West Beach Coastal Processes Modelling

Assessment of Coastal Management Options

Final 3.0

DEWNR

Final Report

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The expert in **WATER ENVIRONMENTS**

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Prepared for	DEWNR
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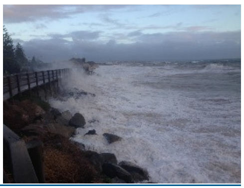

West Beach May 2016

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1 Introduction

DHI was engaged by the Department of Environment, Water and Natural Resources (DEWNR) to undertake an investigation of the West Beach sediment cell to identify the causes of long term and ongoing recession of the shoreline and to evaluate a range of management options for this sediment cell.

The report documents the investigation undertaken to investigate the causes of erosion at West Beach and the evaluation of management options to mitigate the erosion and improve the amenity of the West Beach sediment cell.

The West Beach sediment cell extends from north of the Adelaide Shores boat haven to the Torrens Outlet and is displayed below in Figure 1-1.

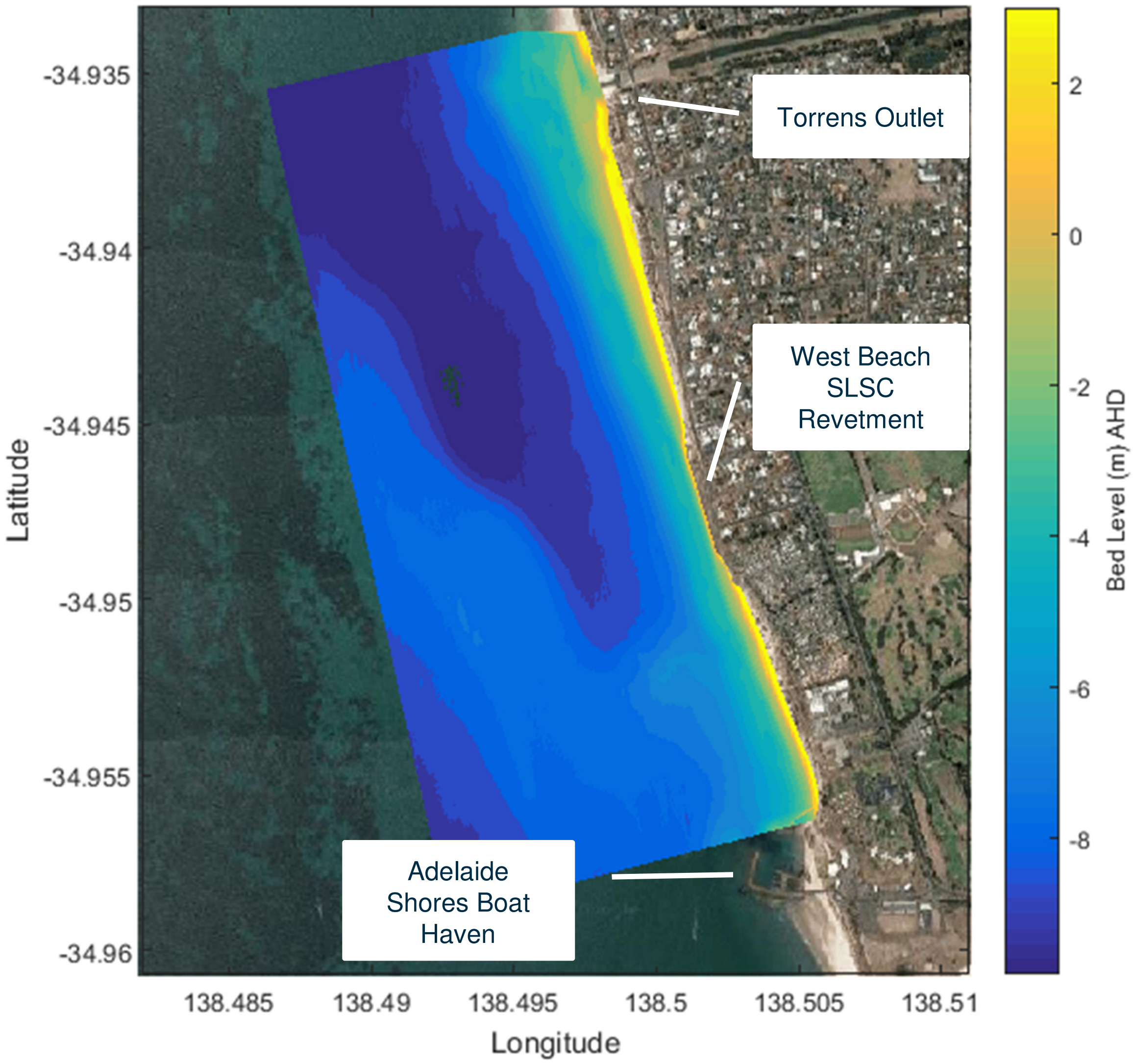


Figure 1-1 West Beach Sediment Cell Overview

2 Background

Active management of West Beach sediment cell through renourishment activities has been undertaken since the 1970's by DEWNR and its predecessors. Ongoing nourishment of West Beach has been undertaken in response to the limited natural sand supply available from the updrift, southern beaches as well as due to the impact of the development (circa 1996) of the Glenelg Harbour and Adelaide Shores boat haven, which intercepted the northward sand supply to West Beach.

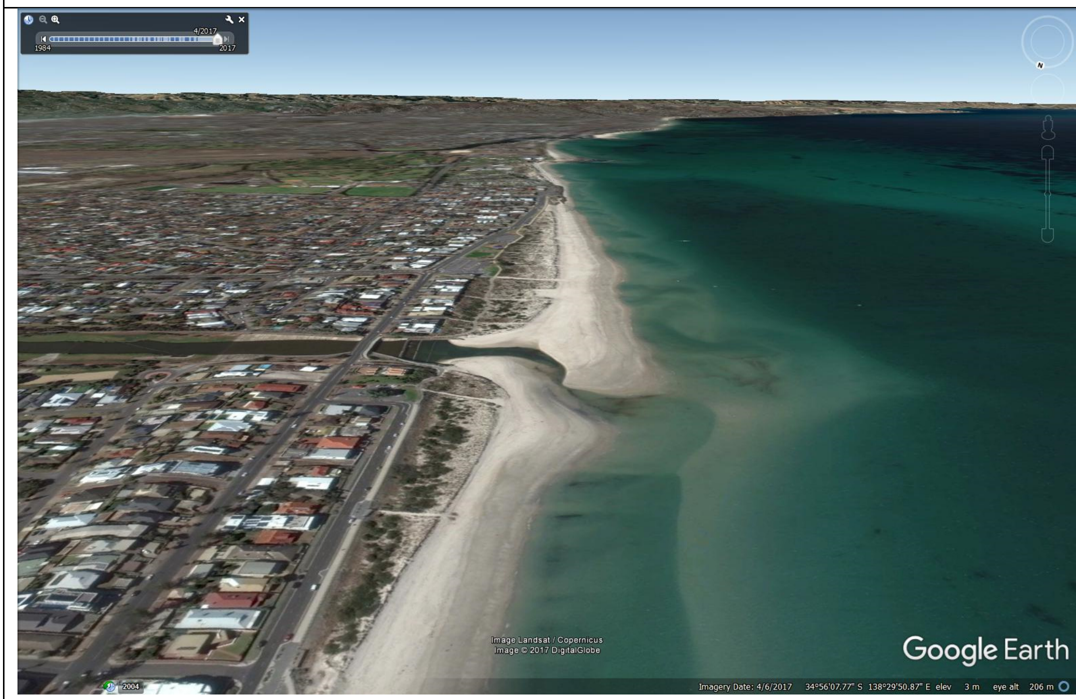
The current management strategy for West Beach was developed as part of the Adelaide's Living Beaches Strategy (ALB) by the then Department of Environment and Heritage in 2005. The analysis undertaken as part of the development of the ALB strategy determined an annual net longshore transport capacity at West Beach of approximately 50,000m^3, although particular uncertainty in the model estimates for the West Beach sediment cell were noted. Based on this underlying longshore transport capacity, the following management strategy was adopted for West Beach:

- Bypassing of approximately a net 10,000m^3/yr of sand and seagrass past the Adelaide Shore boat haven onto West Beach;
- Backpass 40,000m^3/yr of sand from Torrens Outlet to West Beach;

In 2012 a backpass pipeline was commissioned to enable sand to be harvested from the Torrens Outlet and pumped back to the Adelaide Shores dunes to effect nourishment of the West Beach sediment cell without the need for large numbers of truck movements on local streets.

Despite large annual backpass campaigns of approximately 65,000m^3/yr on average being undertaken by DEWNR over the last approximately 7 years, significant, ongoing recession of the shoreline between the Adelaide Shores boat harbor and West Beach Surf Life Saving Club (SLSC) has been observed.

West Beach Circa 1968 (DEWNR)



West Beach April 2017 (Google Earth)

Figure 2-1 West Beach Comparison 1968 - 2017

3 Scope of Works

The scope of works commissioned by DEWNR and undertaken by DHI has consisted of the following five main parts:

1. Analysis of available data to develop a conceptual model of the coastal processes causing erosion at West Beach;
2. Setup and verification of a detailed coastal sediment transport model of the West Beach sediment cell;
3. Assessment of a number of alternative coastal management options for West beach with the model;
4. Assessment of options to mitigate seagrass ingress and wave action in the Adelaide Shore Boat Haven;
5. Preparation of a study report documenting the project methodology, modelling results and recommendations.

4 Analysis of Available Data

Analysis of relevant available data for West Beach and adjacent sediment cells has been undertaken to develop a robust conceptual model of the contemporary coastal processes at West Beach and to attempt to identify the underlying cause(s) of the observed erosion. The analysis has also provided a basis for informing the setup of the sediment transport model and for providing an independent check on the modelled transport capacities

The analysis of the relevant available data has included the following:

- Review of historic nourishment volume records;
- Analysis of historical coastal profiles surveys; and
- Analysis of available detailed bathymetry data.

The following sections document the analysis of relevant available data for West Beach.

4.1 Historical Nourishment Volumes

Extensive nourishment programs involving by-passing, back-passing and replenishment from external sediment sources has been undertaken for decades on Adelaide's Metropolitan beaches, including West Beach.

As the nourishment activities on the study area shorelines are significant and have at times been of the same order as the natural transport capacities, an appreciation of the extent of these nourishment programs is required to assist to interpret historical changes to littoral volumes and to differentiate natural transport processes from management interventions.

Table 4-1 shows the management intervention volume records (2011- present) for the West Beach sediment cell, including Torrens Outlet, provided by DEWNR. The management interventions over this period can be essentially grouped as followed:

- Back-passing from Torrens Outlet to Adelaide Shores Dunes (~55,000m^3/yr);
- Forward-passing from Torrens Outlet to Henley Beach sediment cell (~12,500m^3/yr); and
- Replenishment from external beach sediment cells (51,000m^3 one-off in 2016).

In addition, regular maintenance dredging of the Adelaide Shores boat haven is undertaken by DEWNR. While it is not possible to determine the precise volumes of sand dredged and placed in the spoil ground on the northern side of the boat haven, as the dredged material typically comprises very significant quantities of seagrass wrack, however, it is considered relatively small and in the order of 5,000-10,000m^3/yr.

For each year the West Beach nourishment volumes have been summed up and plotted in the bar chart shown in Figure 4-1. It is seen that year 2011 and 2016 had very large nourishment volumes and that most of the sand nourished at West Beach was taken from Torrens Outlet, i.e. it was back-passed within the West Beach sediment cell.

Table 4-1: Nourishment volumes at West Beach provided by DEWNR. The lines marked with red show volumes which were pumped

Year	Month	VOLUME m3 in-situ	Method	Collection Area	Deposition Area
2017	May	29,300	Trucks	Torrens outlet	Adelaide Shores Dunes (WB Trust)
2016	Nov	20,800	Trucks	Pt Malcolm (Semaphore breakwater)	Adelaide Shores Dunes (WB Trust)
2016	Aug	9,700	Trucks	Torrens outlet	Henley Beach South
2016	July-Aug	8,900	Trucks	Adelaide Shores Harbour (beach within harbour)	Adelaide Shores Dunes (WB Trust)
2016	July-Aug	4,100	Land plane	South of Torrens outlet	Rockingham dunes (West Beach)
2016	May-Jun	30,200	Trucks	Pt Malcolm (Semaphore breakwater)	Adelaide Shores Dunes (WB Trust)
2016	Mar-Jun	71,000	Pumped	Torrens outlet	Adelaide Shores Dunes (WB Trust)
2015	Nov	1,700	Land plane	South of Torrens outlet	Rockingham dunes (West Beach)
2015	Nov	10,100	Trucks	Torrens outlet	Henley Beach South
2015	Nov	7,500	Trucks	Adelaide Shores Harbour (beach within harbour)	Adelaide Shores Dunes (WB Trust)
2015	Apr-Jun	50,000	Pumped	Torrens outlet	Adelaide Shores Dunes (WB Trust)
2014	Nov	7,100	Trucks	Torrens outlet	Henley Beach South
2014	Aug	8,900	Trucks	Pt Malcolm (Semaphore breakwater)	Adelaide Shores Dunes (WB Trust)
2014	May-Aug	66,000	Pumped	Torrens outlet	Adelaide Shores Dunes (WB Trust)
2013	July	17,700	Trucks	Torrens outlet	Henley Beach South
2013	Jun-Sep	31,000	Pumped	Torrens outlet	Adelaide Shores Dunes (WB Trust)
2012	Sept	15,400	Trucks	Adelaide Shores Harbour (beach within harbour)	Adelaide Shores Dunes (WB Trust)
2012	Oct	17,700	Trucks	Torrens outlet	Henley Beach South
2012	Dec	10,500	Pumped	Torrens outlet	Adelaide Shores Dunes (WB Trust)
2011	Aug-Sep	53,000	Trucks	Torrens outlet	Adelaide Shores Dunes (WB Trust)
2011	May-Jun	57,000	Trucks	Torrens outlet	Adelaide Shores Dunes (WB Trust)

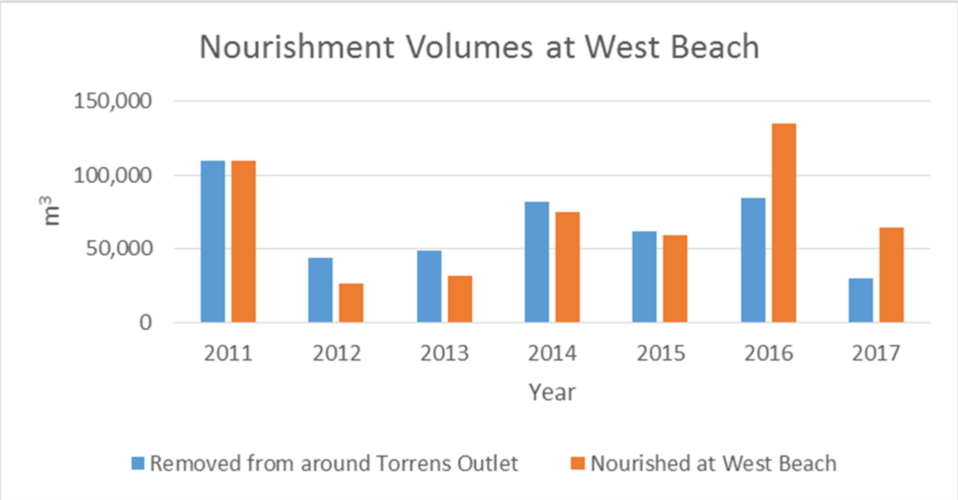


Figure 4-1: Historical Nourishment Volumes at West Beach

Historically, significant volumes of sediment were also introduced to the southern Adelaide beaches from external sand sources (either offshore or from the end of the littoral system at North Haven). Table 4-2 shows the records of external sand which has been nourished to Adelaide's metropolitan beaches from 1990 to 1999. It is noted that around 1.2 million m^3 of sand was added to the system over this period. This sand mainly nourished Brighton Beach and North Glenelg, both of which are up-drift (to the south) of West Beach. The significance of these major external nourishment campaigns in the 1990's on Adelaide's metropolitan beaches and West Beach are discussed in more detail in subsequent sections of this report.

Table 4-2: External sand nourished to Adelaides Metropolitan Beach. Received in file *External Sand Summary.xlsx* from DENWR on 5-7-2017.

Summary of Addition of External Sand to Adelaide's Metropolitan Beaches

Year	Volume	Source	Deposition	Start	Finish	Method
1990	100,603	Nth Haven dredging	Nth Glenelg	16-Jan-90	16-Mar-90	**Dredged**
1991	187,169	Pt Stanv (offshore)	Brighton	31-Jan-91	30-Apr-91	**Dredged**
1994	172,839	Pt Stanv (offshore)	Brighton	17-Jan-94	13-Apr-94	**Dredged**
1995-96	181,522	Pt Stanv (offshore)	Brighton	17-Nov-95	07-Feb-96	**Dredged**
1997-98	602,712	Pt Stanv (offshore)	Brighton	29-Oct-97	07-Feb-98	**Dredged**

4.2 Detailed Bathymetry Surveys

Detailed bathymetric surveys of the West Beach sediment cell have been undertaken by DEWNR. The surveys comprise of ~50m survey transects along the length of the sediment cell from the back of the dune to approximately 600 metres offshore in depths of 7-8m. The detailed surveys are available for 1990 and were repeated to support the present study in April 2017.

Analysis of the surface levels and volume differences (1990 – 2017) between the two surveys has been undertaken and are displayed below in Figure 4-2. Notable changes in the bathymetry of the West Beach sediment cell are documented as follows:

- Significant deepening (~-2m) of the nearshore zone along the length of the West Beach cell;
- Significant declines in the dune volumes both north and south of the seawall;
- Some localized accretion of sediment in the offshore bar feature, attached to the dredge spoil ground of the Adelaide Shores boat haven.

The littoral volumes of the two surveys, defined as the volume existing between the -5m and +5m AHD contour have been calculated for both surveys, the difference between the two littoral volumes show a decline of -437,130m^3 between the 1990 and 2017 bathymetric surveys of the West Beach sediment cell. This volume difference, calculated from two detailed surveys, is compared to the volume differences calculated from beach profile surveys over the same period in Section 4.3.2.

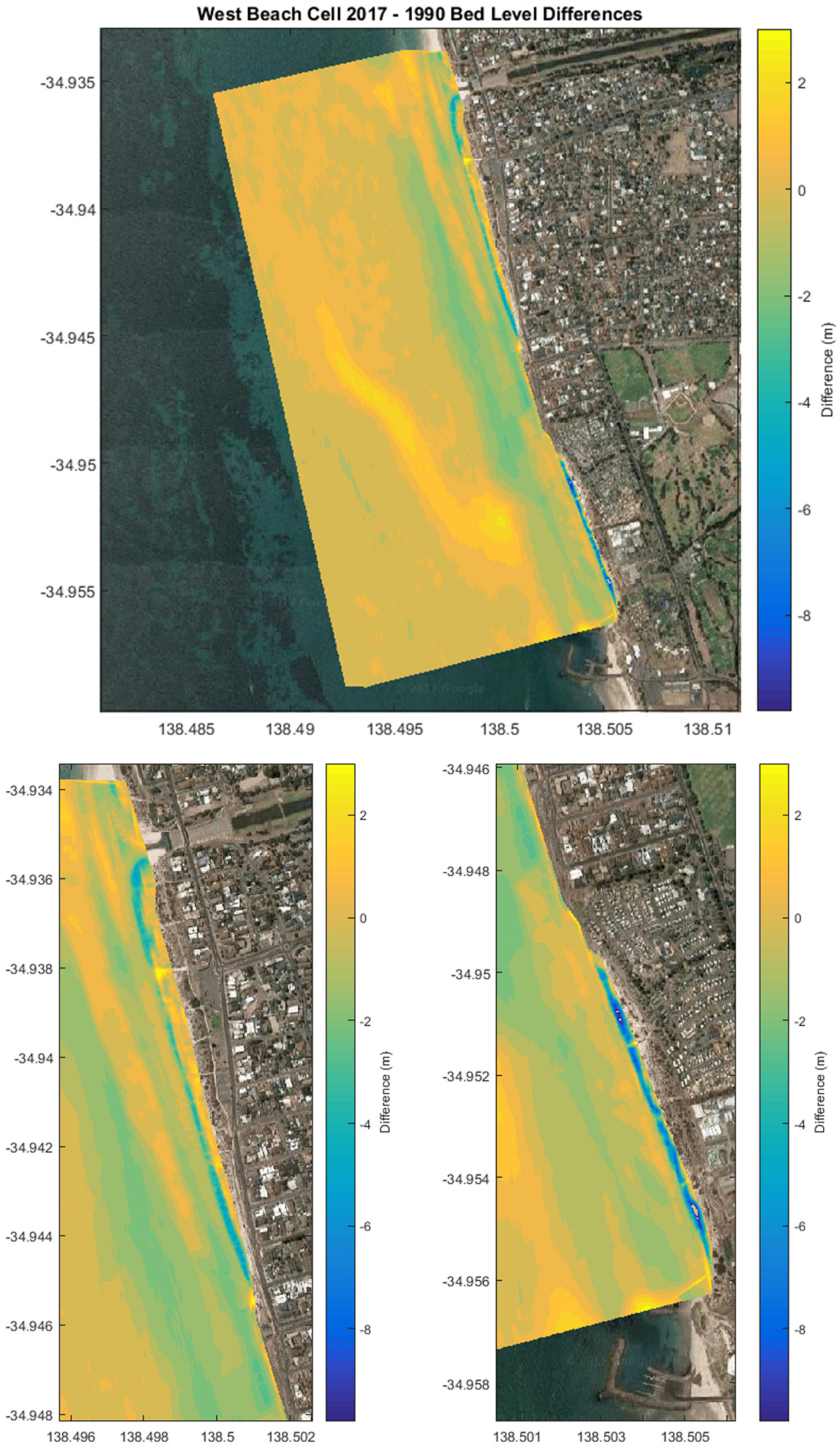


Figure 4-2 West Beach 2017-1990 Bed Level Differences

Comparison of the relative position of key surface elevation contours; -5m – approximate depth of closure, 0m – mean shoreline position and +2m – upper swash limit, between the 1990 and 2017 surveys are provided below in Figure 4-3 and Figure 4-4. The comparison of the relative contour positions provide insight into the distances and direction of the shoreline evolution between these two periods.

