs and Semaphore jetties, there is a trend of recession from 2010 to 2017 followed by growth between 2017/18 and 2020, and the profile is, overall, 2m seawards from the 2010 condition.

Profile 200003, which is situated at Largs Jetty, was excluded from the assessment by Water Technology (2020) as the profile is along the beach access and is not representative of natural processes. Along the beach to the north of Largs Jetty our assessment indicates accretion since 2010 of greater than 30m, which is consistent with the findings of Water Technology (2020).

Dune width is a useful measure of performance of management actions, providing that it can be calculated in a consistent manner. It is likely that the differences indicated between the numbers calculated by this study and the work of Water Technology relate more to differences in the methodologies adopted. We recommend also that overall volume changes should be used to augment these measures and facilitate decision making, as beach volumes include consideration of the net loss of sand from an area, where as sand may be transferred from the beach to the dune and vice versa.

The key pattern indicated by Water Technology's analysis, that the rate of deposition increases markedly with distance north of Largs Jetty is robust.

4.3 Updated Volumetric Assessment

In addition to the more detailed assessment provided for West Beach ("Cell 3"), DHI (2018) also examined patterns of change along the remainder of the metropolitan coastline. The alongshore presentation of their analysis is provided in Figure 4.14 of their report. The previous analysis of DHI did not consider the impact of sand harvesting and nourishment operations, which means that their estimation of alongshore transport rates and cumulative volume estimates will contain some error and this may be significant. A methodology which would mitigate against these errors is demonstrated in Section 4.5.

Regardless, DHI's results are still useful and broadly indicative. It is difficult to replicate DHI's results exactly, as their report implies that some profiles have been duplicated alongshore in their analysis. The reason for the duplication is to account for locations where there are discontinuities in the alongshore transport process, but the available surveyed data are insufficient to capture those effects. However, DHI's report does not outline which profiles have been duplicated and where those copies have been applied.

Our updated analysis is limited to the cells for which we were provided profile data (i.e., West Beach and further north). To provide a comparative assessment, we have focussed on changes between two time periods: (i) 2011-2017 (Figure 11) to overlap with DHI's analysis; and (ii) 2017 -2020 (Figure 12) to update the analysis with more recent data. These two figures show the change in profile area above -5m AHD (m^2, or m^3/m) over the period considered. The changes can only be calculated when the profile was surveyed at both end dates for the period being considered. By using a trapezoidal approximation, which effectively multiplies the change in area by a representative alongshore distance, the change in volume in cells 4, 5 and 6 have been calculated. We note that a more detailed assessment of volume, accounting for discontinuities and the relocation of sand to Cell 3 is already presented in Section 4.1. The calculated volume changes for each cell are presented in Table 5.

These values are difficult to interpret. Ways in which volumetric monitoring and modelling could be improved are discussed in Section 4.5 and Section 7. A key difference between the two periods is that there is substantial indicated erosion between the Semaphore Breakwater and Jetty (southern end of Cell 6) between 2011 and 2017, but not between 2017 and 2020.

The differences in available survey data dates and the notable variation in patterns of erosion and accretion between adjacent profiles also suggest that analysis could improve significantly with more comprehensive survey (closer spaced profiles captured every year, or airborne laser scanning). The one clear trend that emerges from our analysis is a tendency for the beach to accrete within Cell 6, particularly to the north of Semaphore Jetty.

Table 5 Estimated Cell Volume Changes, based on Profiles 2011-2017 and 2017-2020

Beach Compartment	2011 – 2017 (m^3)	2017 – 2020 (m^3)
Cell 4	-75,607	12,317
Cell 5	-30,766	-18,771
Cell 6	9,467	95,667

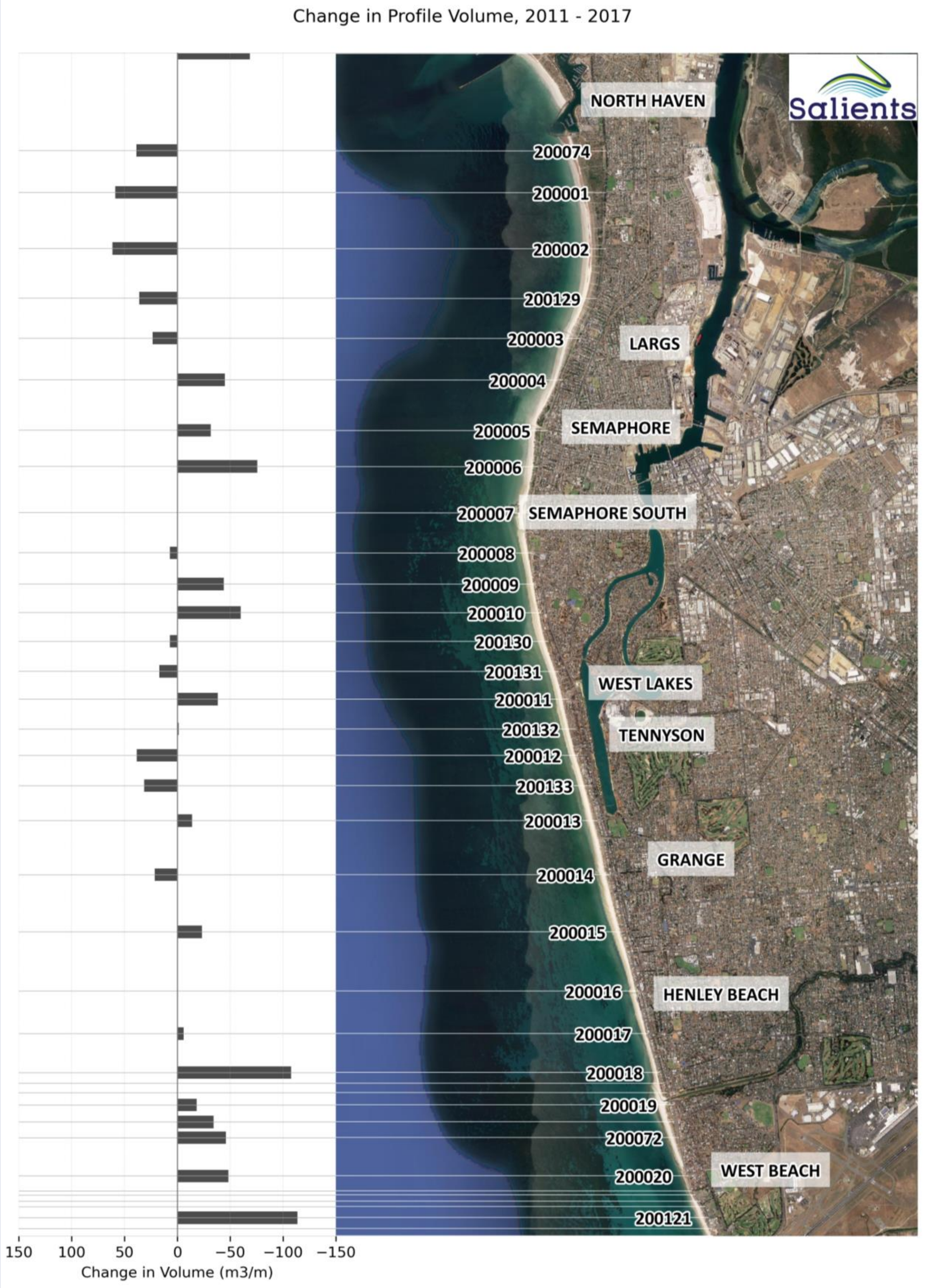

Figure 11 Change in Surveyed Profile Volumes (2011-2017)