- The offshore shoal feature has slowly migrated north and inshore;
- No noticeable sustained change in subaerial beach orientation could be identified between the two surveys;
- The significant erosion which has occurred nearshore on West Beach has steepened the coastal profile and rotated the -5 m depth contour anti-clockwise, towards the equilibrium orientation with the prevailing wave climate.

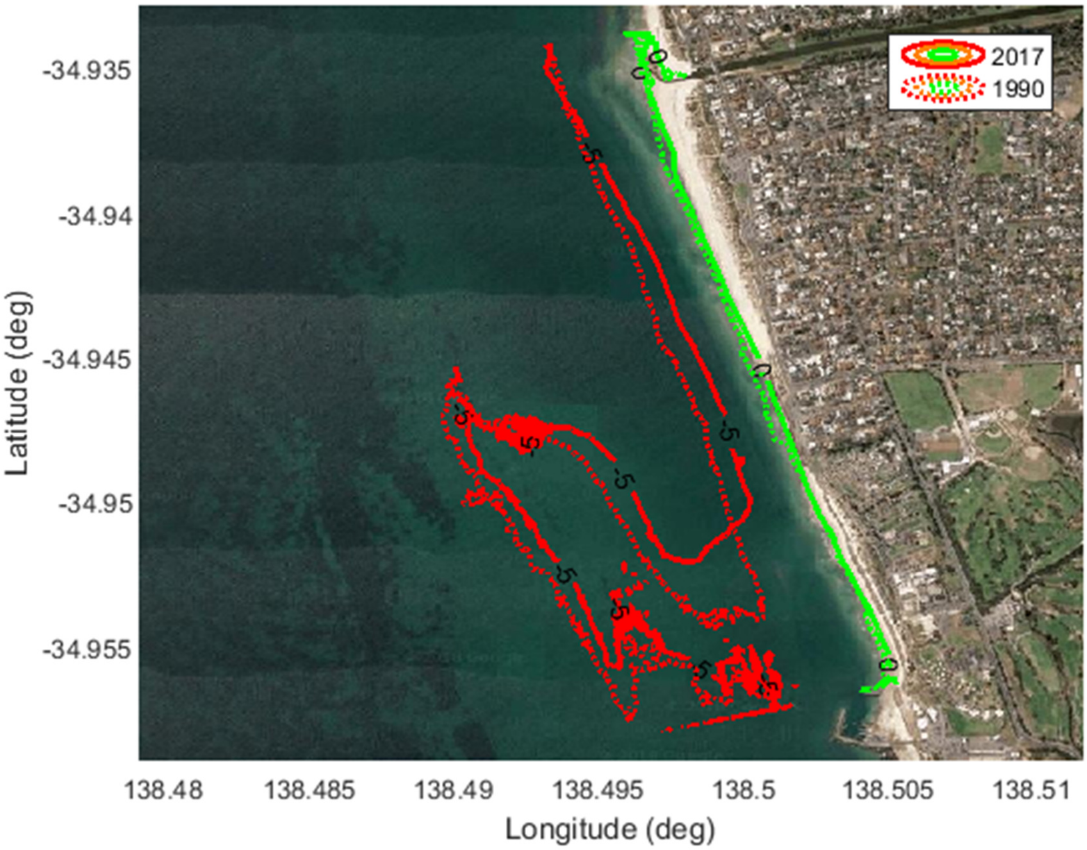


Figure 4-3: The -5 and 0m depth contours for both 1990 survey and 2017 survey.

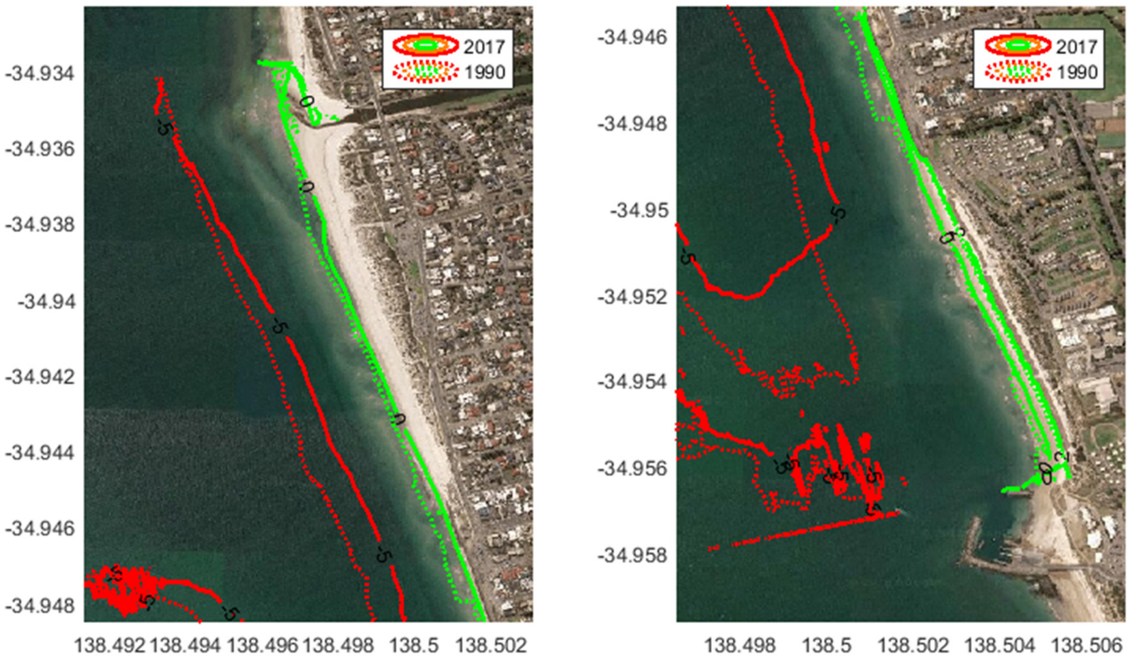


Figure 4-4: The -5 and 0m depth contour for both 1990 survey and 2017 survey, detailed on north (left) and south (right) end of the beach.

4.3 Coastal Profile Analysis

DEWNR and its predecessors have undertaken a continuous and extensive survey profile measurement program of the Adelaide Metropolitan shorelines since the mid 1970's. This coastal profile survey data set provides an extremely important resource for understanding the long term variations in the coastal processes and for quantifying the rates of sediment transport and littoral volume changes along the West Beach study area and adjacent sediment cells.

Surveyed coastal profiles for West Beach and adjacent shorelines were available for the locations shown in Figure 4-5. 8 of the profiles have been surveyed since 1976 and the rest since 1993.

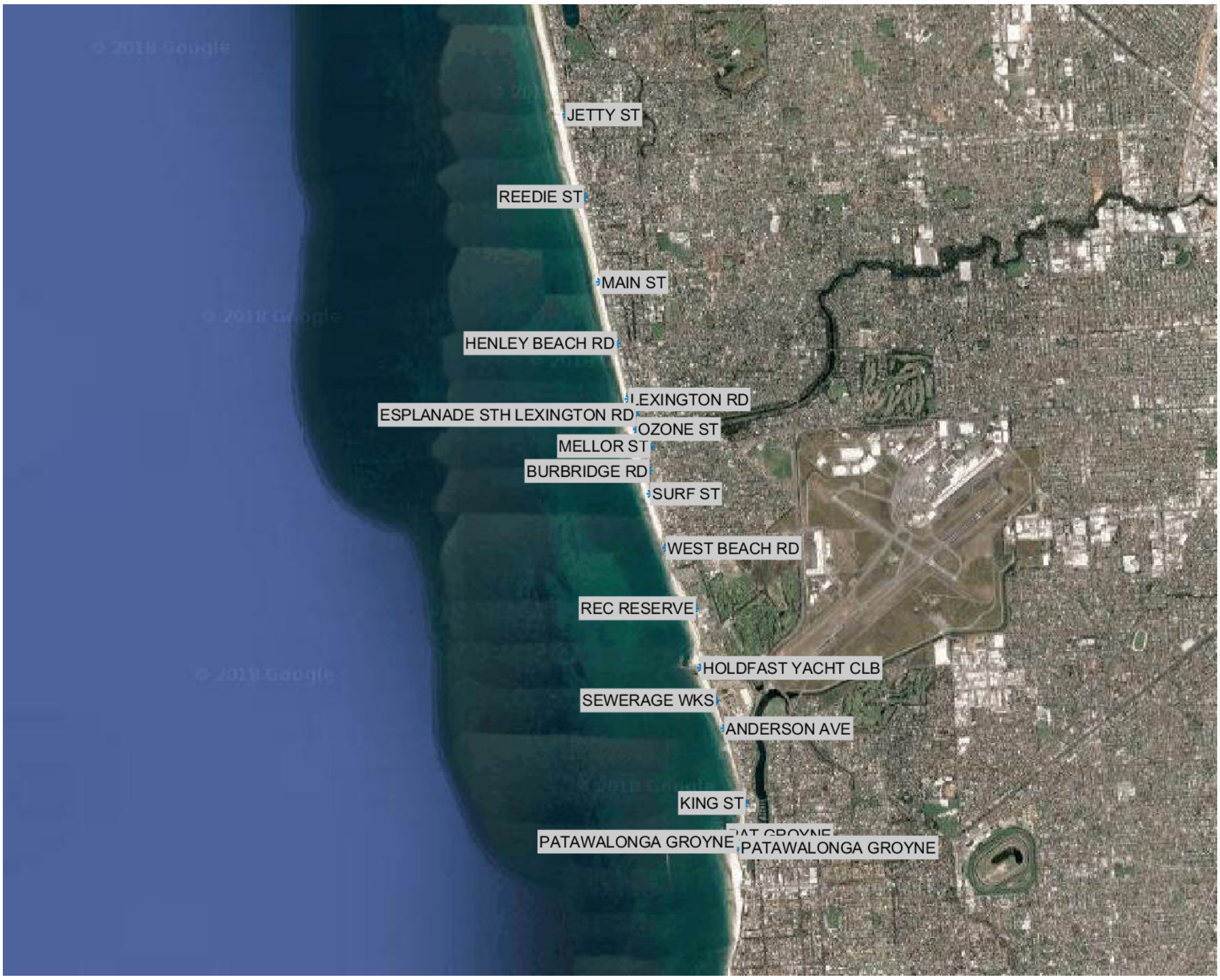


Figure 4-5: Locations of the measured coastal profiles in the vicinity of West Beach.

4.3.1 Examples of Eroding and Accreting Profiles

The coastal profile at the REC Reserve is shown in Figure 4-6, where all measured profiles are shown in grey and the first and last measured profile is highlighted in color. The figure shows that the coastal profile at the REC Reserve has experienced persistent erosion. The retreat of the dune at +2 m AHD is 30 m.

The erosion experienced at the REC Reserve is however not persistent along the entire study site, in the north end of the series at Jetty St (in the downdrift Henley Beach cell), the profile is accreting as shown in Figure 4-7, the advancement of the dune at +2 m AHD is 40 m at this profile.

It is also important to note that significant profile change in Figure 4-6 and Figure 4-7 is observed to depths down to approximately -5m AHD/MSL and this depth has been adopted as the approximate depth of closure for subsequent analysis of the littoral volume changes.

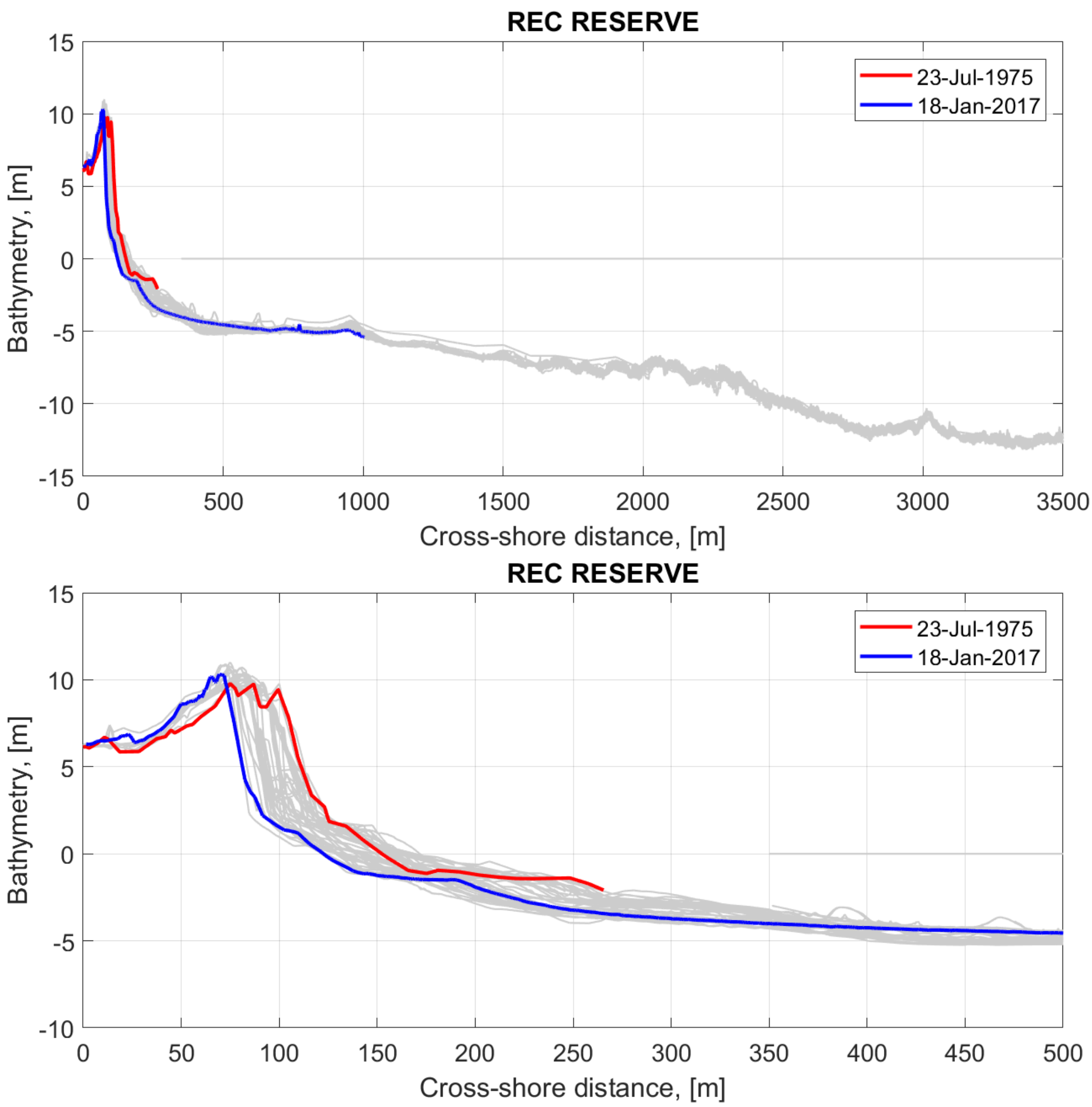


Figure 4-6: The measured coastal profiles at the REC Reserve. Full profile (top) and zoom at nearshore section (bottom).

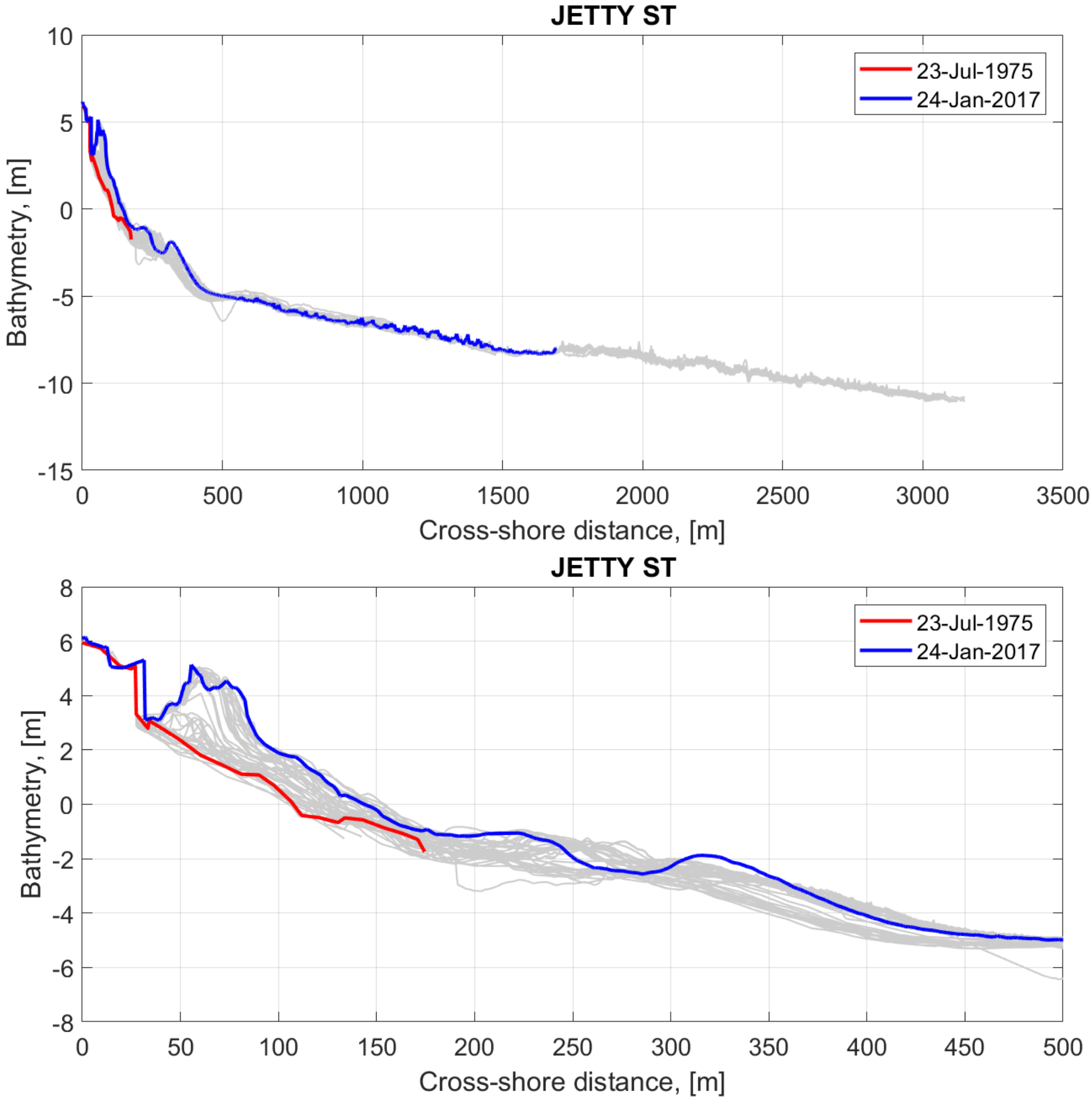


Figure 4-7: The measured coastal profiles at Jetty Street. Full profile (top) and zoom at nearshore section (bottom).

4.3.2 West Beach Cell Littoral Volume Changes

The annual change in littoral volumes has been calculated from the measured coastal profiles of the West Beach sediment cell and adjacent shorelines with the following methodology:

1. Integrating the volume of sand per metre between from the back of the dune system out to -5 m AHD as indicated in Figure 4-8. The beach volume per metre of beach length has been calculated for all available profiles. In case a measured profile does not extend below -5m this profile was not included in the analysis. Profiles not extending above 0 m were also excluded;

2. To reconcile the different timings of the all the surveys throughout the years, the volumes at each profile were interpolated in time to provide an estimated volume on Jan 1st for each year;

3. The total littoral volume is calculated by trapezoidal integration per metre between each surveyed profile. On some occasions some copying of profiles in space to better reflect

the actual variation in profiles along the shoreline such as at a discontinuity from a boat harbour for instance was undertaken.

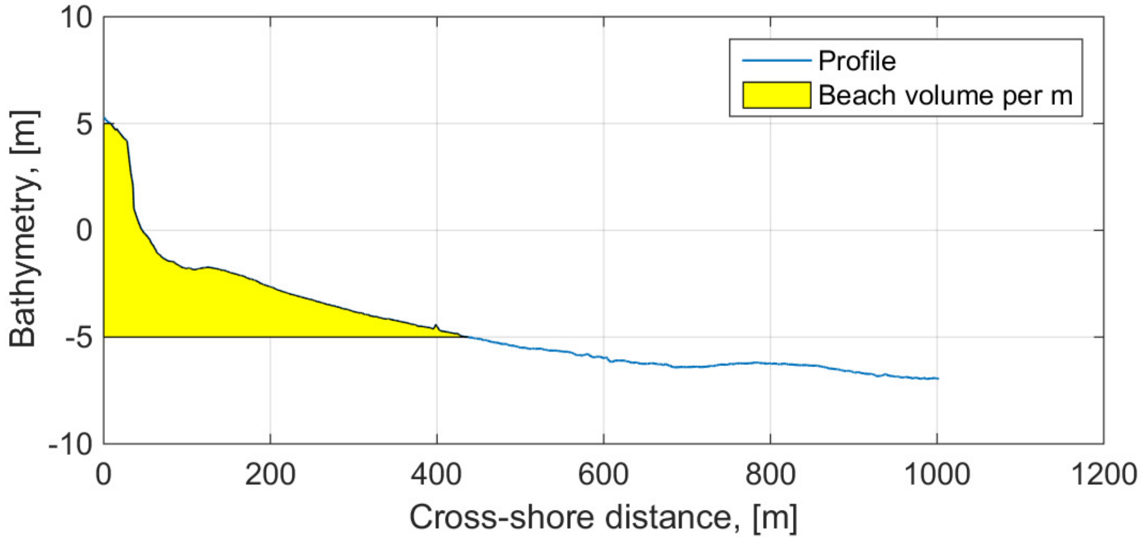


Figure 4-8: Sketch showing the beach volume per metre between +5 m and -5 m AHD.

The relative change in littoral volume per metre of shoreline length over time for all profiles is shown in Figure 4-9 and Figure 4-10. From these figures it is possible to identify the following:

- Profiles up-drift of the Glenelg Marina (Patawalonga Groyne) and updrift of the Adelaide Shores boat harbour (Holdfast Yacht Club now Adelaide Sailing Club) experienced large accretion between 1997 and 2005.
- At REC Reserve the beach volume generally decreases between 1976 and 2017, but with a few periods with increase most notably in 1995 and 2009; these increases are probably due to nourishment campaigns.
- At West Beach Rd the beach volume shows steady decrease in all surveys. North of West Beach Rd, at Surf St and Burbridge Rd the coastal profiles shows accretion until around 2004, but erosion since then.

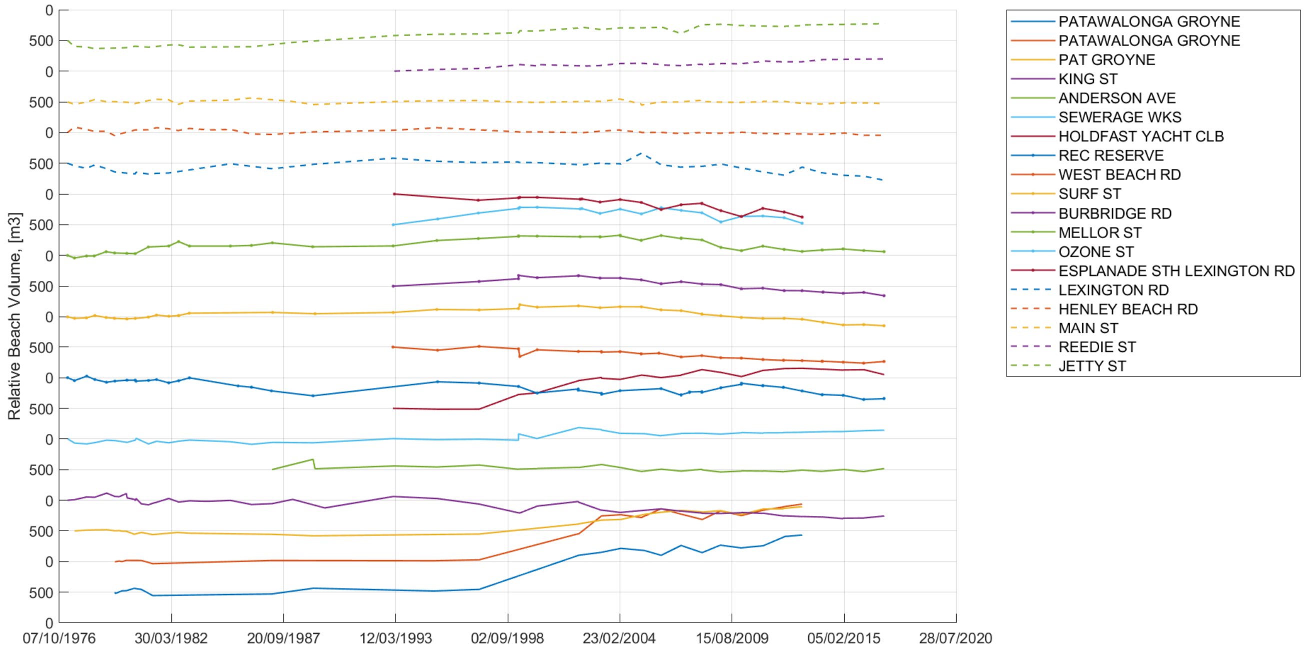


Figure 4-9: Relative change in profile volumes. Note that the absolute y-axis units are not real, a constant profile volume has been added to each profile such that profiles can be ordered from bottom to top in the plot according to their south-north location in Figure 4-5.

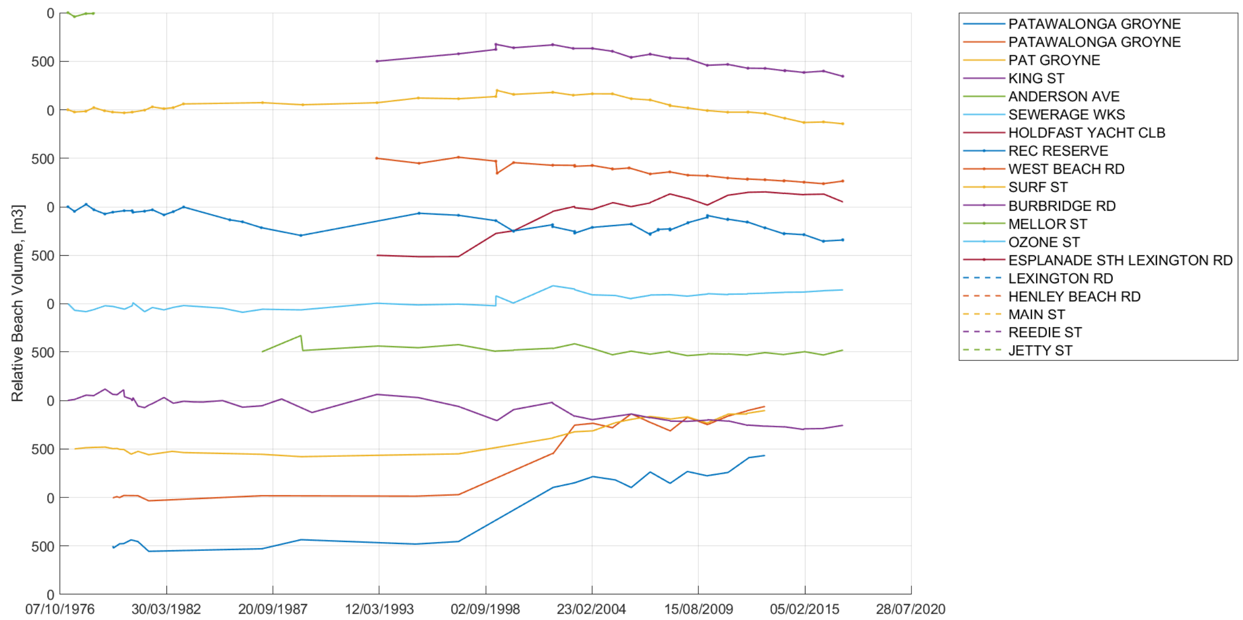


Figure 4-10: Zoom of Figure 4-9.

Based on the available surveys and known historical changes to the adjacent shorelines and their management, the profile analysis has been divided into the following time periods to ease interpretation:

- 1980-1993: Limited amount of survey lines;
- 1993-1997: Pre-harbour construction, large up-drift nourishment volumes;
- 1997-2001: Initial adjustment of beach volume up-drift harbours;
- 2001-2005: Later adjustment of beach volume up-drift harbours; and
- 2005-2011: Pre sand back pass pumping
- 2011-2017: Post sand back pass pumping

For each time period above, the change in coastal profile volumes have been integrated along the shoreline and the accumulated change in littoral volumes has been estimated within the West Beach sediment cell. The results of this analysis are displayed in Figure 4-11. Figure 4-11 shows the following observed historical changes to littoral volumes within the West Beach sediment cell:

- Prior to 1997, the shoreline from down-drift the *Holdfast Yacht Club* to *Torrens Outlet* (around Mellor St) was relatively stable or accreting sediment. It is noted that this period included large external sediment replenishment campaigns to the southern beaches and was prior to the construction of Glenelg Marina and Adelaide Shores boat haven.
- The construction of the Adelaide Shores boat haven caused a notable (~20,000 m^3/year) increase in the beach volume up-drift of the boat haven between 1997 and 2001. The large build up at the boat haven likely led to down-drift erosion between Holdfast Yacht Club and Surf St over this period.
- Between 2001 and 2005 the shoreline up-drift the Holdfast Yacht Club experienced erosion on the south end and accretion on the north end causing the normal to the shoreline orientation to turn slightly southward. During this period the shoreline at REC Reserve experienced small accretion while some erosion occurred at profiles from West Beach Rd to Lexington Rd.
- From 2005 to 2011 the shoreline up-drift the Holdfast Yacht Club is stable (no erosion/accretion). The down-drift shoreline accretes at the REC Reserve and significant erosion of approximately 40,000m^3/yr erodes from West Beach Rd to Henley Beach Rd.
- From 2011 to 2017 very significant down-drift erosion from REC Reserve to Mellor Street is observed at a rate of approximately 60,000m^3/yr.

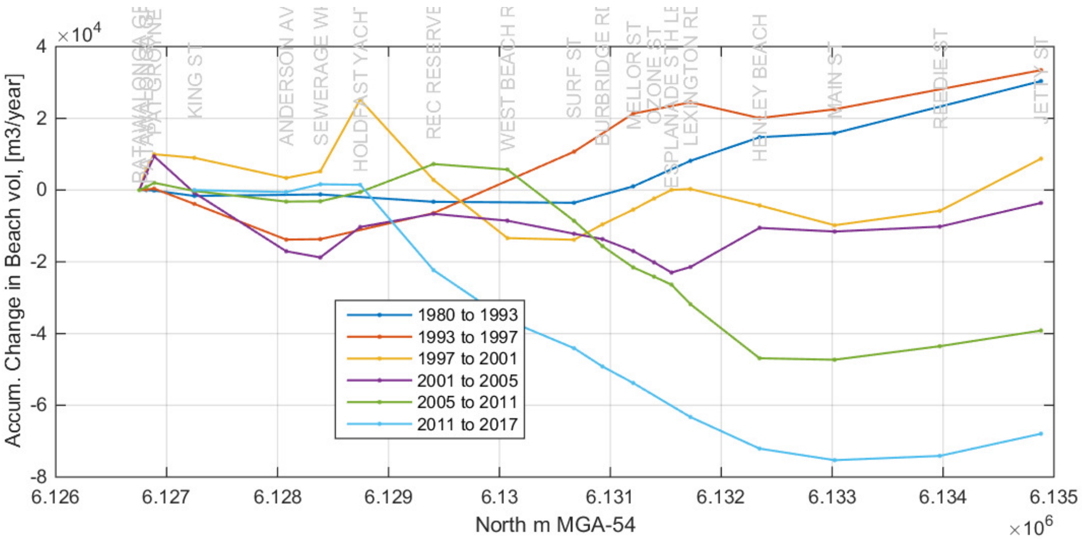


Figure 4-11 Accumulated change in littoral volumes along the West Beach and adjacent shorelines from south to north. Detailed explanation of the methodology applied to develop this figure is provided in Appendix A.

The change in littoral sediment volumes in the West Beach sediment cell over the entire period of available surveys relative to the 2005 volume is displayed below in Figure 4-11. Figure 4-11 indicates the following:

- Significant decline in sediment cell volume in the late 1980's and minimum volume equivalent to that which existed in 2013;
- Significant accreting volume prior to the harbour construction and following large up-drift nourishment campaigns through the 1990's;
- Steady decline in sediment cell volume post harbour construction in 1996-1997;
- Accelerating decline in sediment cell volume following commissioning of the back-pass pipeline from Torrens Outlet in 2011.
- A very significant overall decline in the West Beach sediment cell volume exceeding approximately 500,000m³ between the maximum in 1997 to 2016.

It should be noted from the analysis of the beach profile surveys below in Figure 4-12, that the volume difference between 1990 and 2017 is estimated at approximately -300,000m³. This is materially less than the -437,130m³ calculated from the detailed bathymetric surveys in Section 4.2. The cause of this discrepancy between the two different survey sources has not been identified but may be due to a combination of small differences in survey accuracy between successive surveys and the fact the spatial extents of the two survey sources of West Beach do not overlap exactly. Nevertheless, the magnitude of the estimated volume declines from both surveys is significant and valuable for informing coastal management decision making.

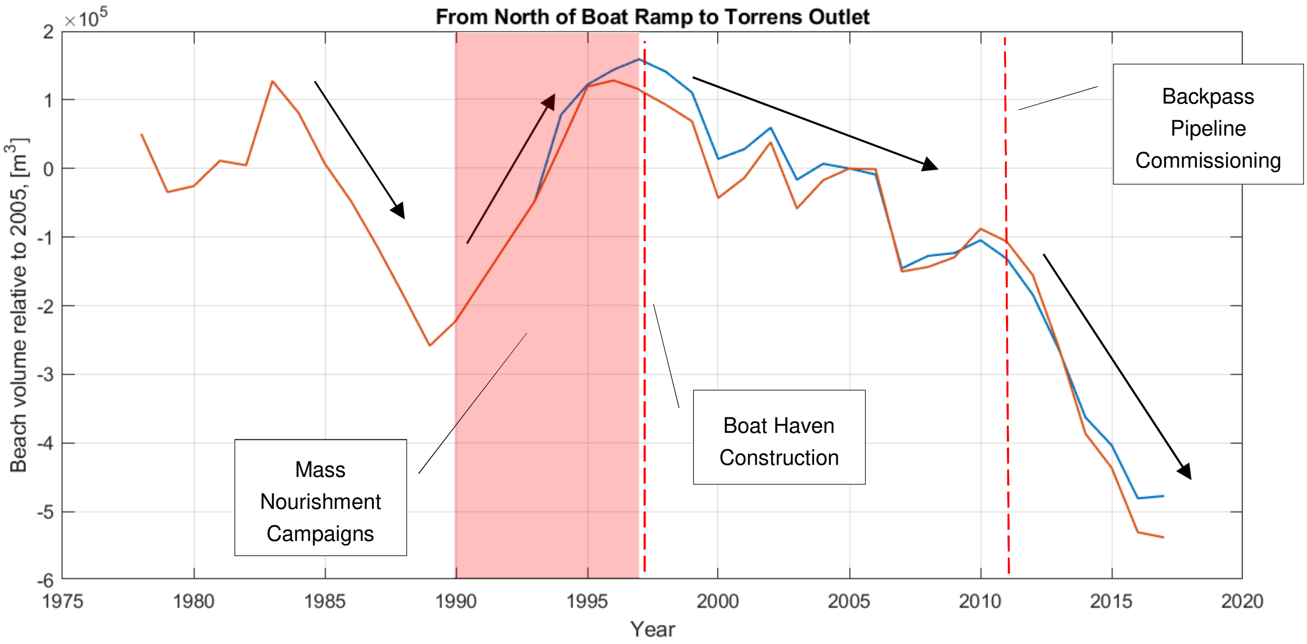


Figure 4-12 Change in West Beach sediment cell volumes relative to 2005 volume (Orange trace based on the 3 profiles available for entire historical record, Blue trace based on additional profiles available since 1993)

The above analysis of the historical changes in the West Beach sediment cell volumes is considered to have highlighted the scale of the erosion problem facing the management of this sediment cell. The analysis is also considered to have provided some insights into how the West Beach sediment cell shoreline has responded to historical changes and interventions within this cell and on up-drift shorelines.

A first order estimate of the annual longshore transport capacity in the West Beach sediment cell can be developed by adding the additional external nourishment volumes and back-pass volumes delivered to West Beach to the observed decline in the sediment cell volumes. For the period 2011 to 2016, this results in a potential longshore transport capacity of ~115,000m^3/yr (~60,000m^3/yr decline in sediment cell volume + ~55,000m^3/yr back-pass nourishment) as sketched in the sediment budget in Figure 4-13.

This analysis is considered significant as it indicates that the littoral drift from West Beach and further north is considerably greater than the previous estimates of the transport capacity of ~50,000m3/yr along this shoreline. The previous significantly lower transport capacity estimates have been used as a basis for the current coastal management interventions on West Beach.

As this first order estimate is significantly larger than the ~50,000m^3/yr previously estimated for the West Beach sediment cell, the littoral volume change analysis of the West Beach sediment cell was extended to the entire Adelaide Metropolitan littoral system. This was undertaken to enable the volume declines and first order transport capacity of the West Beach cell to be reconciled with observed changes to the down-drift sediment cells.

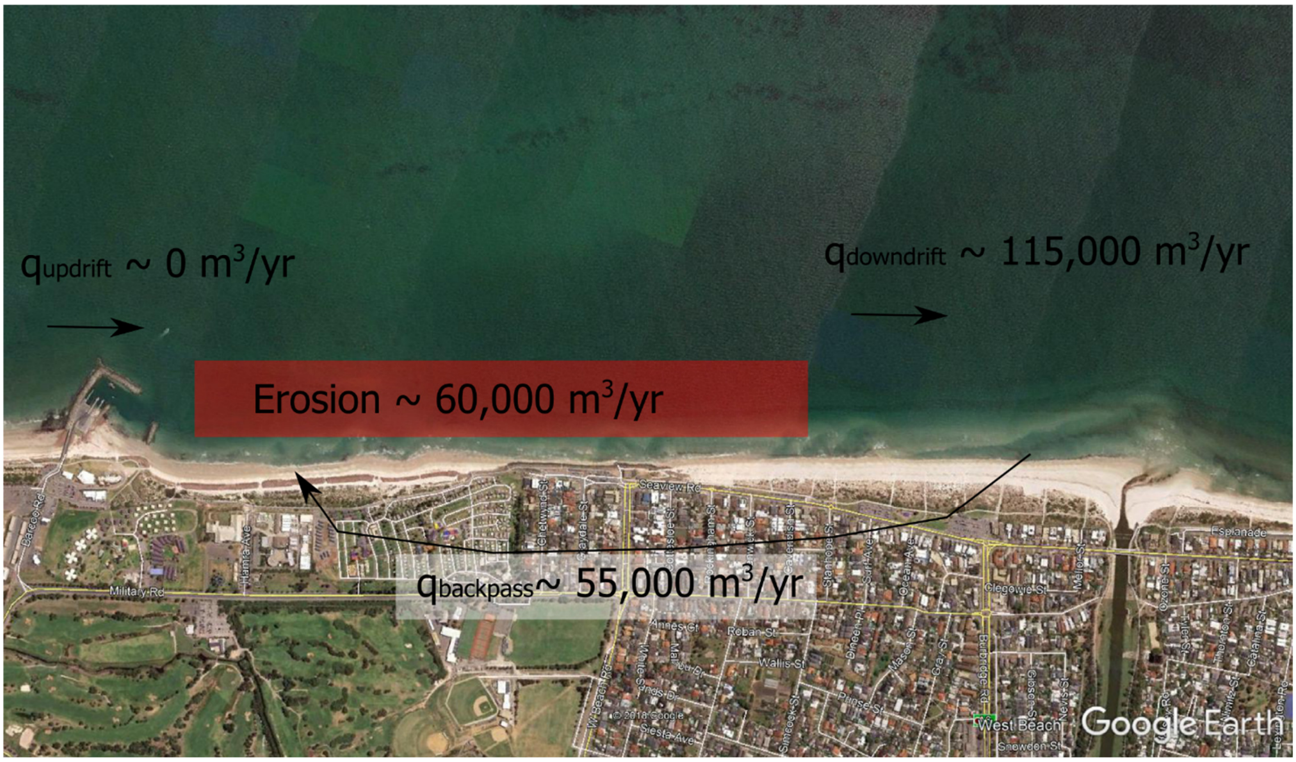


Figure 4-13: Sketch of the sediment budget at West Beach for the period 2011-2017

4.3.3 Extended Analysis

The integration of the changes in coastal profile volumes has been extended along the entire available survey data set of the Adelaide Metropolitan coastline, from Brighton Yacht Club to North Haven SLSC. The change in accumulated volumes has been divided into the same five time periods as previously displayed for the West Beach cell to ease interpretation. The results of this analysis are displayed in Figure 4-14 and the following comments are provided on the results of this analysis:

- In a perfectly closed littoral system with no external supply, the accumulated changes in littoral volumes would equal zero across the system. In reality however, net accumulation of sediment is typically observed in the northern end of the littoral system, indicating external sediment supply. This supply may include natural sources of sediment transported from the south, external supply from nourishment campaigns, biological sources such as carbonates (shells) and sand released from deeper offshore due to historical losses of seagrass.