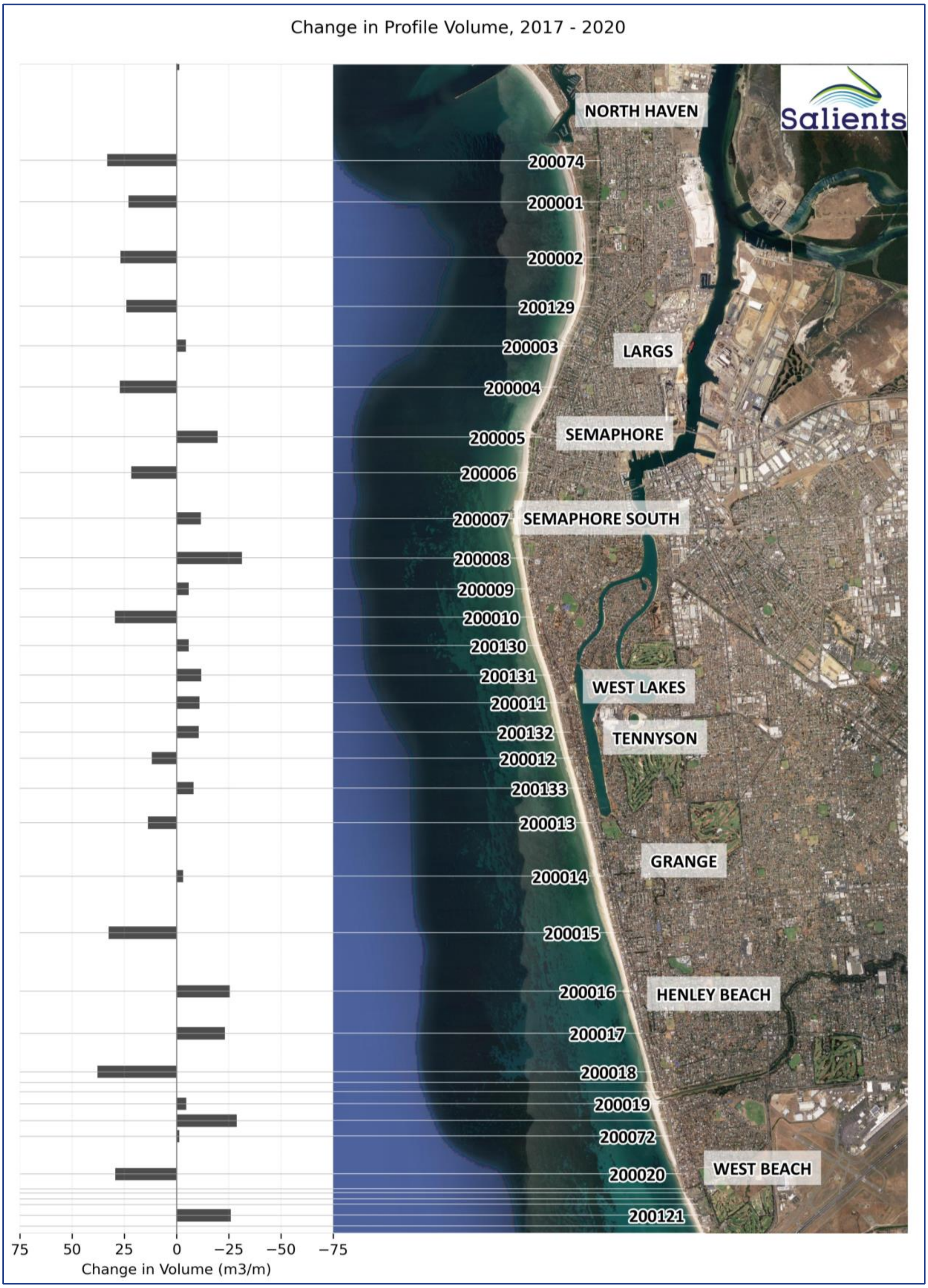

Figure 12 Change in Surveyed Profile Volumes (2017-2020)

4.4 Examination of Satellite Data

We have utilised the Digital Earth Australia Coastlines (DEAC) satellite dataset[6] to further examine shoreline changes within the study area during the past 10 years. The dataset is based on freely available Landsat satellite imagery collected regularly (on average, once every 16 days).

Individual images are georeferenced, and pixels categorised to identify areas of land and water using indices such as the normalised difference water index (NDWI), or modified version (MNDWI) which is reportedly better at discrimination in areas where white water is present (swash zones etc.). Using contouring techniques, the location of the shoreline is estimated, allowing better accuracy than the 30m pixel size present in the raw Landsat images. For a sandy beach, Root Mean Squared Errors (RMSE) of less than 4m are reported (Bishop-Taylor et al., 2019). We note that higher resolution imagery is now becoming more readily available and improved accuracies using imagery from newer satellites is now possible. Regardless, the dataset reflects shoreline change patterns that are consistent with recent experience and therefore useful for examination.

The shoreline locations derived from all relevant Landsat images in each calendar year were collated and, alongside the local tide elevation at the time each image was captured, was used to derive an average representative shoreline location for that calendar year. The shoreline thus derived is representative of median or 'typical' position of the coastline at approximately mean sea level (0 m AHD).

Figures showing the shorelines are presented in Figure 13 (West Beach) Figure 14 (Semaphore to Largs Jetty) and Figure 15 (North of Largs Jetty). For clarity, the lines presented are limited to 2010, 2012, 2017 and 2019.

Importantly, the "shoreline" does not necessarily show the full picture of how the beach is evolving, as changes may have occurred below tide level, which have not yet manifested in a corresponding change at the shoreline, and sand may have accumulated in the dunes landward of the shoreline (either through wind transport or by placement from other locations. However, the patterns are indicative.

Figure 13 illustrates a tendency for recession both to the north of the West Beach Boat Harbour, and along much of the beach to the north of the SLSC Revetment. In both cases, the impact is most keenly felt towards the southern end of the beach sections, indicating that what is being witnessed are edge effects downdrift of obstacles to littoral transport (West Beach Boat Harbour for the southern end of the beach, and the SLSC revetment for the northern end of the beach). Behaviour along the northern end

[6] https://www.ga.gov.au/dea/products/dea-coastlines

of the beach is complicated by significant removal of sand during the early 2010s from the Torrens outlet.

Figure 14 illustrates a tendency in early years for accretion of the salient behind the Semaphore Breakwater, although the removal of sand from the salient in recent years saw the shoreline recede to a more landward position in 2019. The shorelines north of the Breakwater indicate ongoing recession, which was most marked in earlier years (2010 – 2012) and most pronounced in the vicinity of Kanowna Rd and Hannay St (near Profile 200006). The degree of recession becomes less pronounced towards Semaphore Jetty.

Figure 14 also indicates that the shoreline between Semaphore and Largs Jetties has been relatively stable over the past 10 years. This is also reflected in our analysis of Profile 200004 in Table 4, where the surveyed front of the foredune (represented by the 2m AHD contour) has only moved +/- 2m over this period with no clear trend. We note that sand is presently being excavated and trucked from the beach here to provide for the nourishment of the southern end of West Beach. We recommend that this length of shoreline be monitored carefully and regularly to get a thorough understanding of the short-term beach response to sand sourcing. This would help to inform operation of the pipeline when it is constructed.

Figure 15 shows a trend of accretion to the north of Largs Jetty. The accretion pattern emerges within around 500m north of Largs Jetty and becomes very pronounced within 500 – 1500m north. Interestingly, the estimated 2012 shoreline sits landwards of the corresponding 2010 line in many locations along this length. The reasons behind any apparent shoreline recession in this area are unclear and this is not reflected in the profile analysis presented in Table 4 for profiles north of Largs Jetty. We note that the algorithms that were used to derive shorelines in the DEAC dataset rely upon signals within the "green" and "shortwave infra-red" bands. The discrimination between land and water could be thwarted by a flat, slowly draining beach face and/or the presence of large deposits of wet seaweed across the beach. A quick inspection of the satellite imagery for 2012 available through Google Earth indicates that these conditions may have been prevalent during much of 2012. This demonstrates the care required in interpreting these data, particularly given that the algorithm which discriminates the boundary between land and water should ideally be calibrated to local information. In generating the DEAC shorelines, Geosciences Australia have adopted a single set of representative values for the entire Australian Coastline and a more accurate result could be obtained by calibrating against data available from Adelaide's coastline.