- The analysis of the entire littoral system is considered in particular to highlight the very significant impact the mass external nourishment campaigns of the mid to late 1990's had on the littoral volume of the entire system. The accumulated change in littoral volume of the system between 1997 to 2001 is calculated as increasing by approximately 1 Million m^3 and is in the order of the external nourishment volumes delivered to the southern end of the system over this period.
- The accelerating declines in the volume of the West Beach cell from 2005 onwards are clearly evident, even at the entire littoral system scale. An equivalent volume of sediment eroded from the West Beach cell over these periods has accreted in cells 6 & 7 (Largs Bay & North Haven), at the end of the littoral system. Net accretion at a rate of approximately 100,000 m^3/yr is also typically observed at the northern end of cell 4 (Henley Beach) and in cell 5 (Semaphore Park).
- The results of the accumulated changes from 2011 to 2017 are notable in that it is the only period that shows a net decline in the total volume of the littoral system.

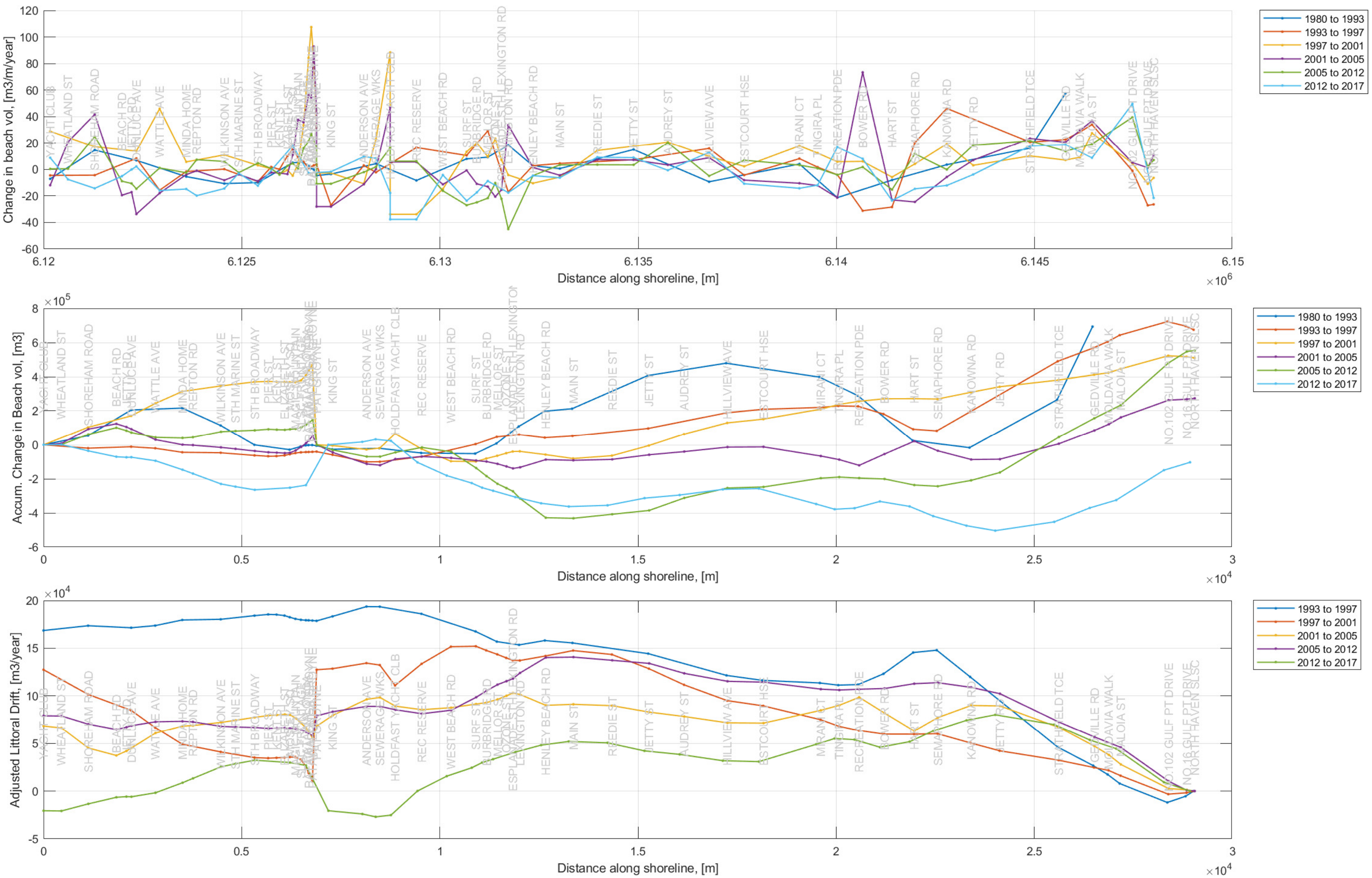


Figure 4-14 A: **Change in beach volume for each period**, B: **Accumulated change in beach volume for each period** and C: **Estimated littoral drift** along the entire Adelaide Metropolitan coast from south to north. The names of the profile locations is written vertically in grey at each profile location along the shoreline. Torrens outlet is located between Mellor St and Ozone St.

By assuming the transport beyond the North Haven cell is close to zero (this can be justified as sedimentation rates are very low in the Outer Harbour channel (pers. comm. Carl Kavina, General Manager Flinders Ports)), an independent estimate of the historical annual transport rates along the entire Adelaide metropolitan shoreline system can be calculated and is displayed below in Figure 4-14 C. It is important to note that nourishment volumes have not been factored into this analysis. However, the analysis is considered to provide an important line of evidence suggesting that the longshore transport capacity on the West Beach and adjacent Henley Beach cell is likely to be between 50,000 to 150,000m^3/yr, with a median estimate of approximately 100,000m^3/yr considered a reasonable interpretation of these results. These transport rates are in line with previous first order estimate for the West Beach cell and materially higher than has been previously assumed in the management of this cell.

5 Conceptual Coastal Process Model

The analysis of the available data in Section 4 has enabled a conceptual model of the coastal processes of the West Beach sediment cell to be proposed. The development of the conceptual model is considered a particularly important component of the investigation as it informs the subsequent configuration of the numerical sediment transport model and its validation and the selection of potential coastal management options.

The key features of the conceptual coastal process model of the West Beach sediment cell are defined below:

- The mass external nourishment campaigns undertaken in the 1990's 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 1990's 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 continued 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 10-20,000 m^3/year.

6 Selection of Management Options for West Beach

Selection of potential management options for West Beach was undertaken based on the updated understanding of the coastal processes of the West Beach sediment cell developed in this study, input from stakeholder consultation and practical and economic feasibility considerations provided by DEWNR. Potential options were evaluated giving consideration to the following principal technical constraints and considerations:

- All management options would require a significant initial nourishment campaign to restore littoral volumes in the West Beach cell and improve beach amenity and erosion buffers;
- Increasing the back-pass volumes to West Beach from the Torrens Outlet were not considered effective or desirable without additional external sources of sand;

- Ongoing, annual external nourishment campaigns of the order of 100,000m^3 to West Beach would either require unacceptably large numbers of truck movements, which may be disruptive to residents and road users, and/or would be uneconomic (with dredge plant in particular);
- All management options would need to provide for the ongoing supply of sediment to the downdrift Henley Beach cell, to ensure the erosion impacts observed at West Beach were not simply moved downdrift over the longer term.

It should be noted that the evaluation of potential management options for West Beach has not considered in detail the economic, social or environmental consequences of these options.

Options involving the construction of hard engineering structures to re-orientate the West Beach shoreline were considered and included offshore breakwaters and headland control structures. A range of risks and disadvantages were identified with these options and included the following:

- The significant cost associated with the construction and ongoing maintenance of hard engineering structures;
- The inability of the structures themselves to provide a long-term solution to the underlying sediment deficit problem identified in this study at West Beach. Hard engineering options would still require significant initial and ongoing sand nourishment to prevent additional downdrift erosion problems emerging in the future;
- The complexity of predicting the shoreline responses from these structures and the associated risks that these structures could create additional, acute erosion impacts on West Beach and/or downdrift shorelines;
- Potential public safety issues associated with rapid changes in depths and currents these structures can generate close to shore in their vicinity;
- Impacts to visual amenity on West Beach associated with the construction of more hard engineering works on the beach and potential for reduced access and compartmentalisation of the beach for recreation.

Hybrid type options involving significant sand nourishment combined with hard engineering structures to reduce the sediment transport rates locally on West Beach were also considered. While these options were considered to have the potential to provide a long term, sustainable management solution to the erosion problems at West Beach, they were not however considered cost effective. As the unit costs of supplying sand for beach nourishment reduce as the scale of the nourishment and associated engineering plant increases, the effect of combining hard engineering structures to reduce the scale of ongoing renourishment of West Beach would most probably be to increase the unit costs of the ongoing nourishment campaigns. When combined with the cost and maintenance of the structures themselves, this option was not considered cost effective and also came with additional risks and disadvantages identified with constructing hard engineering works on West Beach.

For these reasons and with consideration of the principal technical constraints and considerations described above, the most feasible, sustainable and cost effective management option identified for West Beach was one that incorporated some variation on a large scale nourishment option, to restore the littoral volume in the West Beach cell and provide a large source of sediment to meet the downdrift transport capacity of the Henley Beach cell into the future. The main advantages of this option were considered the following general considerations:

- The unit costs of supplying large nourishment volumes decreases as larger, more efficient engineering plant can be utilised;
- The provision of large sources of sediment to West Beach will provide an ongoing supply of sediment to the downdrift Henley Beach cell and mitigate erosion risks in this cell into the future;

- The shoreline response to the introduction of large volumes of sediment can be more reliably predicted and the design of the nourishment campaigns can be constantly adjusted into the future based on the observed shoreline impact, which reduces the overall risks of the management option;
- Potential public safety and visual amenity risks associated with this option are considered significantly reduced and/or can be mitigated as part of the nourishment design.

It is however recognised that large scale nourishment option for West Beach is not without its disadvantages including its likely costs and the periodic disruption to the beach users and environment during the nourishment campaigns. However, given the scale of the underlying erosion problem and the alternative options available, large scale nourishment is considered likely to provide the most cost effective and sustainable improvement to West Beach and downdrift beaches and comes with considerably less overall project risks.

6.1 West Beach Management Option Concepts

Four (4) management scenarios have been developed for West Beach, they are described in detail in the following subsections. In Section 9, the impact of the four scenarios on the morphology of West Beach and Henley Beach is tested with the calibrated shoreline model.

6.1.1 Scenario 1 – Do Nothing

The do nothing scenario is the baseline impact scenario to demonstrate the impact on West Beach with no active management interventions and provides a baseline for evaluating the relative effectiveness of future alternative management option interventions. In practice this means that no new structures are constructed, no sand is introduced or back-passed at West Beach and the shoreline is allowed to evolve naturally into the future.

6.1.2 Scenario 2 – Mass Nourishment

The mass nourishment management concept for West Beach involves the renourishment of the West Beach sediment cell and the placement of a large store of sand in the vicinity of the Torrens Outlet to supply the downdrift Henley Beach cell over the medium term.

This coastal management concept is referred to as mass nourishment or a sand engine. The concept has several advantages in that it improves the economics of utilising larger scale dredge plant, to reduce the costs per cubic metre of the dredging and nourishment, whilst providing a source of sand to meet the downdrift transport capacity for many years, reducing the impact on the environment and on beach users from frequent, annual nourishment campaigns.

A mass nourishment type management campaign was previously undertaken for the southern Adelaide beaches in the 1990's. The significant impact of this campaign on the littoral volumes throughout the Adelaide Metropolitan coastline have been documented in this study and likely underpinned the supply of sand to the downdrift Adelaide metropolitan beaches for up to 10 years following the completion of this campaign.

More specifically, the option would require approximately 500,000m^3 of sand to nourish the West Beach cell and 300,000m^3 of sand to nourish Henley Beach South to restore the littoral volumes back to the late 1990's cell volumes. An additional ~1,000,000m^3 would also be placed on West Beach updrift of the Torrens Outlet at Torrens Outlet dunes. This would provide approximately 10 years of supply (at a transport capacity of ~100,000m^3/yr) to Henley Beach cell. It is envisaged the large store of sand would enhance the natural groyne function of Torrens Outlet and assist to slightly re-orientate the updrift shorelines of West Beach, thereby reducing the longshore transport capacity and subsequent extent of ongoing nourishment of West Beach.

Sand could continue to be harvested from the new source at Torrens Outlet and backpassed to the southern end of West Beach as required, to renourish the beach and depending on the effectiveness of the groyne function of the mass nourishment. Backpassing from Torrens Outlet is only expected to be required after 5-10 years from the initial mass nourishment.

The specific sand source has not been identified in this study but could include sand sourced from external offshore sources or harvested from the end of the littoral system at North Haven and rainbowed into the nearshore with a hopper dredge. Final placement of the sand onto West Beach could be undertaken with a small cutter suction dredge and pipeline or via harvesting of the newly placed sand at Torrens Outlet and pumping to the southern end of West Beach via the backpass pipeline.

Figure 6-1 displays a schematic representation of the mass nourishment coastal management option for West Beach.

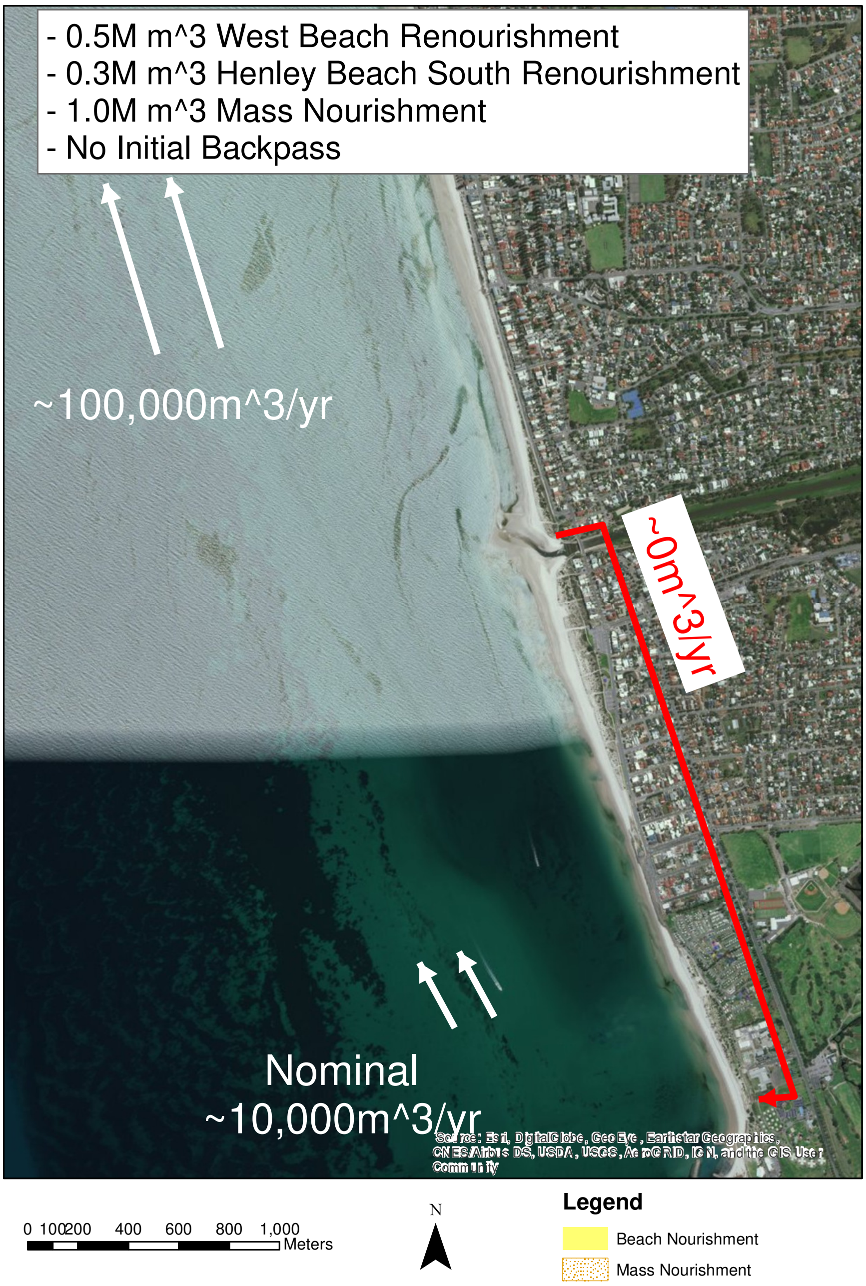


Figure 6-1: Scenario 2: Mass Nourishment Coastal Management Option for West Beach

6.1.3 Scenario 3 – Interim Management

The interim management scenario was provided for assessment by DEWNR to evaluate the likely response of West Beach to a new, interim management strategy.

This scenario includes the following:

- Small scale initial nourishment of Torrens Outlet and Sth Henley cell of approximately 100,000m^3 (based on an estimate of the feasible amount that can be delivered via trucks)
- Extension of the West Beach rock revetment along Adelaide Shores Dunes.
- Back-passing of ~30,000m^3 pre summer to create a seasonal beach in front of Adelaide Shores.

Figure 6-1 displays a schematic representation of Scenario 3.

Figure 6-2: Scenario 3: Interim Management Concept

6.1.4 Scenario 4: Large Scale Back-passing from Northern Sediment Cells

This scenario assumes that sand can be sustainably harvested from the northern sediment cells at a rate of ~100,000m^3/yr and that the pipeline infrastructure is in place to backpass this amount annually to the West Beach and Henley Beach sediment cells.

The large scale back-passing scenario included the following main components:

- For the first 4 years:
  - Backpass 150,000 m^3/yr to West Beach to provide a net increase in West Beach cell volume of around 200,000 m^3

- Backpass additional 20,000 m^3/yr to Henley Beach South to compensate the ongoing erosion in this cell.
- For the remaining 3.5 years of the simulation, reduce total back-passing 100,000 m^3 to West Beach and nothing to Henley Beach. South

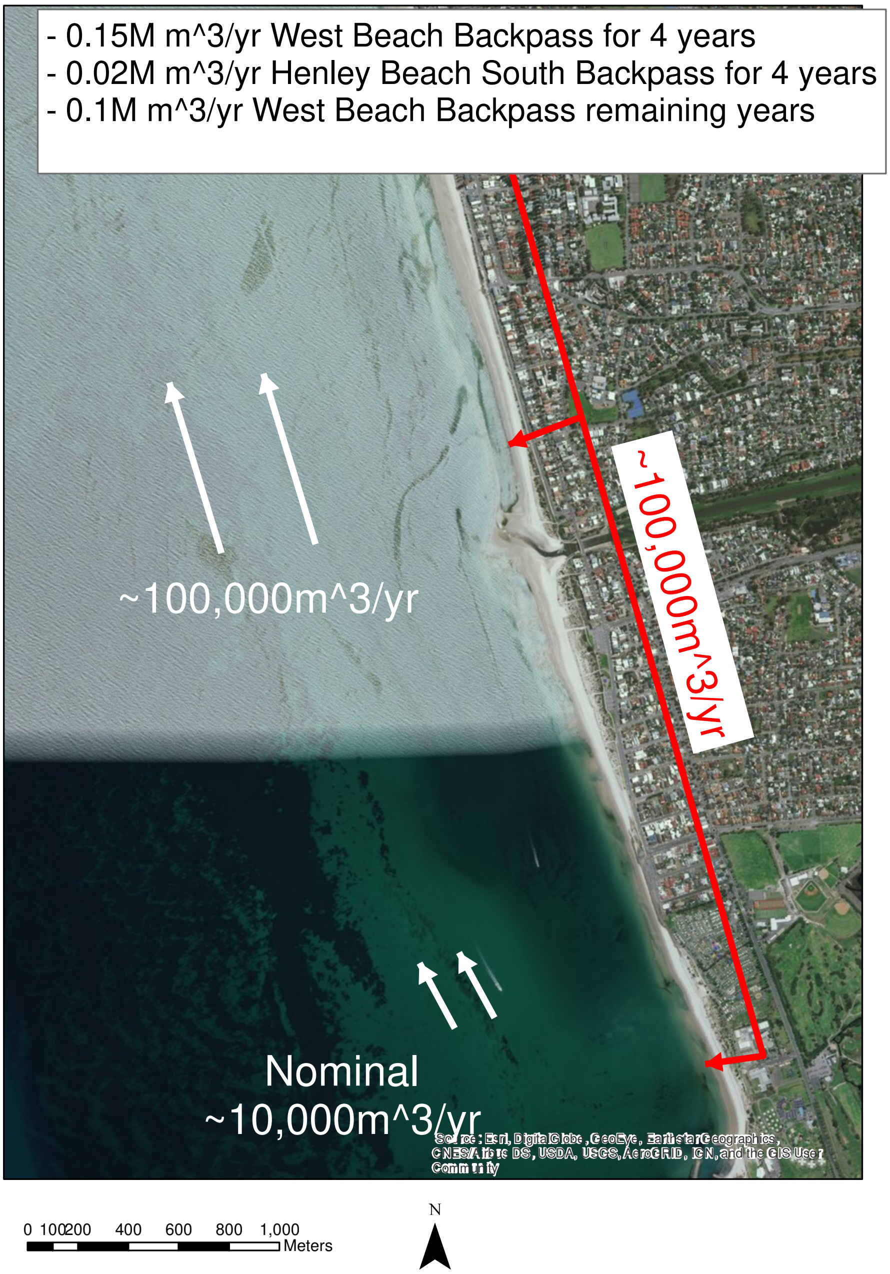


Figure 6-3 Scenario 4: Large Scale Backpass Management Concept

6.2 Discussion

The management options described in the previous sections are considered to have the following strengths and weaknesses:

- Scenario 1 (Do nothing)
  - Strengths: Cheapest option in terms of direct cost
  - Weakness: The beach will erode and the infrastructure behind it will eventually be impacted
- Scenario 2 (Mass nourishment at 10 year intervals)
  - Strengths: Adds needed sediment volume to the littoral system effectively mitigating the underlying erosion problem. Rare intervention and disruption to the beach environment.
  - Weakness: May be difficult/expensive to find adequate sediment source. Large mobilisation costs required for size of dredging equipment required.
- Scenario 3 (Interim Management Concept)
  - Strengths: May be a cheap option for providing a small beach for recreational use in summer at the south end of West Beach.
  - Weakness: Does not solve the underlying erosion problem, therefore eventually the the erosion will spread further north eventually impacting infrastructure further north.
- Scenario 4 (Large scale abckpassing)
  - Strengths: Adds needed sediment volume to the littoral system effectively mitigating the underlying erosion problem. Flexible intervention: Every year the eroded sediment volume can be replaced by back-passing system. Part of the back-passing system has already been built reducing the total costs.
  - Weakness: Annual and prolonged intervention to the beach environment every year.

7 Hydrodynamic and Wave Hindcast

A detailed 7.5 year hindcast of hydrodynamics and wave conditions in the Gulf St Vincent has been performed to provide boundary conditions to support the detailed sediment transport modelling of the West Beach study area.

The physical forcing phenomena of interest that can mobilise and transport sediment within the West Beach study area include:

- Astronomical tides (water levels and currents);
- Meteorological phenomena (sea level residuals, inverse barometric pressure effect, wind driven longshore currents);
- Surface gravity waves (locally generated wind waves and ocean swell).

The ability to model the sediment transport processes on West Beach requires these physical forcing processes to be accurately simulated for West Beach and has been achieved through the application of detailed hydrodynamic and spectral wave models of the Gulf St Vincent. The development, calibration and hindcast simulations performed with these models are discussed in the following sections.

7.1 Numerical Models

The hydrodynamic model utilised in this study is a non-linear shallow water model based on the numerical solution of the two dimensional incompressible Reynolds averaged Navier-Stokes equations, subject to the assumptions of Boussinesq and of hydrostatic pressure. The model solves the characteristic equations of continuity and momentum and can include the effects of density variations. The model utilises an unstructured mesh, consisting of both triangular and quadrilateral elements, to provide spatial representation of the solution domain. This approach allows for increased resolution in the areas of interest, whilst providing for larger elements in the outer model areas. The numerical engine incorporates parallel computing methods utilising either Graphical Processors (GPU) or High Performance Computing (HPC) clusters to efficiently support computationally demanding modelling investigations.

7.1.1 Bathymetric Mesh

The bathymetry and computation mesh schematisation of the model domain are displayed below in Figure 7-1.

The bathymetry of the Gulf St Vincent was derived from hydrographic survey chart data held under license by DHI. The bathymetry in the vicinity of the West Beach study area was supplemented with the detailed site specific survey completed for this project by DEWNR.

The model contains open boundaries at the entrance to Investigator Strait and at the approaches to Backstairs Passage.

The computational mesh has been refined to provide high resolution through the key area of interest at West Beach and areas with large hydrodynamic gradients such as through Backstairs Passage.

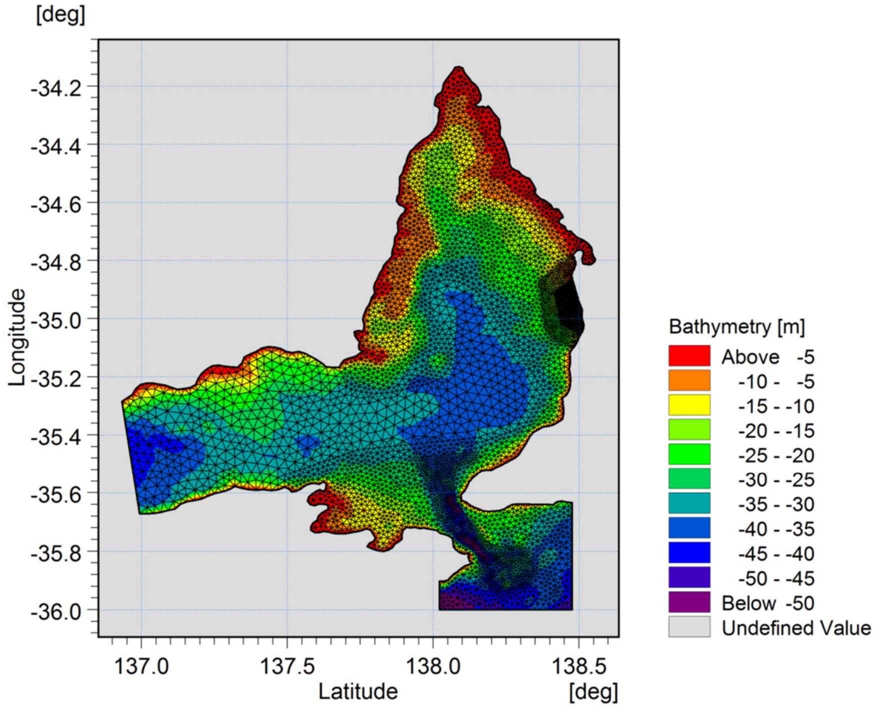


Figure 7-1 Overview of the model bathymetry and mesh schematisation

7.1.2 Hindcast Boundary Conditions

The following boundary conditions and underlying data sources were prepared for the model:

Investigator Strait

- Astronomical tidal water levels derived from tidal constituent data at Stenhouse Bay and Western River;
- Sea level residual reanalysis hindcasts derived from the Bluelink Reanalysis (Bran 2.2)
- Integral wave parameters for wind sea and swell derived from DHI's operational global wave model.

Backstairs Passage

- Astronomical tidal water levels derived from tidal constituent data at Vivonne Bay and Victor Harbour;
- Sea level residual reanalysis hindcasts derived from the Bluelink Reanalysis (Bran 2.2)
- Integral wave parameters for wind sea and swell derived from DHI's operational global wave model.

Global Boundary

- Wind and pressure fields derived from the Climate Forecast System Reanalysis (CFSR) on a 0.25^0 grid

7.1.3 Calibration

A calibration process was undertaken to relevant and available measurement data to ensure the model configuration accurately produced observed behaviour of key physical variables near the study area.

Calibration of the hydrodynamic model was achieved through comparisons of observed total water levels at the Port Adelaide Outer Harbour gauge operated by Flinders Ports. Figure 7-2 displays comparisons of observed and modelled water levels over a one (1) month period.

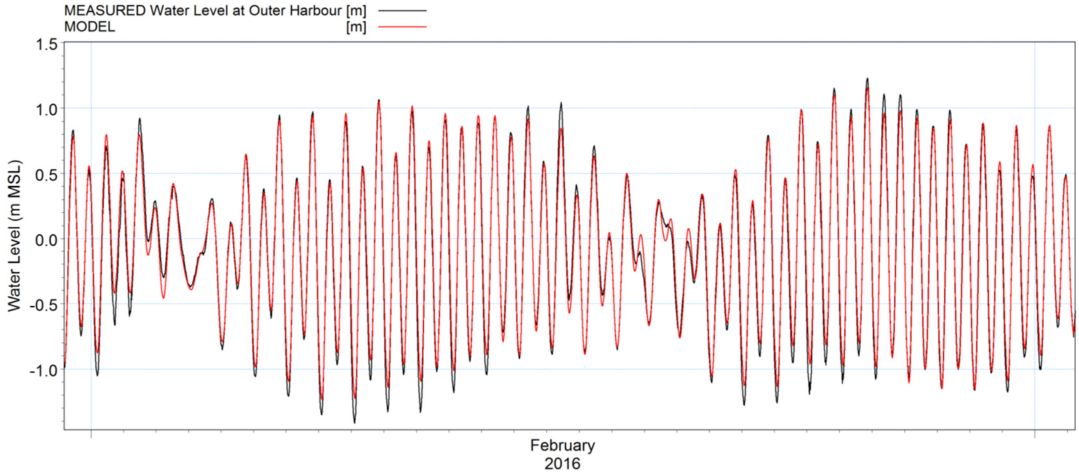


Figure 7-2: Comparison between modelled and measured water level.

Calibration of the spectral wave model was undertaken through comparisons to limited wave measurements undertaken by the Bureau of Meteorology (BoM) at 4 locations to the south of the West Beach study area around Port Stanvac (Figure 7-3). The wave measurements were undertaken by way of a bottom-mounted pressure transducer.

Figure 7-4, Figure 7-5, Figure 7-6 and Figure 7-7 shows the comparison between the measured and modelled significant wave height and wave period. A good agreement between the measurements and model predictions is observed.

Figure 7-3: Locations of deployments.

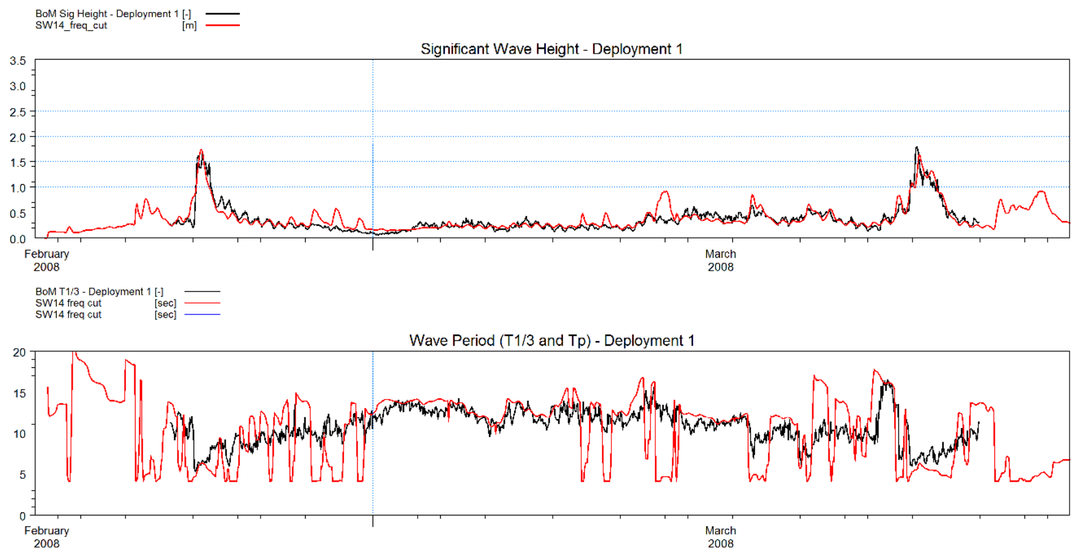


Figure 7-4: Comparison between simulated and measured significant wave height (top) and wave period (bottom) for deployment 1

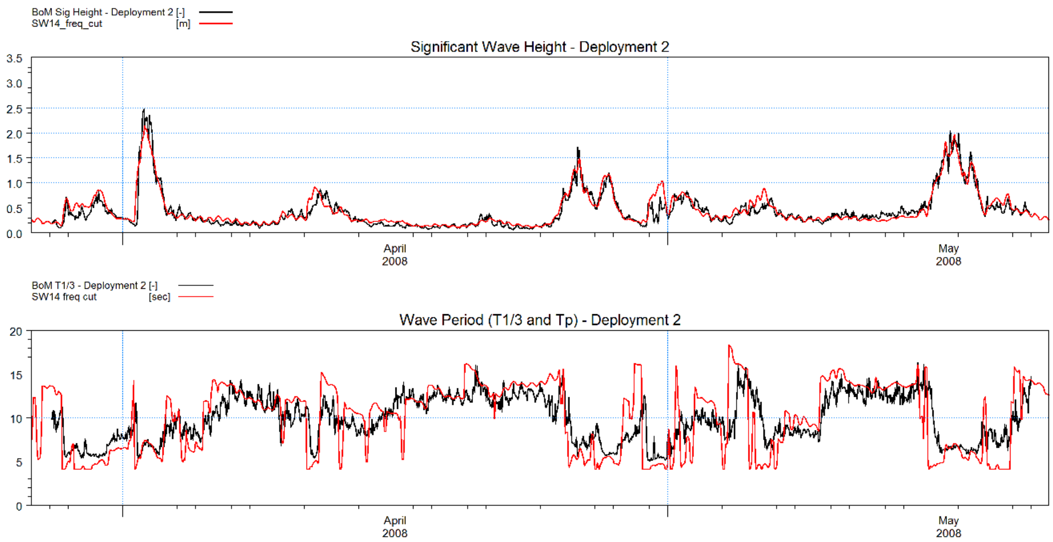


Figure 7-5: Comparison between simulated and measured significant wave height (top) and wave period (bottom) for deployment 2

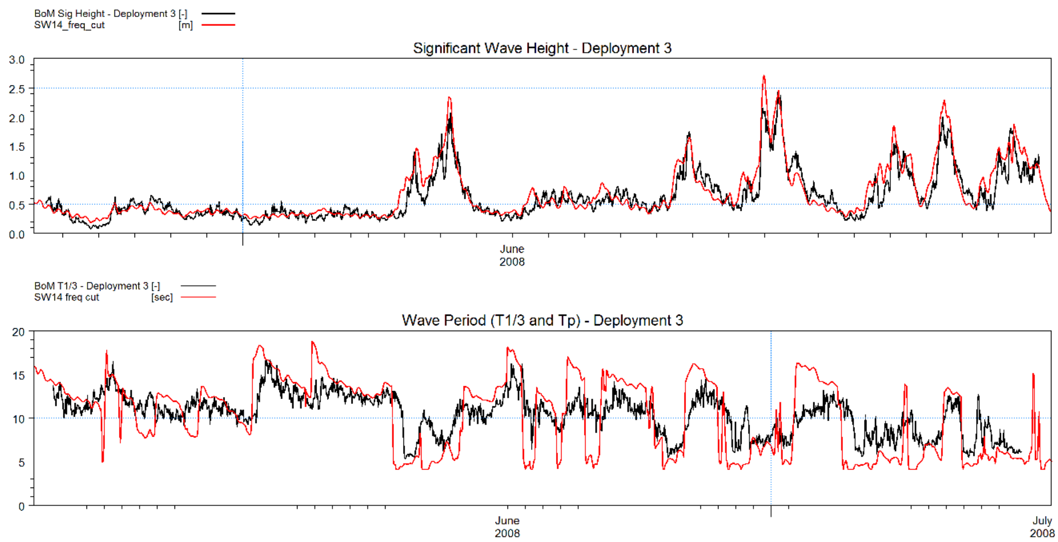


Figure 7-6: Comparison between simulated and measured significant wave height (top) and wave period (bottom) for deployment 3

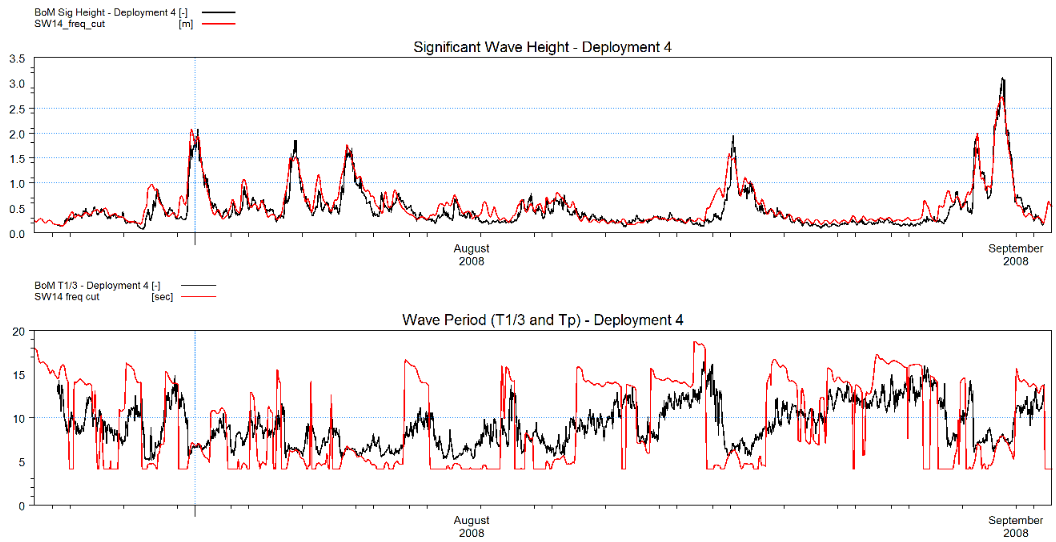


Figure 7-7: Comparison between simulated and measured significant wave height (top) and wave period (bottom) for deployment 4

7.2 Hindcast Simulations

The calibrated model was used to simulate the wave conditions at West Beach for the period from Jan 1st 2009 to July 1st 2016. Due to the significant computational resources required to perform the hindcast, the simulations were executed on the 'Raijin' High Performance Supercomputer at the National Computer Infrastructure (NCI) facility in Canberra.

The simulated wave rose extracted in 6 m water depth at West Beach is shown in Figure 7-8

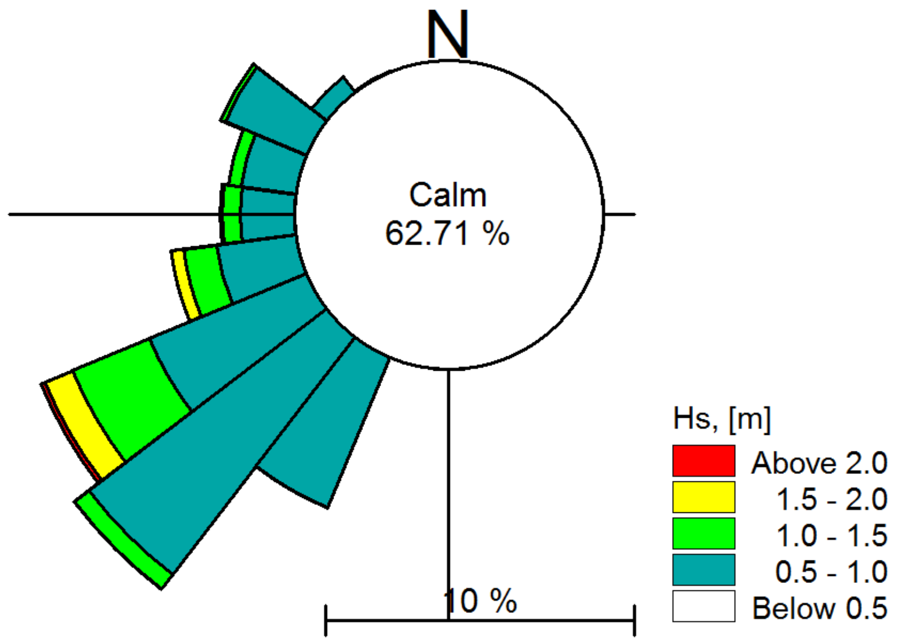


Figure 7-8: Simulated Wave Rose for West Beach for the period from Jan 1st 2009 to July 1st 2016.

8 Shoreline Model Development and Calibration

The MIKE 21 FM Shoreline Morphology (SM) model was set up and calibrated to match observed historical changes in beach volume at West Beach and Henley Beach.

8.1 Model Description and Setup

The MIKE 21 FM Shoreline model combines a 2D description of the waves, hydrodynamics and sediment transport with a one-line description of the shoreline position. This means that the model is very well suited to long term predictions of shoreline morphology in complex settings such as West Beach.

Figure 8-1 shows the coverage of the computational mesh together with the initial bathymetry for one of the simulations.