Figure 13: Satellite Derived Shorelines: West Beach

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Salients

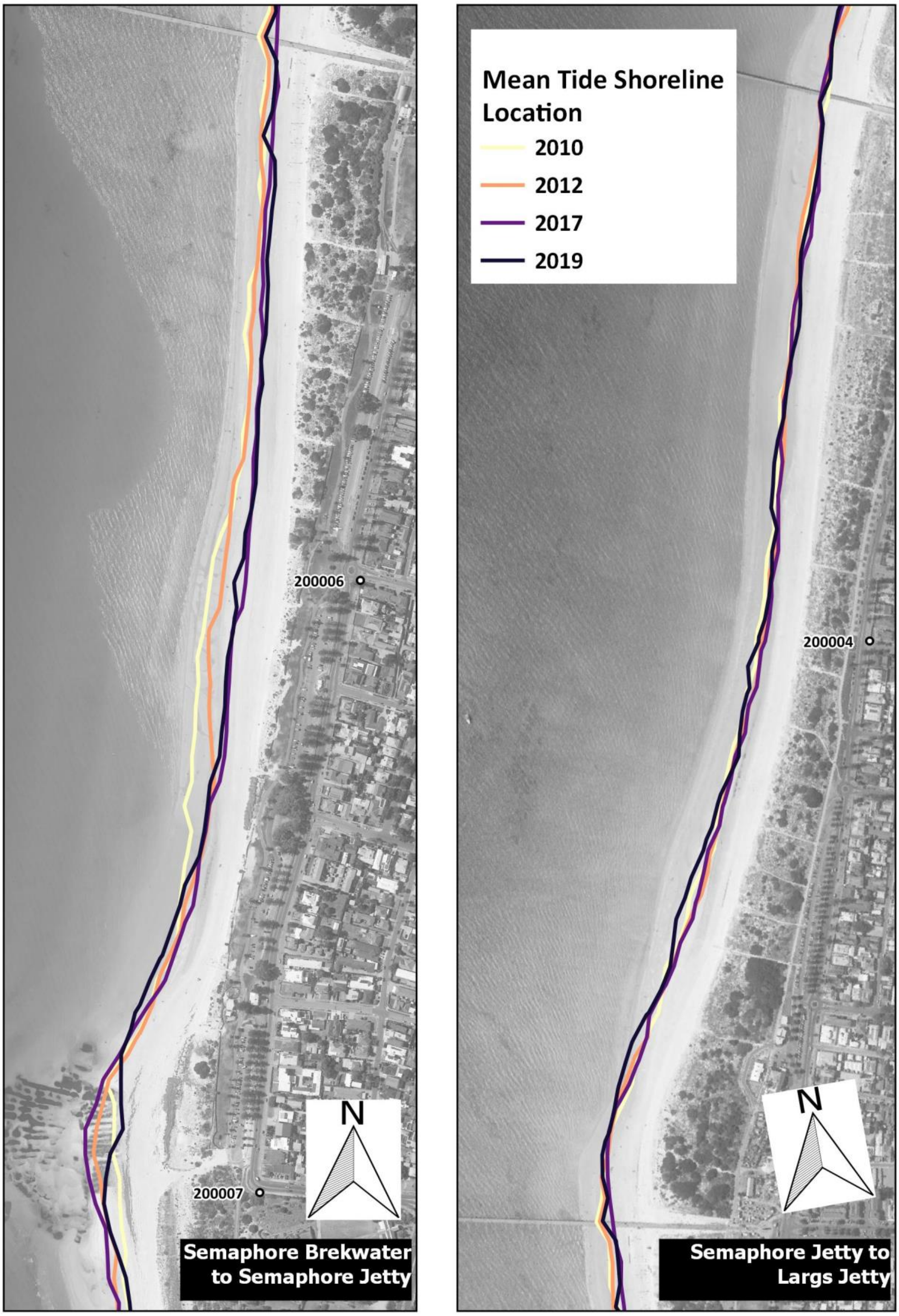

Figure 14: Satellite Derived Shorelines: Semaphore to Largs				0 60 120 180 240 m APPROX SCALE
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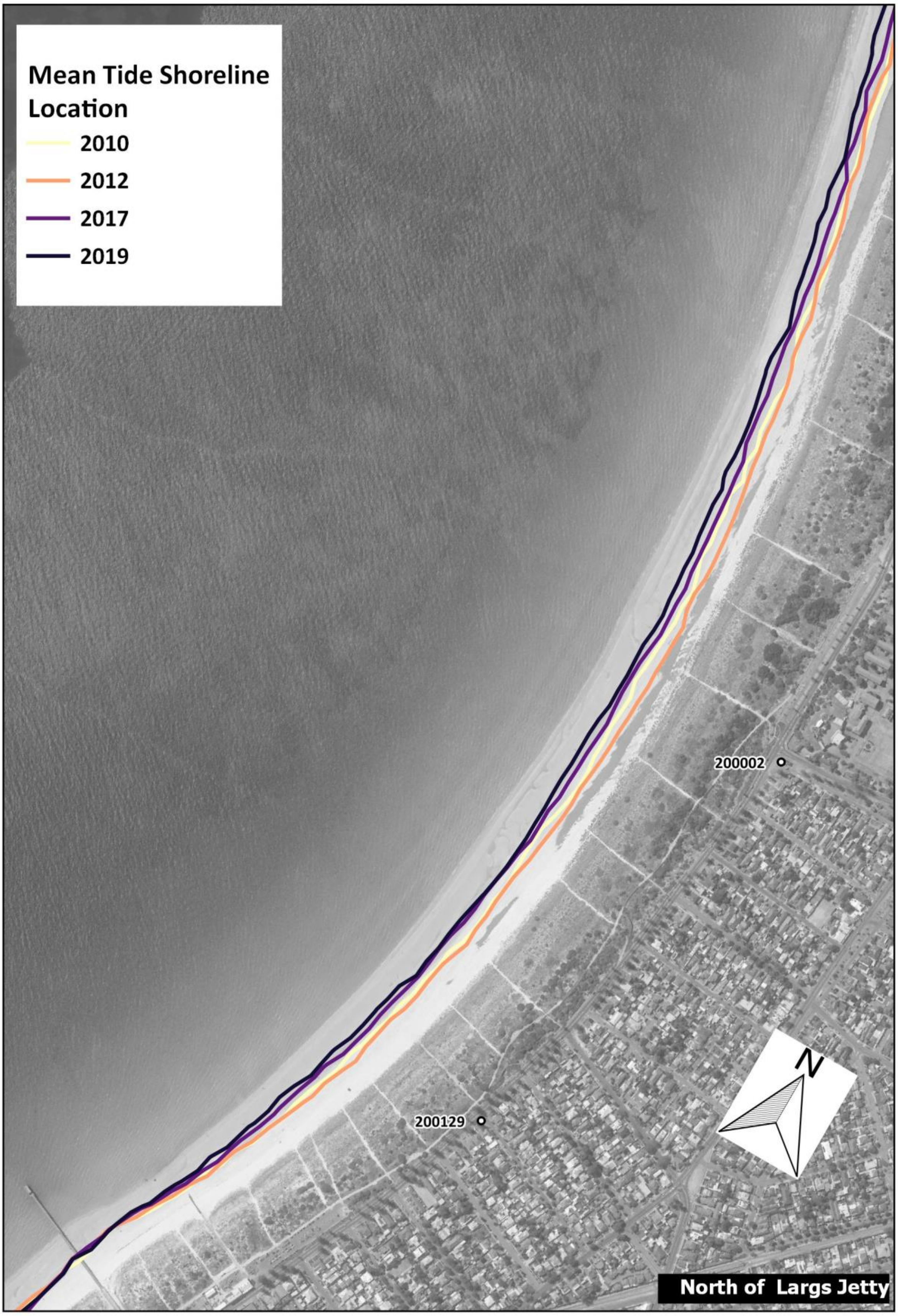

Figure 15: Satellite Derived Shorelines: North of Largs Jetty

0 100 200 300 400 m
APPROX SCALE

Adelaide Northern Beaches Impact Assessment

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Even so, the shorelines do show trends that are expected in most locations. Other areas of interest along the shoreline north of West Beach Harbour, but not shown in the figures presented above are:

1 North of Torrens Outlet, there has been notable recession, but this was apparently most pronounced between 2010 and 2012 and typically limited to the area south of Henley Beach Road.

2 Further north along Henley Beach, towards Grange Jetty the shoreline has remained relatively stable, potentially with some accretion between Henley Beach Jetty and Grange Jetty.

3 North of Grange Jetty, the shoreline is again relatively stable, with some evidence of accretion north of Terminus St, but to the south of Hillview Avenue.

4 A mixed pattern of erosion and accretion is present between Hillview Avenue and south of the Semaphore Breakwater, tending more towards accretion. The pattern landward of the Breakwater is mixed due to the excavation of sand from this area to nourish other places along Adelaide's coastline over recent years.

5 To the north of Largs (i.e., north of the extent shown in Figure 15), the shoreline all the way to the Marina at North Haven shows a consistent pattern of around 30-40m of accretion over the past 10 years.

4.5 Volumetric Box Modelling

Simplistic mass balance, or "Box", modelling may prove to be a useful analytical technique to track the movement of sand throughout the northern beaches of Adelaide's metropolitan area.

The following process is recommended with the calculation updated on an annual basis:

1 Break the coastline into sensible units for analysis. This would comprise division into "sub-cells" where processes can be examined on a local scale. For example, cell 3 (West Beach) would be divided into three separate sub-cells: (i) 3-1, to the south of the SLSC revetment, (ii) 3-2 in front of the SLSC revetment, and (iii) 3-3 between the SLSC revetment and the Torrens Outlet.

2 Using the surveyed profile data, calculate the net loss of sediment from each sub-cell.

3 Tabulate the totals of sand either harvested from or used to nourish each sub-cell.

4 Use the following assumptions:
a. No onshore/offshore transport beyond the -5m contour

b. No loss of sand via wind-blown transport

c. No wave driven transport into the West Beach cell from the south.

5 Balance the calculation to estimate alongshore sand movement between cells for the year.

An example of the calculation for West Beach, based on annually averaging the six-year totals from Table 2, is shown in Figure 16. In this example, the transport north of the Torrens Outlet (i.e., out of Cell 3-3) towards southern Henley Beach of 24,470m³ is less than the alongshore transport potential at this location. In other words, there is a deficit and a tendency towards erosion at this location.

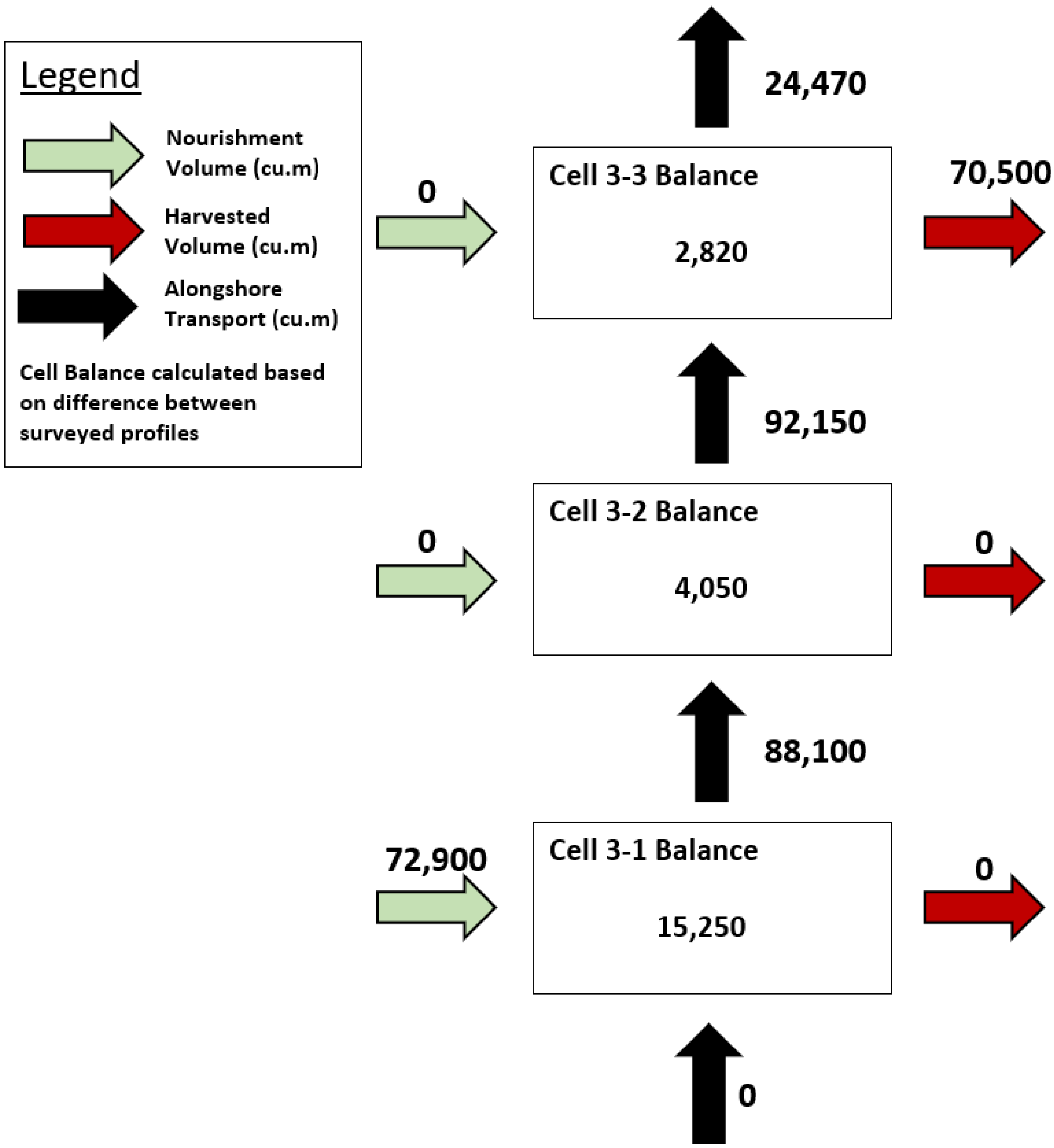

Figure 16 Sample Box Model Calculation – West Beach
(alongshore transport rates shown are based on the period between 2011 to 2017 when transport rates were likely higher than average, refer to text)

We note that the method described is deterministic and linear. There will be inevitable errors, associated with the calculation of volumes of harvested sand and the application and interpolation between surveyed profiles. Considering the nature of the calculation, these will accumulate and manifest as a "misclose" in the calculation at the northern extent of the littoral transport system (North Haven), where the transport system terminates and the balance of movement northward out of cell 6 should equal zero.

Some effort would be required to interpret and refine the model to provide useful estimates of actual trends and the alongshore transport flux at each location. We suggest that this calculation could be completed each year following profile surveys, and before management actions for the next year are decided upon. A key source of error, relating to the integration of volume change from profile information could be largely eliminated by using remote sensed Laser Aerial Depth Sounding (LADS) data on an annual basis in future.