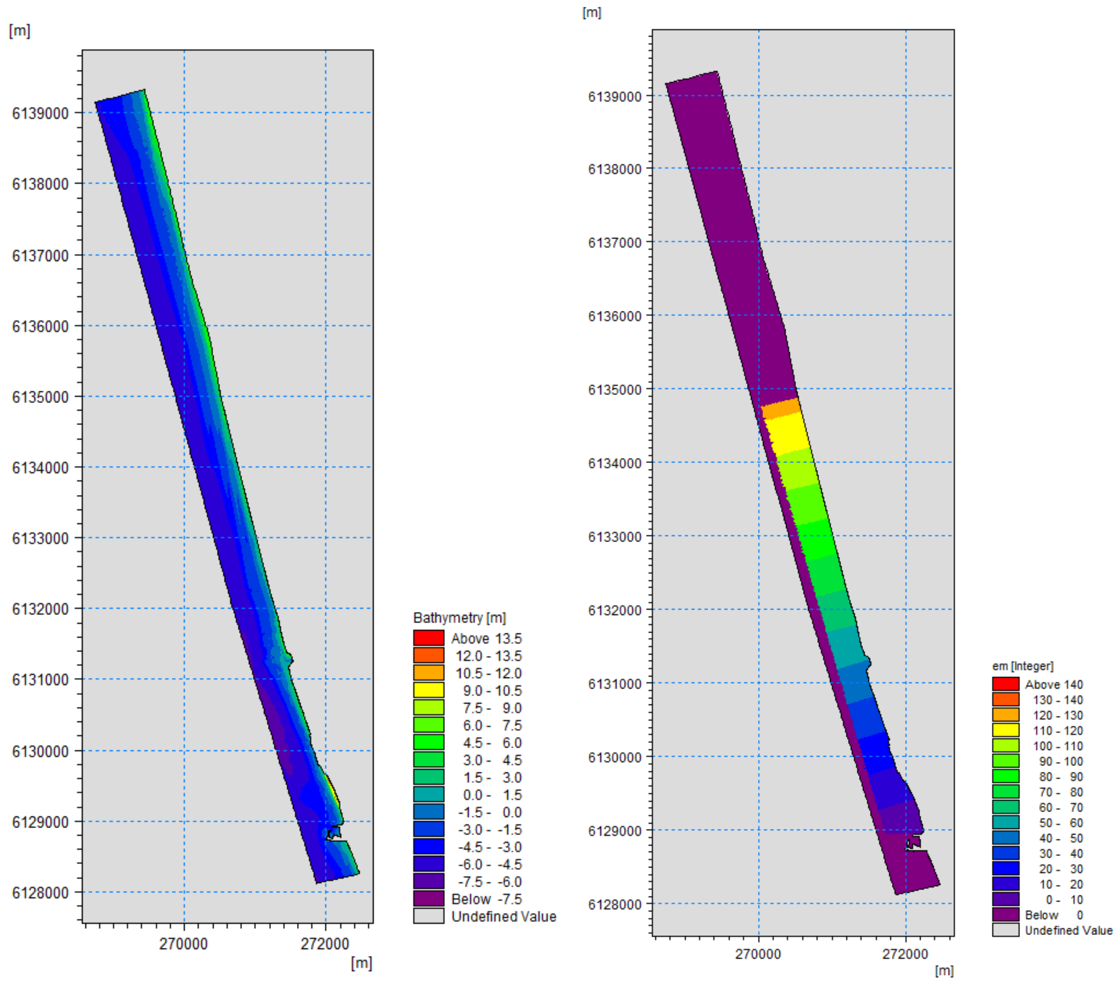


Figure 8-1: Left: The computational domain together with an example of the initial bathymetry. Right: The map of shoreface strips (Edgemap) along the shoreline at West Beach.

The mesh resolution is 5 metres in the nearshore zone as shown in Figure 8-2 and larger further offshore.

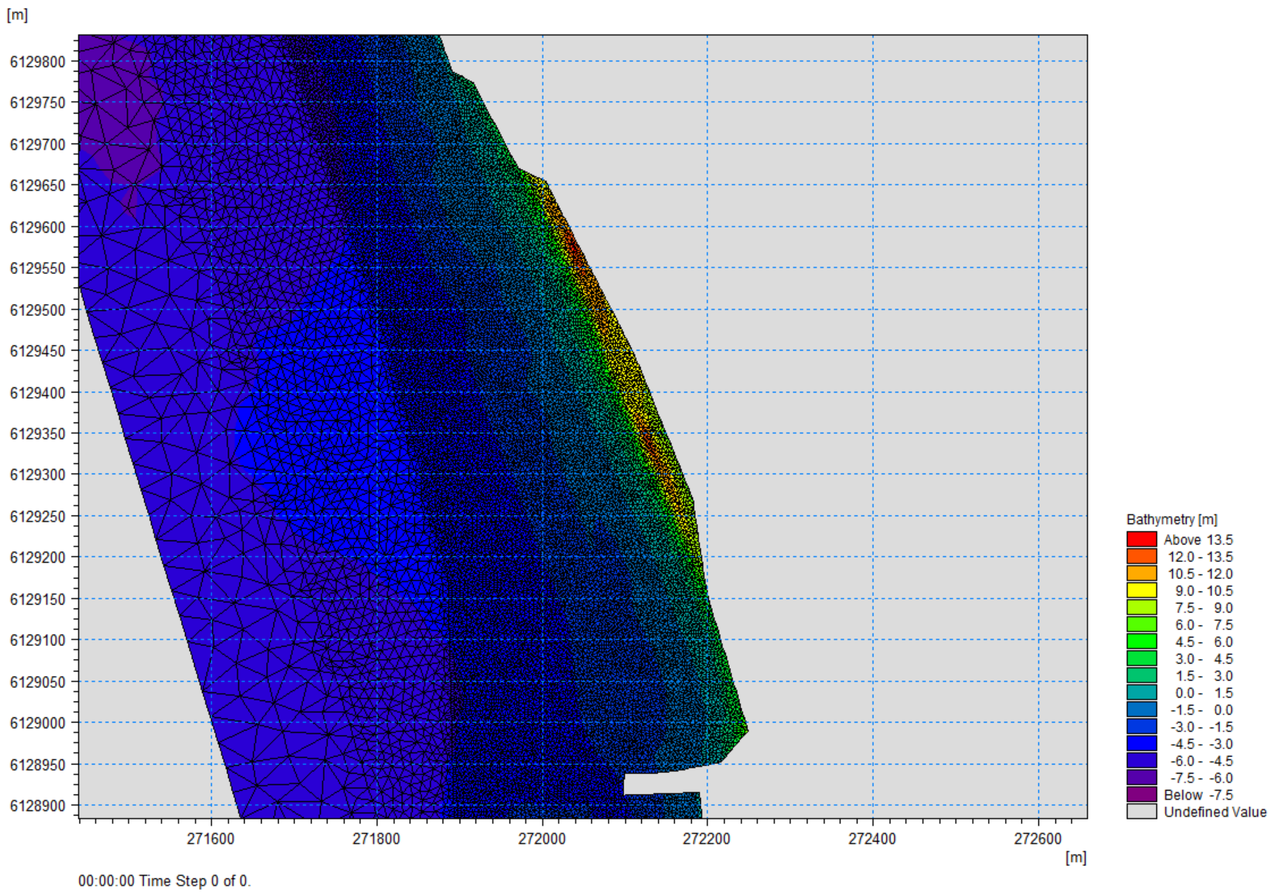


Figure 8-2: Computational mesh at the south end of West Beach.

The wave model utilized is the MIKE 21 FM Spectral Wave Module, which solves the wave action equation on a flexible mesh (i.e., a mesh consisting of both triangles and quadrilaterals). Due to limited model domain size, the decoupled quasi-steady solver could be utilized to reduce computational run times. The model includes the effects of depth and current induced wave refraction, wave shoaling, wave generation due to wind forcing, wave breaking using the Battjes and Jansen formulation and bottom friction using a roughness height formulation. Wave diffraction and wave generation due to wind were not considered important and were excluded from the model setup.

The wave model is forced at its offshore boundary using wave conditions extracted from the wave hind cast calculated in the previous section. The boundary conditions consist of Significant Wave Height (Hs), Peak wave period (Tp), Mean Wave Direction (MWD) and Directional Spreading (DSD). The hydrodynamic model is the MIKE 21 FM Hydrodynamic Module, which solves the non-linear shallow water equations on the same flexible mesh as the wave model. The hydrodynamic model is driven by the gradients in the radiation stresses obtained from the spectral wave model.

Tides are important both for the position of the longshore transport in the coastal profile, for the cross-shore redistribution of sediment, and for the dissipation/propagation of waves over the reef, whereas the tidal currents are not important for the sediment transport. Therefore, a constant time varying tidal elevation is applied on the offshore boundary only; this tidal variation is extracted from the Regional HD described in section 0. The north and south boundaries have been closed to avoid instabilities in the hydrodynamic model. These boundaries are far enough removed from the area of interest that this simplification does not affect the results.

The sediment transport model is the MIKE 21 FM Sand Transport Module, which calculates the sediment transport capacity due to the forcing from combined waves and currents. The intrawave boundary layer is solved using the integrated momentum method by Fredsoe (1984) and the suspended sediment concentration during the wave cycle is found by solving the vertical diffusion-advection equation for suspended sediment using the bottom boundary condition for the bed sediment concentration, c_b by Zyserman and Fredsoe (1994). Based on the gradients in the calculated sediment transport capacities, the eroded or accreted sediment volume is calculated in each computation element.

The MIKE 21 FM Shoreline Model divides the shore-face into a number of strips of shoreline; each strip is perpendicular to the local orientation of the shoreline as shown in Figure 8-1 right. On each strip of shore-face, the eroded or deposited sediment volume is integrated. This integrated volume is then combined with the predefined coastal profile shown in Figure 8-3 to calculate the change in the position of the shoreline at each time step, and thereby the change in bathymetry on the shore-face at each time step. Outside the area covered by the strips, the bathymetry is constant during the simulation. For further details on the MIKE 21 FM Shoreline Model see MIKE Powered by DHI (2017), refer to Kaergaard and Fredsoe (2013) and Kristensen et. al. (2012).

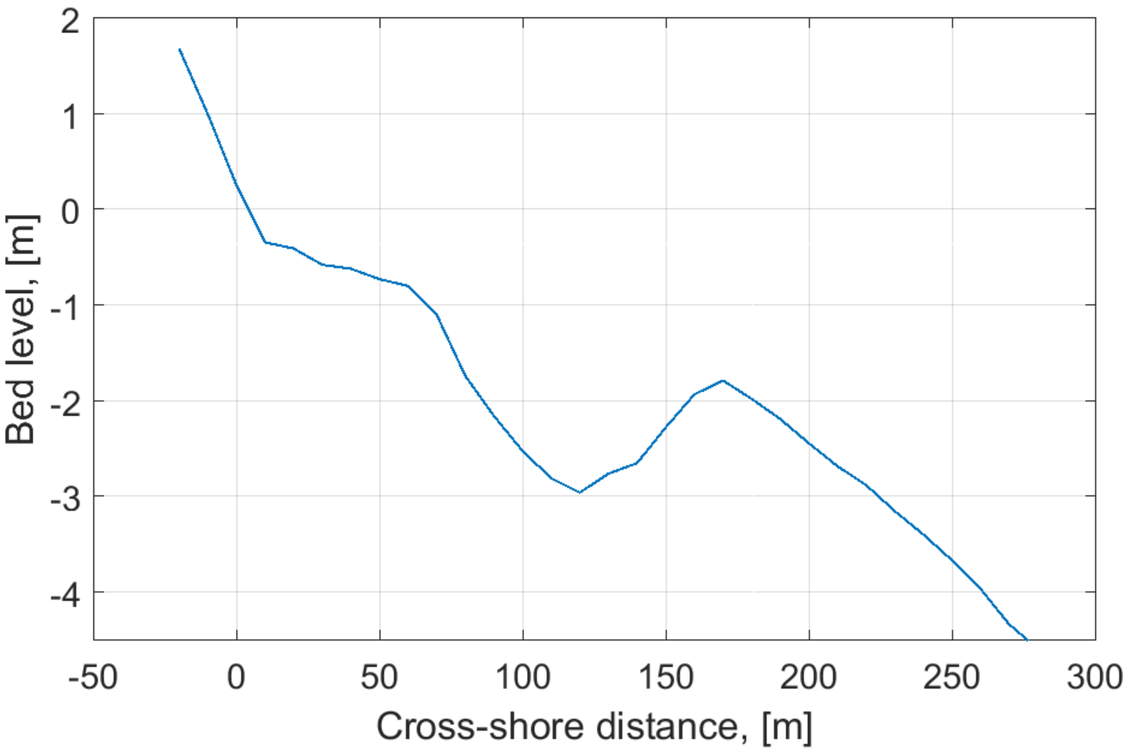


Figure 8-3: Coastal profile used in the SM model.

8.1.1 Pre-processing of the Wave Boundary Conditions

To reduce the computational time the off-shore wave and tide elevation time series have been pre-processed by replacing the actual conditions during calmer periods with representative wave/tide conditions. All major storm events are fully retained in the pre-processed time series while calmer periods are treated as events. Calm periods are identified as having Hs<1 m. Figure 8-4 compares the raw and pre-processed boundary condition, as seen the two wave roses are very similar.

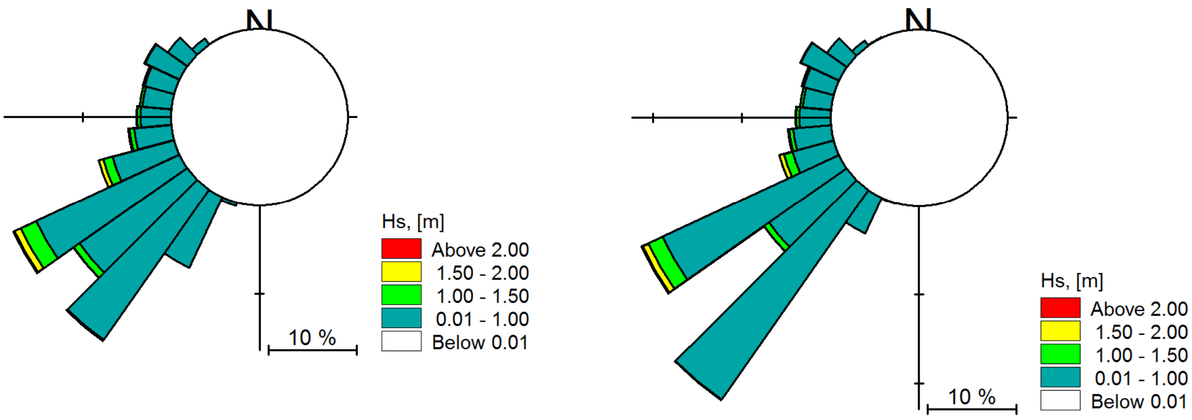


Figure 8-4: Comparison of the raw and pre-processed wave boundary conditions. Left: Raw. Right: Pre-processed

8.2 Back-passing System

The influence of the back-passing system on the fluxes of sediment within the West Beach cell has been included in the model by applying predefined sink and sources of sediment that result in additional changes to the profile bed level at recovery and disposal areas as shown in Figure 8-7.

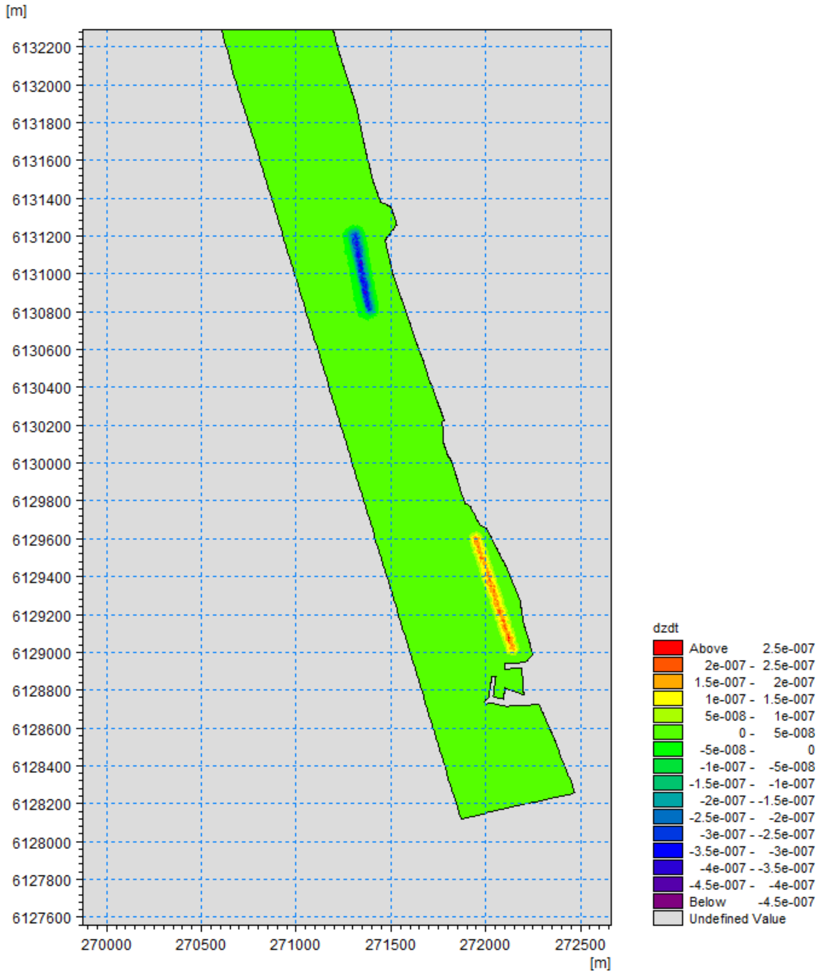


Figure 8-5: Additional bed level changes representing the back passing system. A negative value implies sediment is being removed from the computational element and a positive value implies sediment is added to a computational element.

8.3 Model Parameters

Table 8.1 shows the main model parameters, which were applied in the shoreline model. The map of the manning number is shown in Figure 8-6.

Table 8.1 Model parameters for the Shoreline Model

Parameter	Value
Spectral Wave Model (SW)	
Directional discretisation	36 directional bins
Water level variation	From HD model
Current variation, Wind forcing, Ice, Diffraction	Excluded
Wave Breaking	Battjes and Jansen, $\gamma = 0.8$ $\alpha = 1$
Bed roughness, kn	0.01 m
Hydrodynamic Model (HD)	
Bed roughness, Manning number	Map
Eddy viscosity, Smagorinsky coefficient	0.28
Coriolis, wind, ice, tidal potential, infiltration	Excluded
Wave radiation stresses	From SW model
Sediment Transport Model (ST)	
Sediment size	0.18 mm
Geometrical spreading	1.3
α	4
Shoreline Model (SM)	
Number of shoreline edges	124
Coastal profile	Constant in time and space
Offshore transport	Excluded.

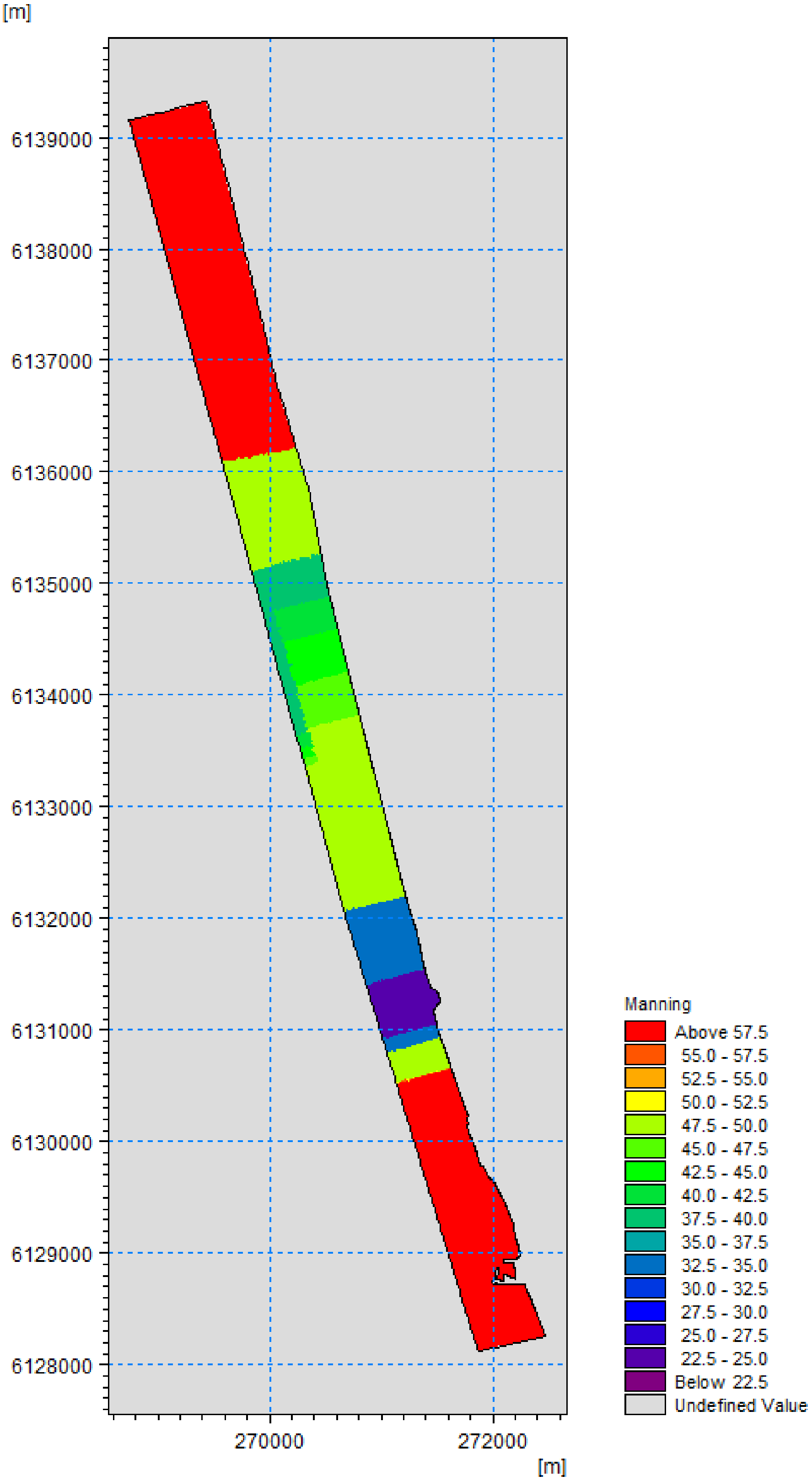


Figure 8-6: Map of Manning number used in the shoreline model.