5 Impacts and Mitigation Strategies

Generally, impacts will occur during construction of the buried pipeline, and operation once the pipeline is commissioned. Operation activities would typically involve sourcing sand from the beach in reasonable proximity to intake locations via a scraper, transport of that sand to a sand collection unit (SCU) at the intake location, dumping and then loading of that sand using a hydraulic excavator through the SCU (where larger items and vegetative matter will be screened out) and then combining the screened sand with seawater pumped from a nearby source to form a slurry (ratio of 40%:60% by weight sand: water) for pumped transport via the pipeline.

At the discharge location the slurry is allowed to flow freely from its discharge location across the back of the beach with the mix water eventually flowing into the ocean and/or infiltrating into the beach. Some grading/spreading using earthmoving equipment at the discharge location might be considered.

DEW have requested that our study team review the potential impacts of the pipeline, considering the findings of others. Our presentation here comprises a collation of impacts of beach excavation works from previous reports reviewed by our study team. Similarly, mitigation strategies identified by others have also been listed. Our scope does not include detailed re-assessment and/or review of ecological and social impacts. Instead, previously identified impacts are tabulated in Sections 5.2 and 5.3 respectively. A more detailed consideration of coastal processes is presented in Section 5.1.

5.1 Impacts on Coastal Processes

5.1.1 Discussion of Potential Impacts

Potential concerns regarding coastal processes are primarily associated with impacts at the locations from which sand will be sourced. In the case of the proposed pipeline, the sand source locations are understood to be limited to the north of Grange.

Based on the existing coastal process understanding expressed in the recent assessment by DHI, the coastline between West Beach and North Haven can be considered a long, continuous littoral system with the long-term balance of sand eroded from the southern extents (West Beach) matching that which accumulates on the northern beaches. In some locations, such as the Torrens outlet and behind the Semaphore breakwater, the transport is slowed.

If sand is removed from a location, it will be eventually infilled again from the south (updrift) beach. However, that removal and the subsequent infilling will result in less sand being transported to the downdrift beach (to the north) until the beach has recovered. This reduction will either cause some recession or slow the rate at which a beach may have otherwise accreted.

Based on our consideration of processes, during the past 10 years the only areas that have shown clear patterns of accretion are located to the north of Largs Jetty and immediately updrift from or in the lee of the Semaphore Breakwater. Between Semaphore and Largs Jetty the littoral transport process has been, approximately, in equilibrium.

The recommendation here is that sand should be recovered from either leeward of the Semaphore Jetty or located as far north as possible between Semaphore and Largs jetties or, if possible, from north of Largs Jetty.

Finally, areas where erosion and accumulation occur will vary over time. For example, a preliminary assessment of satellite-based shoreline mapping from the past 10 years and inspection of satellite imagery dating back to the early 2000s indicates that there has been some accretion north of Grange Jetty through to Hillview Avenue. The accretion is not as pronounced, however, as that further north, towards Largs Jetty. However, the buffer between the beach and residential properties along Seaview Road in Tennyson is limited in some areas. Removal of any sand from this area would need to be undertaken and monitored carefully.

There have been concerns raised in the past regarding whether sand harvesting will expose areas to dangerous levels of storm erosion. Within the northern beaches of Adelaide, particularly to the north of Semaphore Jetty, the available dune buffer against erosion is substantial and the beach here has tended towards accretion over the past decade. Water Technology (2020) noted that storm erosion amounts are small compared to the amounts that would be harvested and transported along the northern beaches and that the beach would recover quickly. Water Technology did note that a storm occurring rapidly following harvesting may result in steepening of the face of the dune, loss of vegetation and the formation of dune scarps that impair access of the public and some fauna. However, these are impacts that normally occur following storms and need to be managed from time to time regardless.

5.1.2 Proposed Mitigation Strategies

Successful operation of the pipeline which minimises negative impacts will need to be informed by ongoing monitoring and regular analysis of the state of the beach and the way that the shoreline is evolving/responding. A downdrift impact will result from sediment being removed from the beach and the location where this impact will be felt needs to be considered. That area of impact will continue to migrate downdrift until the sediment transport potential is satisfied. The informed opinion of specialist, experienced coastal engineers should be relied upon to assist with these decisions.

The ideal locations for sand harvesting from the northern beaches, based on recent data, are in Largs Bay north of around Ralston St, or from the leeward side of Semaphore Breakwater. If sand is harvested from these locations, the impact on downdrift beaches is either likely to be minimal, or there is ample accreting beach and dune buffer present to provide resilience against any resulting recession.

We recommend that acceptable impacts be defined and agreed with stakeholders, within and downdrift of the areas from which sand harvesting is to be undertaken. Depending on the assets that are at risk from beach recession, this may involve the establishment of an acceptable landward extent for the seaward dune edge, potentially based on the location where the dune was located at some point in the past (say in 2010), or a maximum planned dune recession within the years following the sand harvesting operation from an area. Should this performance indicator be exceeded, harvesting should cease with subsequent monitoring undertaken to confirm that ongoing natural recovery is occurring. If the beach continues to recede, beach repair should be considered.

To facilitate beach repair, we recommend that, if possible, the sand pipeline be designed such that inlet locations can simply function as outlet locations. Furthermore, if the pipeline cannot extend north of Largs Jetty, we recommend that the northern most intake be designed, located and configured in such a way that it can operate as part of a mixed transport operation where sand is trucked from areas further north and then transferred through the SCU into the pipeline for further southward transport.

5.2 Ecological Impacts

Ecological impacts are those impacts which relate to biodiversity and ecosystem integrity. These are tabulated, alongside notes and mitigation strategies in Table 6.

Table 6 Summary of Ecological Impacts and Mitigation Strategies

Impact	Mitigation Strategy
Direct removal and impact on beach infauna	**Comment:** Generally, beach infauna are less diverse and abundant in the upper part of the beach profile, beyond the intertidal zone. However, infauna within the intertidal zone are able to recover and recolonise rapidly from adjacent areas when disturbed. This level of disturbance occurs frequently during storm events.

Impact	Mitigation Strategy
Potential sand cliffing, resulting loss of dune vegetation and public safety issues	**Strategy:** Scraper removal depths to be kept shallow (~250mm) with gentle batter slopes (maximum 1V:10H) formed and maintained with the adjacent beach. Removal activities to be constrained to the intertidal area and offset a minimum distance from the face of the dune (5 or 6m was recommended by Water Technology, (2020). All machinery is to stay off the vegetated dune system. **Comment:** Most of the dune vegetation on Adelaide's coast comprises non-indigenous vegetation (excepting the Tennyson Dunes within our area of interest). The formation of sand cliffs occurs naturally during storms and is a natural response of dunes to storm erosion.
Direct smothering of fauna and flora at the placement site.	**Strategy:** Sand discharge typically occurs on the sandy sub-aerial beach or immediate nearshore where beach infauna are resilient to smothering and recolonise easily. **Comment:** Generally speaking, infauna will be even more resilient to the more frequent sand relocation activities and quicker dispersion that the pipeline will allow (when compared to trucking and dumping campaigns).
Potential addition of pollutants and deleterious material to the placement location.	**Comment:** The sand is effectively being 'recycled' by moving from north to south, to offset the ongoing, natural littoral transport of sand from south to north. The material at source will, at some stage in the past, have been present at the location where it is to be placed. **Strategy:** Sand is to be screened before pumping, meaning that any gross pollutants will be removed before transport. If unexpected issues (e.g., contaminants) are identified, further extraction and placement should halt until they can be resolved.
Introduction of marine or terrestrial pests to the placement location (from the source)	**Strategy:** Regular follow up surveys and, as required, removal of pest dune plants to be undertaken at sand placement locations. Introduction of pests are more likely to result from sand imported from an external source.
Disturbance of Shorebirds such as the Red-capped and Hooded Plover (noise, disrupting movement between foraging and nesting locations etc.)	**Comment:** Some important shorebirds tend to nest on the upper, dry beach profile, moving from this area to the high tide mark (strand line) and intertidal area to forage. **Strategy:** Identify and protect nesting sites prior to work via targeted beach-nesting bird survey and site-specific mitigation strategies. Minimise campaigns as possible (using larger machinery). Focus sand collection activities within the intertidal zone. Establish marked transport corridors along the beach, primarily within the intertidal zone and ensure that all equipment keeps to these corridors. Minimise vehicle movements as possible. Vehicle operators to keep a sharp lookout and to travel at a reduced speed limit. Timetable work to occur out of breeding season (ideally, Winter, but potentially shoulder periods too). Use vehicles with broader tyre surface.