8.4 Model Calibration

The SM model has been calibrated to match the observed profile volume changes at West Beach during 2013 and 2015. The bed level sources were set such that 30,000 m^3 were back-passed from June to September 2013 and 50,000 m^3 were back-passed from April to June 2015.

The calibration process was completed by starting with a simple model setup with a constant coastal profile and constant Manning number along the entire beach. During the calibration process the effect of using alongshore varying coastal profiles was tested, however this did not improve the calibration and it was therefore decided to use a constant coastal profile in this study. The main model parameters, which improved the calibration, were changing the mesh resolution and changing the manning number especially around Torrens Outlet. It was found that a reduced manning number around the Torrens Outlet was necessary to obtain a reasonable calibration. The reduced Manning number around the outlet is a simple way of incorporating the complex morphology around Torrens Outlet in the long-term shoreline model. The morphology around the outlet is very complex due to the interaction of the discharge from the drain during rain events with the wave driven longshore flow.

Figure 8-7 compares the measured and modelled beach volume changes for both periods. A reasonable agreement is observed with one outlier around Torrens Outlet during 2013. This is considered to be due to the complex bathymetry around the outlet which is very difficult to model in detail.

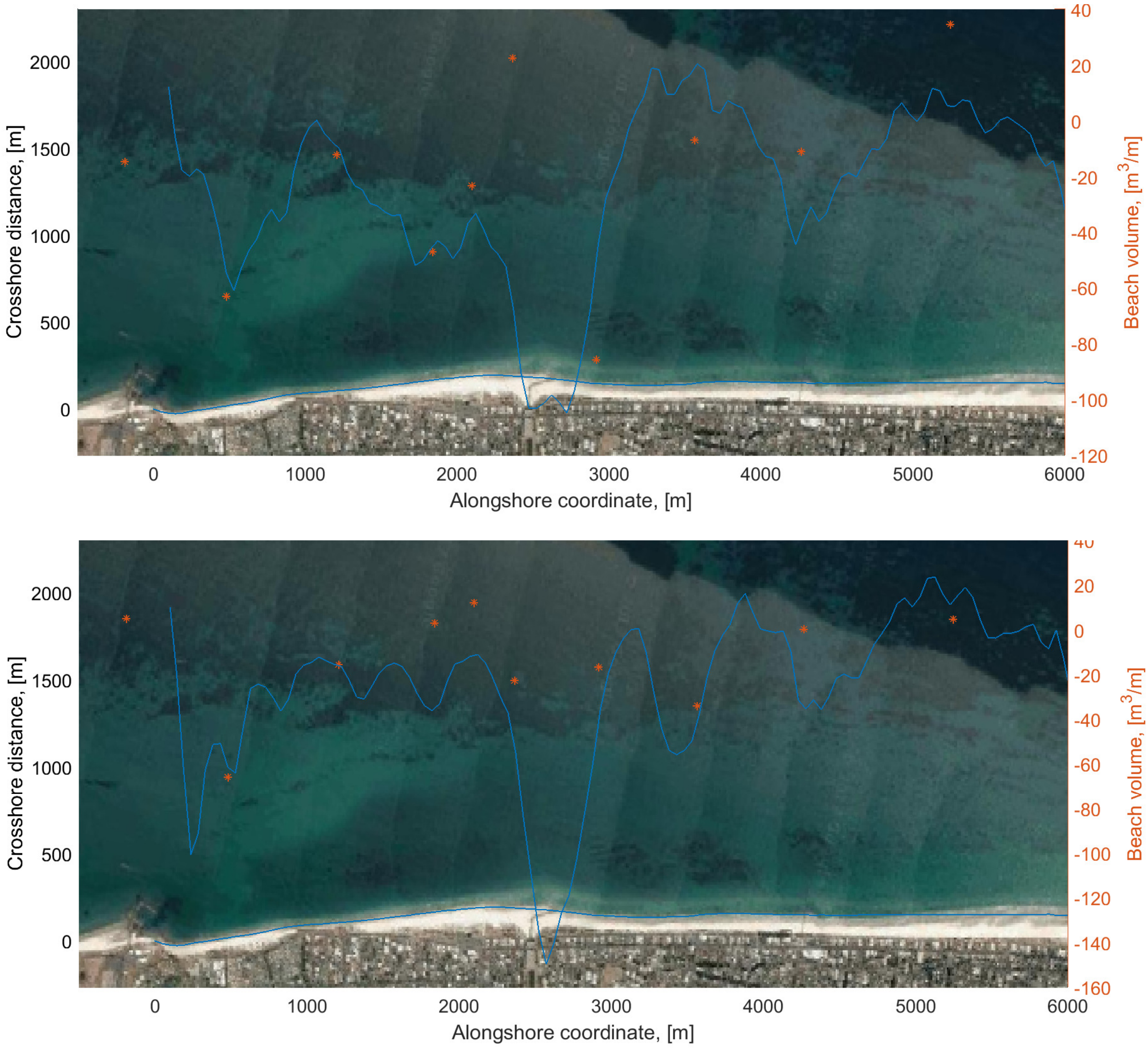
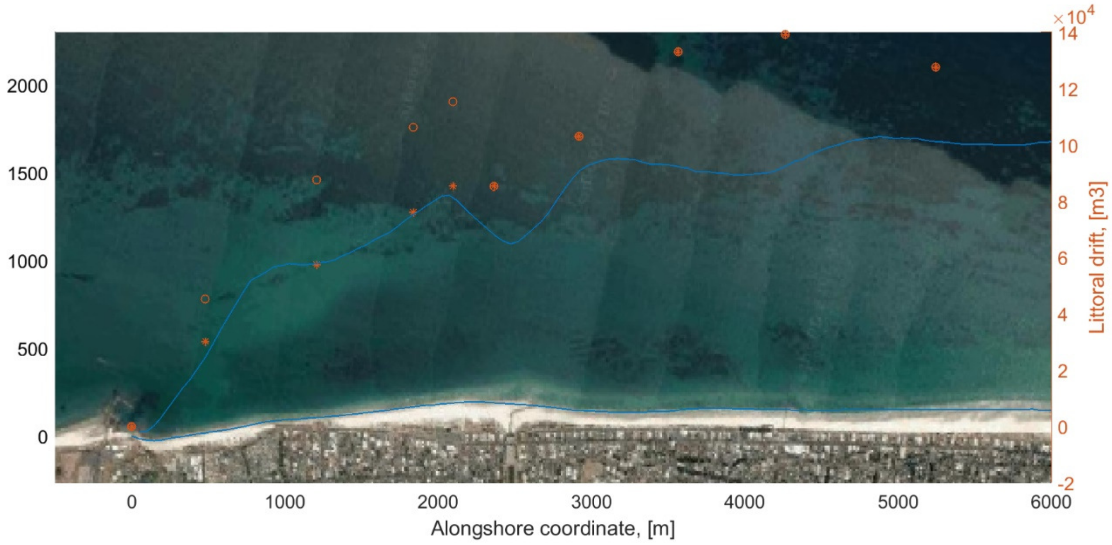


Figure 8-7: Comparison of measured (red dots) and modelled (blue line) beach volume change per metre along West Beach for both calibration periods. Top: 2013 Bottom: 2015.

A comparison of the littoral drift estimated from the measurements and the modelled littoral drift for 2013 and 2015 is shown in Figure 8-8. For the measurements the estimated drift from the raw data is shown with red dots, the red stars show the estimated drift from the raw data with the addition of the back-passed sediment volumes. A reasonable agreement between the model and the measurements is observed.



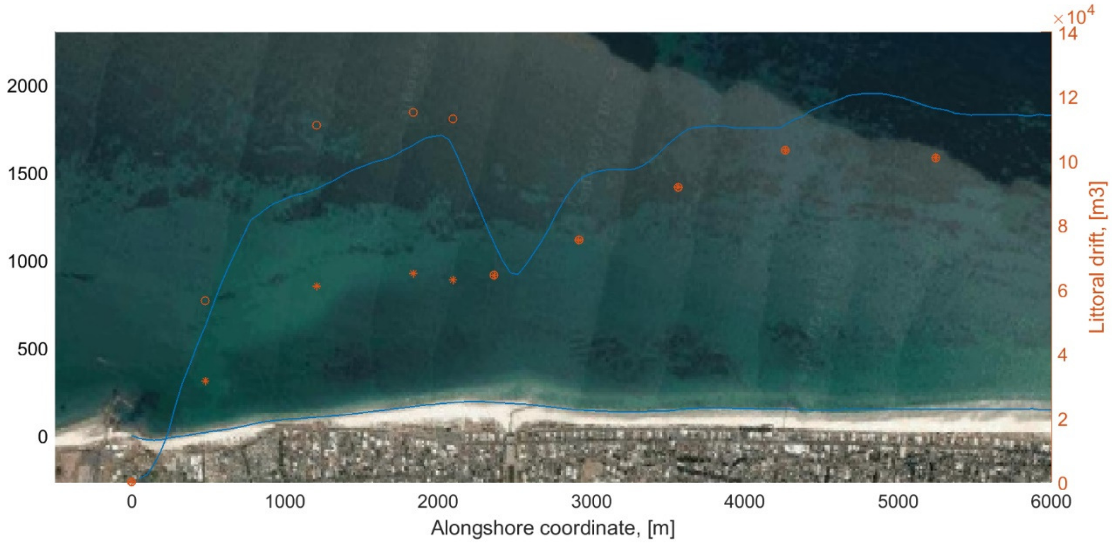


Figure 8-8: Littoral drift estimated from measurements (red circles = estimate from raw data, red stars = back-passing volumes added to estimate from raw data) and modelled (blue lines) for the two calibration periods. Top: 2013. Bottom: 2015.

9 Shoreline Modelling of Mitigation Options

The calibrated SM model was used to simulate the morphological evolution at West Beach for the four scenarios described in Section 6.1. The model was run for the 7.5 year period which the wave hind-cast was available for, i.e. from Jan 1st 2009 to July 1st 2016. The model parameters for the shoreline model were the same as was used for the calibration described in the previous section.

9.1 Initial Shoreline Position

For scenarios 1 and 4, the initial shoreline position is the same as was used for the calibration run, it is shown as the blue line in Figure 9-1; this is termed the base case beach position in the following.

For Scenario 2, three (3) different nourishments are placed on the initial shoreline: a nourishment of 500,000 m^3 distributed along all of West Beach, a nourishment of 1,000,000 m^3 was distributed in-front of the existing rock wall and a nourishment of 300,000 m^3 was placed at Henley Beach South.

For Scenario 3 a nourishment of 100,000 m^3 was placed around Torrens Outlet.

The initial conditions for each of the four scenarios is shown in Figure 9-1. On the right y-axis the change in shoreline position compared with the initial shoreline for Scenario 1 is shown. The blue line shows the position of the base case initial shoreline on the left y-axis.

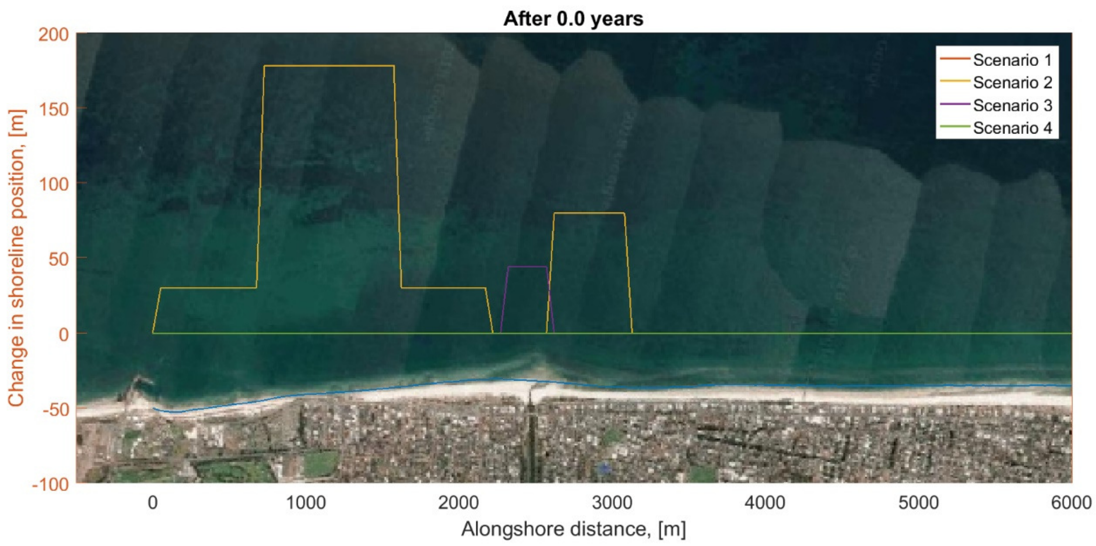


Figure 9-1: Initial conditions for the four (4) coastal management scenarios. Note that the scale of the y-axis does not match the underlying image, but the alongshore location matches between the image and the lines.

9.2 Back-passing Sediment Sink-Sources for the Scenarios

For Scenario 3, 30,000 m³/yr of sand was back-passed in the model from the zone just up-drift of Torrens Outlet during August, September and October to nourish a seasonal beach at south end of West Beach over the summer months. The bed level source map is shown in Figure 9-2.

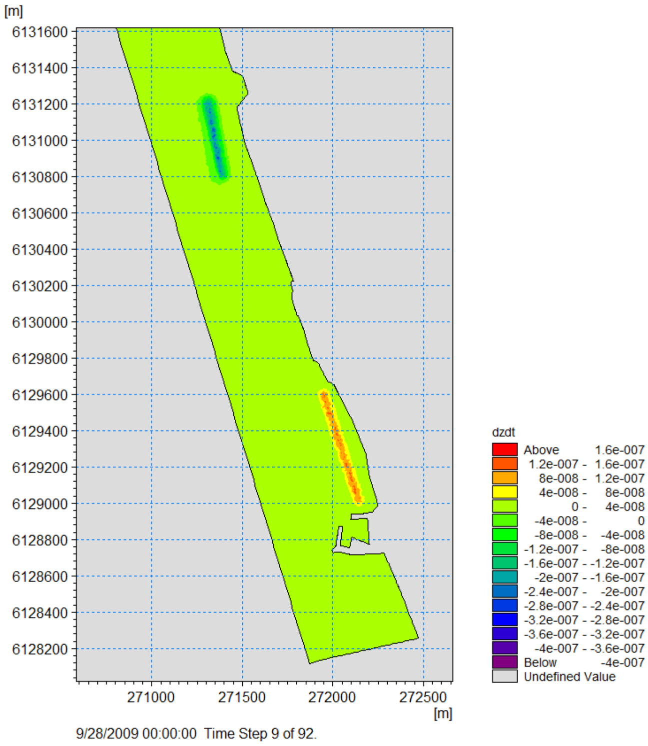


Figure 9-2: Bed level source map for Scenario 3. Values are in m/s and signify rate of change in bed level due to the back-passing.

For Scenario 4, during the first 4 years, 150,000 m³ was added to the south end of West Beach between March and July (see Figure 9-3 left) and 20,000 m³ was added to Henley Beach South during August (see Figure 9-3 right). This assumed a pumping capacity of 30,000 m³ per month from the northern Adelaide beaches.

During the last 3.5 years, 100,000 m³ was added between March and July to the south end of West Beach, see Figure 9-4.

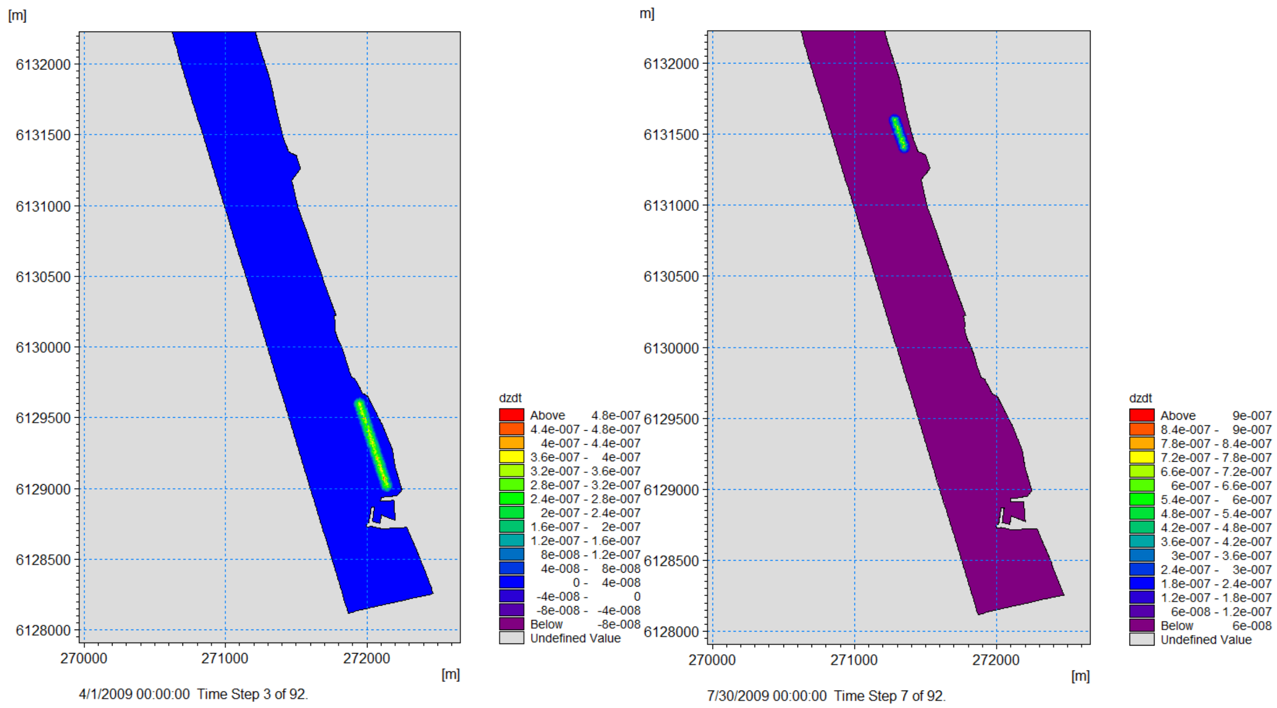


Figure 9-3: Bed level source map for Scenario 4 during the first 4 years. Left: West Beach. Right: Sth Henley Beach. Values are in m/s and signify rate of change in bed level due to the back-passing.

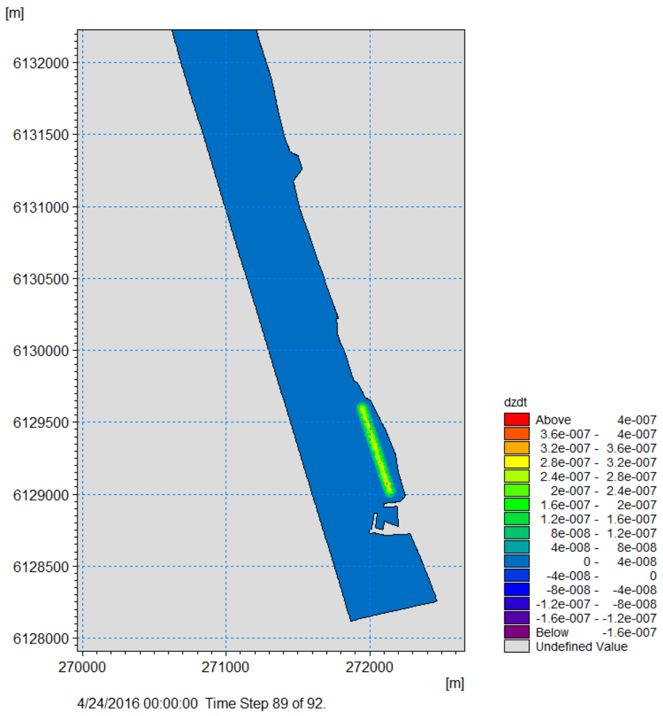


Figure 9-4: Bed level source map for Scenario 4 during the last 3.5 years. Values are in m/s and signify rate of change in bed level due to the back-passing.