Impact	Mitigation Strategy
Direct Crushing of Beach Infauna by Truck Movements	**Strategy:** Minimise vehicle movements and speed. Use vehicles with broader tyre surface to minimise compaction, establish marked transport corridors along the beach and ensure all equipment keeps to these corridors.
Removal of Wrack from Beach	**Comment:** Seagrass wrack is important to the functioning of beach ecosystems. Its breakdown provides nutrients for beach infauna and deposits of wrack are used for foraging by shorebirds. **Strategy:** Remove any surface seagrass wrack from the sand source locations and spread on the upper beach profile around the high tide mark (or strandline). If seagrass screened from the remaining sand at the SCU is free from deleterious materials such as plastics and rubbish, spread that screened matter in a similar manner. Where practical, avoid removing seagrass wrack from the beach.
Loss of Dune Vegetation	**Comment:** Dune vegetation within the source areas of interest is considered of low ecological value with a high proportion of weeds. Regardless, loss and recovery of foredune vegetation is a natural process that occurs during storms and following. Dune vegetation is inherently resilient to disturbance. **Strategy:** Keep all sand removal and processing operations away from the dune face by an agreed distance.
Loss of Dune Width potentially reducing filtration where stormwater is discharged to dunes, thus increasing pollution of the beach.	**Comment:** Water Technology (2020) investigated this issue and indicated that likely losses of dune are not significant enough to warrant concern.

5.3 Social Impacts

Social impacts are those impacts which relate to beach recreation and amenity, visual impacts and noise. These are tabulated, alongside notes and mitigation strategies in Table 7.

Table 7 Summary of Social Impacts and Mitigation Strategies

Impact	Comment/Mitigation Strategies
Presence of trucks and machinery interfere with public use of the beach	**Strategy:** Limiting works to times when the beach is less used by the public (shoulder season and Winter). Limiting total footprint of works area at a given time. Where practical, advertise the schedule of proposed works. **Comment:** Winter has been identified as being less suitable due to "*more frequent high tides*"
Noise caused by earthmoving machinery, particularly reversing alarms.	**Strategy:** Limiting works to times when the beach is less used by the public (shoulder late autumn, winter and early spring) and daylight hours. Minimise early morning extraction at locations closest to residences.

Impact	Comment/Mitigation Strategies
Disruption to public and noise during construction of pipeline.	**Comment:** A short construction period will limit/ reduce the future need for trucks to use the beach and local roads, so the net benefit is positive. The adoption of a pipeline reduces the longer-term use of earthmoving machinery and trucks for transport. **Strategy:** Limiting works to times when the beach is less used by the public (shoulder season and winter) and daylight hours.
Possibility of safety risk arising from collision between earthmoving equipment and pedestrians.	**Strategy:** Work areas to be fenced and signposted, limiting works to times when the beach is less used by the public (shoulder season and winter) and daylight hours when visibility is best.
Intermittent disturbance of beach use when pumping sand and discharging slurry from outlets.	**Strategy:** Wherever possible, limit discharge operations to times when the beach is less used by the public. As appropriate, isolate discharge area vicinity from public using fencing. Install warning system to advise public when pumping is taking place.
Offensive odours from seagrass matter.	**Strategy:** Seagrass accumulated on the beach from sand source location is to be evenly relocated and spread to the upper beach profile, landward of the beach face and intertidal area. The sand collection unit (at the intake location) will screen out remaining vegetative matter before mixing sand with discharge water to form a slurry. Screened vegetative matter will also be relocated to the upper beach profile. This will encourage seagrass to breakdown aerobically at the source locations. Minimal vegetative matter will be present in the slurry at the discharge location. Accumulation of wrack at the shoreline is a natural and ongoing process following storms.
Visual Intrusion	**Comment:** A buried pipeline is considered more visually appealing than the alternatives such as engineered groynes and breakwaters, which need to be exposed above sand and tide levels. Pump booster stations (around the size of a shipping container) need to be installed every 2.2km length of pipeline, but the visual impact can be minimised by carefully selecting the locations.
Greenhouse Gas Emissions	**Comment:** The total energy requirement is greater for pumping via a sand pipeline, when compared to trucking sand. This is because the sand needs to be mixed with water to be transported via a pipeline and that water (60% of the weight) needs to be transported as well. The South Australian Government has set goals to reduce greenhouse gas emissions by more than 50% below 2005 levels by 2030 and to achieve net zero emissions by 2050. Towards the end of its life, the pipeline should therefore be almost completely powered by zero greenhouse gas energy[7].

[7] https://www.environment.sa.gov.au/topics/climate-change/south-australias-greenhouse-gas-emissions, accessed 12/06/2021.

6 Design Considerations

A meeting between representatives of DEW, the study team and the team designing the pipeline was held in Adelaide on Tuesday 23rd March 2021. At that meeting, the potential locations for pipeline inlets were discussed.

While outlets are relatively simple, siting inlets is complicated by the need to construct a pipeline to source transport water for mixing the sand into a slurry before pumping. Furthermore, there are issues associated with ease of access (for maintenance and to move the sand collection unit onto the beach) and the provision of a suitable power supply. These all need to be balanced against the budget which is available to complete the work.

The following sites were identified as likely candidates:

1 At Terminus Street, Grange, which provides ready access to the beach north of Grange.

2 At the end of Bower Rd, Semaphore Park, which provides ready access to the area where sand accumulates leeward of the Semaphore Breakwater.

3 North of Semaphore Jetty, to provide access to the area between Largs and Semaphore Jetties.

4 North of Largs Jetty, although the available budget for the project may preclude this occurring.

Considering our review of coastal processes, the proposed locations are sensible. Practicalities associated with access and sourcing transport water are also key concerns Further refinement of these locations is understandable based on those considerations. Generally, we recommend placing the inlet between Semaphore and Largs Jetties further northwards, closer to areas where accretion is more noticeable. Similarly, if an inlet is achievable to the north of Largs Jetty, we consider a location around 400m north of the Jetty would be ideal, providing access to the areas where dunes have accreted by more than 30m over the past decade, but where sand is still reasonably compatible with that present behind Semaphore Breakwater (i.e., not too fine).

All inlets should be designed to be able to operate as discharge points, to maximise the flexibility. While storm erosion is typically small in comparison to the store of sand available in areas where sand is accreting, the response of the coastline to different seasonal and medium-term drivers is not readily predictable. Building as much flexibility into the system as possible is seen as a sensible design strategy.

The final pipeline design and operating strategy should be informed through a detailed and timely monitoring program covering the entire area of interest (cells 3 to

7). Ongoing decisions can then be tailored to address issues and modified as the understanding of the beach responses improves.

7 Conclusions and Recommendations

7.1 Key Conclusions

7.1.1 Overall

Historically, sand moved relatively freely from south to north along Adelaide's metropolitan coastline. That movement along Adelaide's northern beaches is now affected by structures, such as those at the entrance to the Patawalonga, West Beach Boat Harbour and Semaphore. The artificially created outlet to the Torrens River and jetties along the length of the beach also have some impact on sand movement and the resulting erosion and accretion patterns.

The beaches have been actively managed for around half a century, following the realisation that development which had occurred near the coastline was being threatened by ongoing, natural recession. Initially, management of the coastline included importation of sand from external (offshore) sources. These large-scale beach nourishment operations ceased in the latter half of the 1990s and there is evidence indicating that those nourishment operations continued to have a positive impact on Adelaide's northern beaches until around 2010.

Since 2010, significant erosion at the southern end of West Beach, north of the West Beach Boat Harbour, has been an ongoing management issue. Analysis presented in this report examined the coastline between West Beach Boat Harbour and North Haven. At North Haven, the southern breakwater at the entrance to Port Adelaide River presently acts as a terminus for sand transported northwards along Adelaide's metropolitan coastline.

Sand transport along Adelaide's northern beaches has therefore changed irreversibly, and the coastline continues to adjust to the modified conditions. Management of the beaches in discrete sections (or 'cells') is now the most effective approach. While management can be effectively achieved by dividing the beach into cells, transport across the cell boundaries between West Beach and North Haven still occurs (identified as cells 3 to 6, Department for Environment and Heritage (2005)). Where features of the coastline, such as the Semaphore Breakwater and Torrens outlet, may slow transport and encourage sand to settle and accumulate, sand is still ultimately able to build up and bypass these features.

While management can be optimised by carefully handling the sand already present within the system, external sand sources will be required in future if the existing beach locations and alignments are to be maintained. If the expectation is to retain beaches in the present location in a future which includes ongoing sea level rise, the need for sand from external sources could be expected to increase over time.

Sand is continuing to accrete on the northern metropolitan beaches of Adelaide, mainly in cells 5 (Semaphore Park) and 6 (Semaphore and Largs Bay). The source of this sand is erosion from the beaches further south with that loss presently concentrated around West Beach. To maintain the beach, sand must be artificially replaced at the same rate at which it is being lost. The relocation of sand from cells 5 and 6 to replenish the southern end of West Beach (cell 3) is a sensible and justifiable component of the sand recycling strategy presently adopted.

Any sand relocation operations will have an impact on adjacent beaches and given the dominant south to north movement of sand, will eventually impact on beaches to the north. Where sand is removed from an area, there will be an initial reduction in the amount of sand transported northwards past that area. This will manifest as a reduction in the beach accretion rate to the north or, if sand is extracted at a rate which is too high, could result in recession of the beach. For this reason, the most sensible location for sand removal is from locations where sand is known to be actively accumulating, such as at Semaphore Park and around Largs.

7.1.2 West Beach

The West Beach Boat Harbour intersects alongshore sand supply from the south and, for the foreseeable future, it is recommended that management assume there is no long-term supply of sand from the south.

Based on that assumption, a recent assessment by DHI (2018) estimated that there was a potential alongshore sediment transport averaging around 100,000m^3/yr with potential variation between 50,000 and 150,000m^3/yr.

DHI's estimate was based on surveyed profiles between 2011 and 2017. In revisiting these numbers, we arrived at similar values (~90,000m^3/yr). However, we also completed sensitivity testing using surveyed profiles from 2010, 2019 and 2021, with those years selected as more surveyed profiles were available allowing a more accurate assessment. We found that consideration of longer periods (2010-2019 and 2010-2021) resulted in annualised potential sediment transport rates of closer to 50,000m^3/yr, which is more in keeping with rates estimated by previous research (e.g., Department for Environment and Heritage, 2005).

Our analysis indicates that sand relocation operations over the past decade have significantly mitigated against erosion that would have otherwise occurred at the southern end of West Beach.

Importantly, values indicated in preceding paragraphs refer to <u>potential</u> alongshore sediment transport rates. As transport is assumed to be blocked by West Beach Boat Harbour, there is a <u>deficit</u> in sand transport to the north of the boat harbour. To meet this deficit, sand is eroded from West Beach, mostly from the south of the SLSC revetment. An average deficit of somewhere between 50,000 to 100,000m^3/yr could be reasonably expected, with these values representing the typical yearly amount that needs to be placed on West Beach to maintain it in its present location. However, during some years, these values may be exceeded.

Quoted annual average deficits are determined by averaging behaviour over several years. Losses in any single year may exceed or be significantly lower than the average value. Losses typically occur over a short timeframe (storm erosion) whereas recovery and accretion processes tend to be far more gradual. For these reasons, the timeframe over which averaging occurs and the spatial distribution of available surveyed profiles are very important consideration, and largely explains the differences between our calculations of around 50,000m^3/yr and those reported by DHI.

7.1.3 Semaphore and Largs

The sand that has accumulated and continues to accumulate north of the Semaphore Jetty to North Haven over many decades/centuries has been transported from beaches further south under the action of waves.

The pattern of accumulation in these areas is readily observable by comparing different dates of vertical digital aerial photography and satellite imagery, and through the calculation of volumes using surveyed beach profiles. Measures such as location of the shoreline or the front face of the dune all reflect this accretion. Rates of accretion determined by our analysis are similar to those derived by Water Technology (2020) and we conclude that those estimates are a robust basis for decision making.

Sand can be safely removed from areas of the beach where accumulation continues to occur without adversely affecting the character of the beach, providing that (i) sand is not removed at a rate faster than it is accumulating, and (ii) sand harvesting is carried out carefully, and rigorously monitored to adapt locations of harvesting if necessary.

The further north that sand is harvested for backpassing, the less potential there is for adverse impacts elsewhere. Areas north of Largs Jetty, where the beach has accreted more than 30m over the past decade are particularly suitable for sand harvesting.

7.2 Key Recommendations

7.2.1 Pipeline Design and Operation

The following key recommendations are made regarding pipeline design and operation:

- If funding can be made available; the pipeline should be extended as far north as possible beyond Largs Jetty. If not, the design should consider the possibility that this may occur in future, and due consideration of the future feasibility of this extension made.

- The pipeline design, including the pipeline corridor, inlet, outlet and beach access locations should include adequate allowance for beach erosion over the design life of the infrastructure.
- When planning beach management activities, be they beach protection works, sand sourcing or sand placement, it needs to be acknowledged that they will result in changes to the sediment movement and volumes in adjacent areas or further downdrift over time. The cumulative impact of these changes must be considered.
- Small and frequent responses are preferable to infrequent large scale sand relocation operations. A sand pumping system with multiple configurable inlets and outlets should provide flexibility in managing the beach.

More detail on design considerations and a discussion of inlet locations is presented in Section 6.

7.2.2 Ongoing Data Collection to Inform Management

Ideally, sand management operations should be responsive, using recently collected data on beach behaviour, and its subsequent analysis (see next section). We believe that successful future sand management will be most effective if informed by collecting, standardising and robustly analysing beach condition data. The following recommendations are made:

- Response of the beach to the present Phase 1 works should be monitored carefully. The greatest scope for impact will occur downdrift of the harvest locations and monitoring should be used to confirm that the impacts are acceptable. If unforeseen changes occur, future harvesting of sand from these locations should take note of the recorded behaviour and adjustments made accordingly. We consider that survey by drone would provide a suitable means to gather frequent and comprehensive survey data over coming months from those current harvesting areas.
- The existing beach profile data set is invaluable and should continue being extended in the medium term, noting that mature remote sensing technologies are also useful and may eventually supersede the functionality provided by ground-based survey (e.g., LiDAR/LADS, described below). If possible, all profiles should be captured annually. We note (see Appendix A) that there are substantial gaps at many of the established profile locations.
- Careful consideration should be given to developing beach response ‘triggers’ which would govern certain management actions. For example, it could be agreed that the dune within sand harvesting areas should not erode beyond a particular location. Should this performance indicator be exceeded, harvesting

should cease with subsequent monitoring undertaken to confirm that ongoing natural recovery is occurring. If the beach continues to recede, beach repair should be considered.

- Trigger based management could involve monitoring and responding to beach volumes, beach widths and or dune locations. In determining triggers for sand sourcing and placement activities the definitions and the way in which triggers will be used must be clearly defined and agreed with key stakeholders to increase transparency and minimise the potential for misunderstanding. Decisions on how and when sand sourcing and placement should occur should be discerned with input from stakeholders including the community.

- DEW should investigate the feasibility of collecting yearly, repeated and comprehensive LiDAR/LADS survey of the full beach area being managed. For cost effectiveness, DEW may also consider extending survey to other areas of interest along the South Australian coastline. Such survey, particularly LADS, provides a far more detailed picture of ongoing processes and can be captured over a short time window. These data remove difficulties surrounding the time taken to complete ground survey and the need to spatially interpolate between profiles to calculate volumes. Such data sets could eventually replace profile surveys and would remove much of the guesswork associated with the planning of sand relocation activities.

- While survey and/or remotely sensed elevation data will continue to provide a very useful annual snapshot of conditions (with typically capture over summer) readily available satellite imagery can be used to inform more responsive activities. An example of analysis based on satellite derived shorelines is provided in this study and reveals patterns consistent with the findings of other analytical techniques. However more frequent (e.g., monthly), accurate and targeted results specific to the Adelaide metropolitan coastline could be derived. In particular, the shorelines used in this study (as mapped by Geosciences Australia) relied on relatively coarse satellite imagery (30m pixel size), whereas coverage is now provided by the European Space Agency's Sentinel-2 mission (10m pixel size) and by commercial offerings such as those from Planet Labs (~4m pixel size with 'daily' revisit times). Satellite offerings are not yet mature enough to provide regular updates on beach elevations, so analysis is limited to determining the plan location of different features on the beach (e.g., shoreline, edge of dune vegetation).

7.2.3 Standardised Data Analysis

For the beach to remain in a 'dynamic equilibrium', the amount of sand in a defined alongshore 'cell' needs to remain approximately constant over time. This means that any sand which enters the cell (either by transport from the south, or placement during nourishment activities) must equal the sand volume moved out of the cell (either by natural wave transport to the north or removal by artificial means: e.g., scraping and trucking or pumping).

Understanding how volumes have changed is important if management actions are to balance the sediment budget. If operation of the pipeline is to be responsive, this means that:

1 Frequent and detailed monitoring will be required, considering the recommendation from the preceding section; and

2 Routine analysis will need to be completed using standardised techniques and definitions.

We recommend annual analyses using the following guidance:

- Noting that beach management activities typically occur during the period between late autumn and early spring, profile survey should be captured before the end of the calendar year or as soon as possible afterwards.
- Analysis should be completed annually during January/February to inform sand recycling and nourishment activities during the subsequent period for beach management.
- The following parameters should be determined at each surveyed profile alongside their difference from year to year and trends:
    - Beach width, which could be determined as the distance between the mean low water mark and the 2m contour.
    - Dune location, for which the 2m contour can be used as a proxy for the front of the foredune, and 3m could apply as a proxy for the more robustly vegetated dune.
    - Sand volume (m^3/m) comprising the area of the profile between the origin of the profile and above -5.0m AHD.
    - Dune buffer volume (m^3/m above 1.0m AHD).

The above parameters and their changes during each calendar year should be tabulated and plotted alongshore to determine patterns of shoreline evolution with time.

Beach width and dune location are of aesthetic interest to the community and require maintenance. However, changes in overall volume, and spatial and temporal trends are of more importance when understanding where and how sand is moving and what future behaviour is likely to be.

If desired, DEW should consider formalising and annually updating a "Box Model" of the type outlined in Section 4.5. This would require robust record keeping of all sand relocation activities, so that these can be incorporated into the required modelling.

7.2.4 Other

The South Australian Government should continue to seek suitable external sand sources. Perfect management of the existing coastline where no sand is lost from the area of interest and sand is efficiently recycled from north to south (e.g., Semaphore-Largs to West Beach) can address immediate issues. However, with time, sand will continue to move beyond areas where it is easily accessible (e.g., towards North Haven, with smaller amounts landward, and offshore). Offshore movement of sand, as is postulated with a rising sea level, may become more significant in future. Understanding where sand may need to be imported from in future is important to enable timely mitigation against this process.

For similar reasons, we recommend that past analysis of the suitability of sand grain Semaphore and Largs Bay area be augmented. We note that a recent report based on sampling from the intertidal zone in this area (Department for Environment and Water, 2019) considered this issue. It was found, generally, that sand became finer with distance northwards as expected, and that eventually sand became so fine that it is unlikely to be economical for use on beaches further south. However, this economic assessment is sensitive to the method being considered to transport sand the sand. Ultimately, the calculations indicate that up to four to six times as much volume of the finer sand near North Haven would be required as a replacement for sand eroded from Brighton, based on a single sample collected in 1982. There is no reported sediment analysis from West Beach.

However, a convincing spatial pattern of grain size variation between Strathfield Terrace, located some 1.5km north of Largs Jetty, and Recreation Parade, to the south of Semaphore Park does not seem to be present in the data. We note that grain size can be sensitive to the wave microclimate at certain locations. For example, sampling from different sides of a salient (e.g., behind Semaphore Breakwater) will yield different results, as will sampling from different sides of a jetty.

Similarly, results are expected to change with time as sand moves and the local shape of the shoreline changes. More sampling and testing will help to provide more insight regarding the variability of grain sizes in space and time. It will also provide a more complete understanding of the economics associated with relocating sand from north of Largs Jetty to locations such as West Beach, particularly considering the expense associated with large scale trucking of sand from inland sources.

8 References

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Appendix A Beach Profile Survey Dates

Profile	Established	% Years Surveyed	Missing Years (where < 70% temporal coverage)
		Cell 7	
200122	1986	57%	1988-2000, 2001, 2009, 2018
		Cell 6	
200074	1976	64%	1980-82, 1984-86, 1988, 1990-92, 1994, 1996, 1998, 2001, 2009, 2018
200001	1975	78%	
200002	1975	72%	
200129	1994	81%	
200003	1975	61%	1980-85,1987-92, 1994, 1996, 1998, 2001, 2009, 2018
200004	1975	72%	
200005	1975	65%	1980-85, 1988, 1990-92, 1994, 1996-98, 2001, 2009
200006	1975	80%	
		Cell 5	
200007	1975	78%	
200008	1975	85%	
200009	1975	87%	
200010	1975	89%	
		Cell 4	
200130	1994	81%	
200131	1994	81%	
200011	1975	76%	
200132	1994	81%	
200012	1975	80%	
200133	1994	89%	
200013	1975	70%	
200014	1975	76%	
200015	1975	76%	
200016	1975	80%	
200017	1975	85%	
200018	1975	78%	
200069	1976	51%	1980-87, 1989-92, 1994-96, 1998, 2001, 2014-2018
200070	1976	51%	1980-88, 1990-92, 1994, 1996, 1998, 2001, 2014-18, 2020
200019	1975	80%	
		Cell 3	
200071	1976	62%	1980-88, 1990-92, 1994-96, 1998, 2001
200072	1976	78%	
200020	1975	72%	
200076	1976	18%	1978-2007, 2012-18
200078	1976	49%	1978-79, 1981, 1983-86, 1990-92, 1994, 1996-2002, 2014-18
200082	1976	44%	1978-81, 1983-85, 1990-92, 1994-2002, 2011, 2014-18
200085	1976	40%	1978-87, 1990-92, 1994, 1996-2002, 2005, 2014-18
200021	1975	80%	
200093	1976	53%	1979, 1983-85, 1989-92, 1994, 1996-2002, 2014-18
200096	1976	51%	1979, 1981, 1983-85, 1990-92, 1994, 1996-2002, 2011, 2014-18