9.3 Results

The comparisons of the predicted shoreline positions after 2 years, 4 years, 6 years and 7.5 years is shown for all four scenarios in Figure 9-5 to Figure 9-8. The key results from the simulation of these scenarios are described below:

Scenario 1 (Do Nothing)

For Scenario 1 a recession of the shoreline position is predicted, especially on the south end of West Beach and at the south end of Henley Beach. The north end of West Beach is stable, but both up-drift and down-drift sections of the beach recedes during the 7.5 year period. The North end of Henley Beach is stable.

Scenario 2 (Mass Replenishment)

For Scenario 2, the SM model predicted the following:

- After 2 years the initial large nourishment in-front of the rock revetment has diffused to the adjacent sections of the beach, but the beach is still more than 50 m wide in front of the rock revetment. The nourishment at Henley Beach South has also diffused, but the beach remains around 30 m wide.
- After 4 years the large nourishment has begun migrating north forming a 50 m wide beach from the SLSC to the north end of West Beach. The south end of West Beach has not begun experiencing erosion and Henley Beach is also wider than the base case beach.
- After 6 years the nourishment has moved further north, but still there is no erosion observed at the south end of West Beach nor at Henley Beach.
- After 7.5 years a very small amount of erosion is observed at the south end of West Beach, this erosion can easily be mitigated by back-passing sand from just up-drift of Torrens Outlet where the bulk of the large nourishment is now located.

Scenario 3 (Interim Management)

For Scenario 3, the SM model predicted the following:

- It is observed that the initial nourishment at Torrens Outlet benefits the beach at Henley Beach South for the first 2-4 years after which the sand removed from the area by the back-passing system makes the erosion at Henley Beach South worse than for the do-nothing Scenario 1.
- At the south end of West Beach, the back-passing of sand reduces the erosion compared with the do-nothing Scenario 1, but significant erosion of up to 40 metres is observed after 7.5 years.

Scenario 4 (Large-scale Back-Passing)

For Scenario 4, the SM model predicted the following:

- The shoreline is predicted to accrete especially at the south end of West Beach, but around Torrens Outlet the beach is also accreting compared with Scenario 1 (do nothing) for the first 4 years. This shows that model is predicting the over-nourishment strategy to work as designed.
- For the last 3.5 years of the simulation, the shoreline position is stable along West Beach with a small amount of erosion at Henley Beach South, indicating that it may be a good idea to continue to distribute a small fraction of the back-passed sand to Henley Beach South also for the later years.
- It is recommended that the distribution of the back-passed sand is optimised every year based on the status of the coastal system, i.e. based on how much sand is in each of the sediment cells.

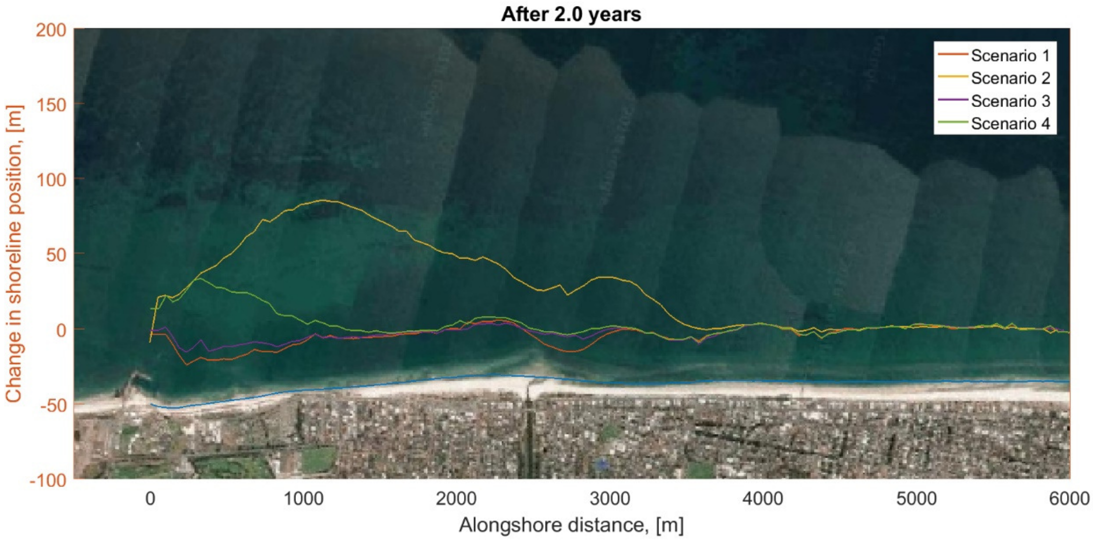


Figure 9-5: Predicted shoreline position for the four (4) scenarios after 2 years. Note that the scale of the y-axis does not match the underlying image, but the alongshore location matches between the image and the lines.

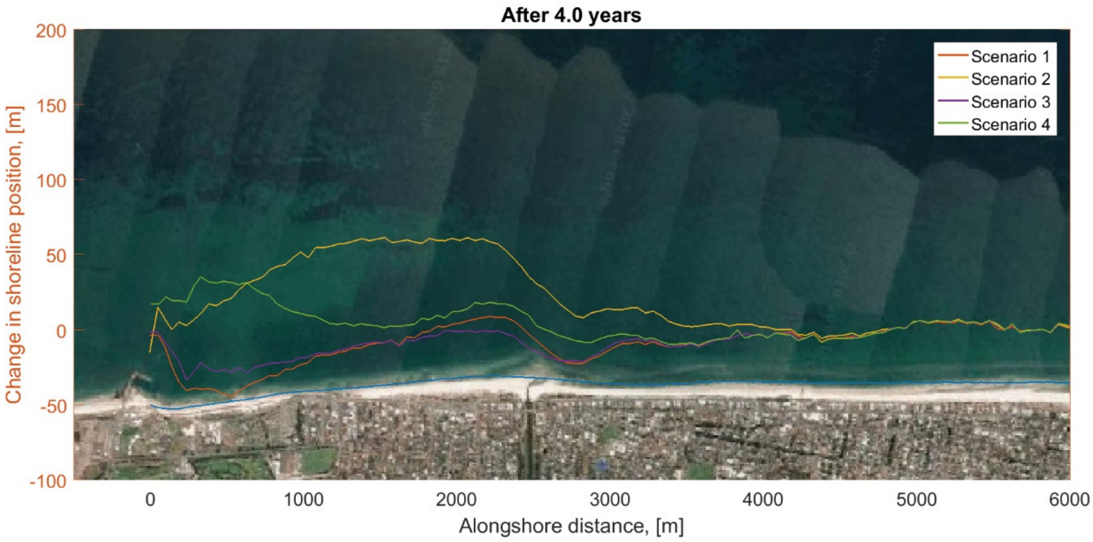


Figure 9-6: Predicted shoreline position for the four (4) scenarios after 4 years. Note that the scale of the y-axis does not match the underlying image, but the alongshore location matches between the image and the lines.

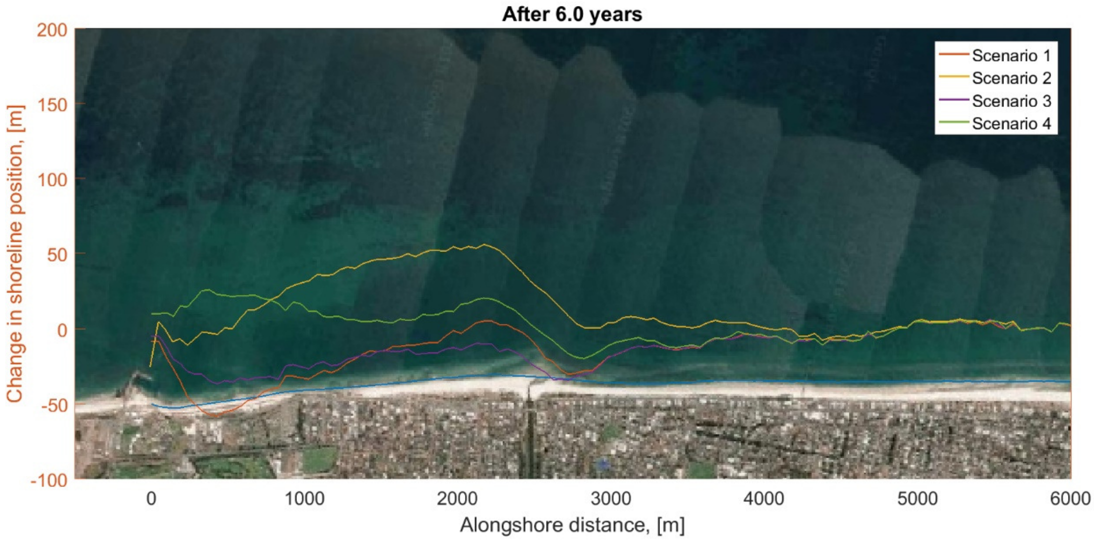


Figure 9-7: Predicted shoreline position for the four (4) scenarios after 6 years. Note that the scale of the y-axis does not match the underlying image, but the alongshore location matches between the image and the lines.

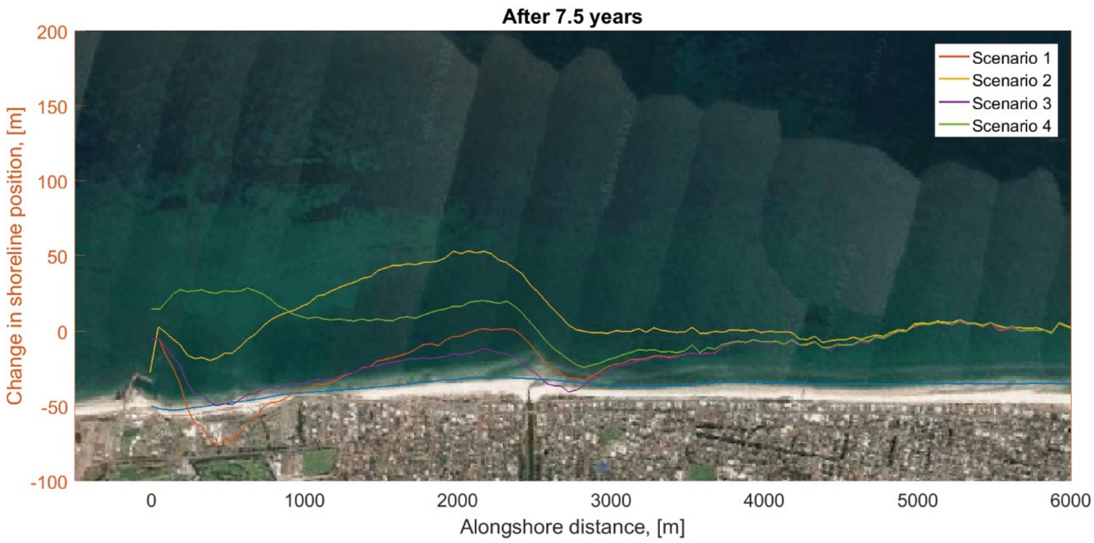


Figure 9-8: Predicted shoreline position for the four (4) scenarios after 7.5 years. Note that the scale of the y-axis does not match the underlying image, but the alongshore location matches between the image and the lines.

Figure 9-9, Figure 9-10, Figure 9-11 and Figure 9-12 show the total net littoral drift along the shoreline for the four (4) scenarios after 2 year, 4 years, 6 years and 7.5 years respectively.

For Scenario 1 (do nothing) and 3 (interim management) the littoral drift along the shoreline is similar. It increased from zero at the boat ramp up to around 100,000 m^3/year along Henley Beach. The largest part of the gradient in transport occurs on the south end of West Beach, but there is also an increasing transport rate along Henley Beach South which is responsible for the observed erosion at these two sections of shoreline.

For Scenario 2 (mass nourishment) the transport is southward on the up-drift side of the mass nourishment and the main part of the gradient in the littoral drift occurs right at the mass nourishment for the first 2-4 years, in line with the design of the mass nourishment. After 7.5 years the transport rate is northward on the south end of West Beach, but the gradient is small although increasing.

For Scenario 4 the gradient in the littoral drift occurs almost entirely on the south end of West Beach where the back-passed sand is distributed. There is also a smaller gradient along Henley Beach South indicating that distributing some of the back-passed sand in this area could be advantageous. The transport direction on the south end of West Beach is seen to be southward with a rate of around 15,000 m³/yr.

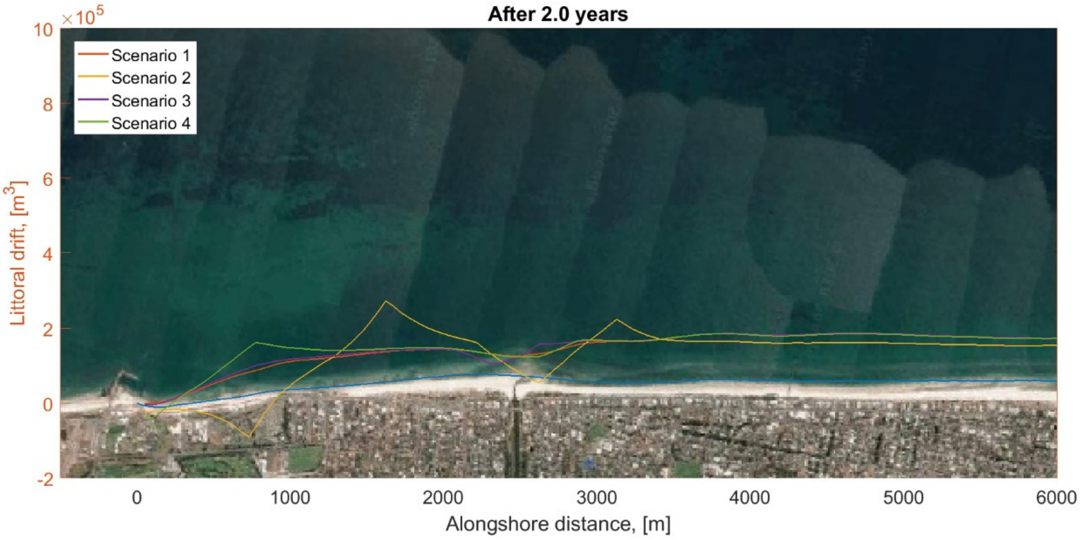


Figure 9-9: Total net littoral drift after 2 years from start of the simulation for all four (4) Scenarios.

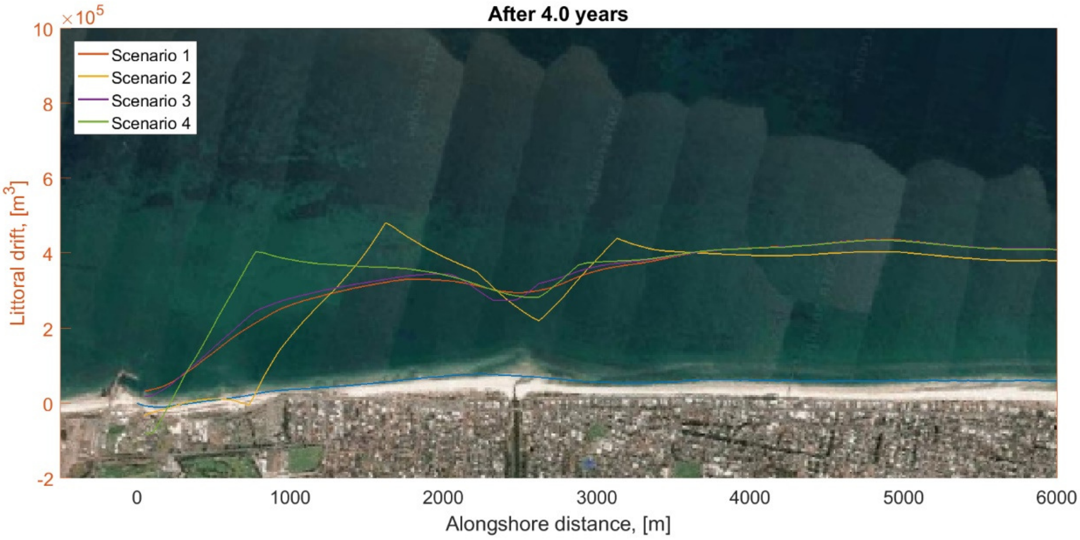


Figure 9-10: Total net littoral drift after 4 years from start of the simulation for all four (4) Scenarios.

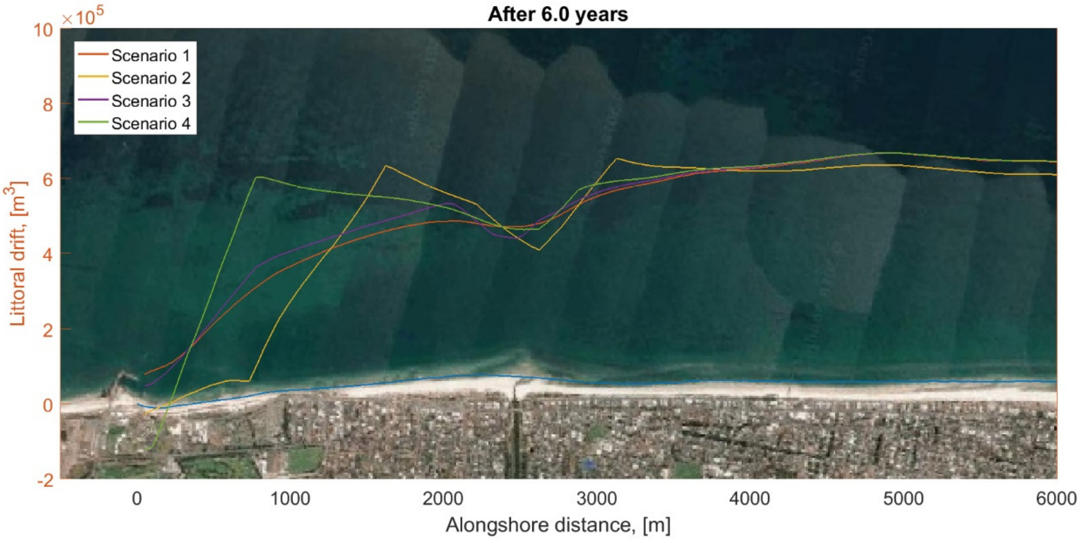


Figure 9-11: Total net littoral drift after 6 years from start of the simulation for all four (4) Scenarios.

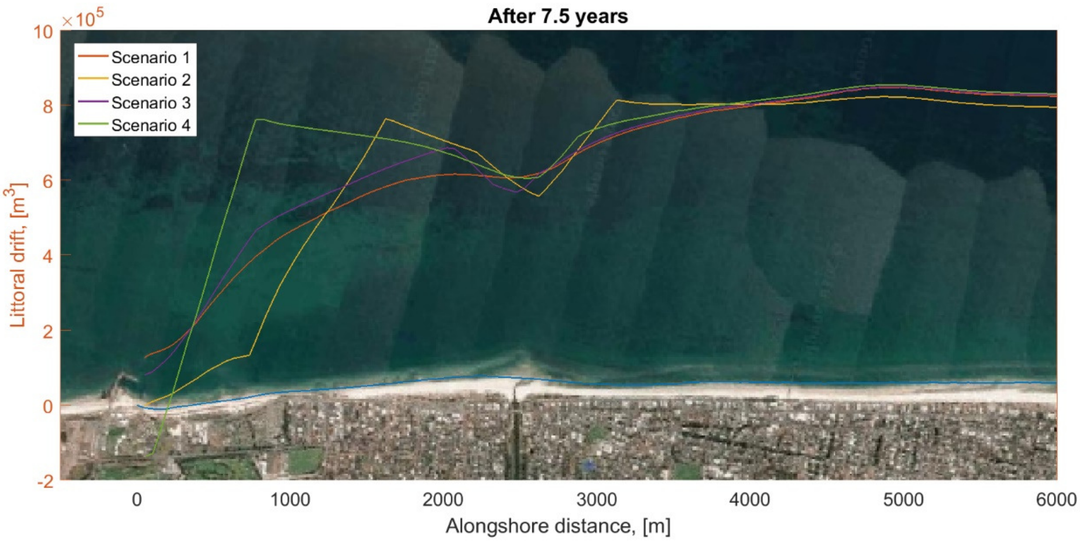


Figure 9-12: Total net littoral drift after 7.5 years from start of the simulation for all four (4) Scenarios.

9.4 Discussion

The results from the previous section shows that both Scenario 2 (mass nourishment) and Scenario 4 (back-passing from the northern beaches) have the potential to provide a long-term sustainable solution to the erosion problems at the south end of West Beach and Henley Beach South. In both these scenarios, the shoreline model is predicting the beach to be wider than the in the base case condition after 7.5 years, with the widest beach predicted for Scenario 4. In both Scenario 1 and 3, the beach at the south end of West Beach keeps eroding and eventually there will be no more sand left to erode at which point the erosion will move further north causing the north end of West Beach to erode.

10 Seagrass Ingress Modelling

The hydrodynamic and wave models of the West Beach study area were used to undertake assessments of potential modifications to the Adelaide Shores boat harbour breakwaters to limit the ingress of seagrass wrack into the harbour basin and to improve the attenuation of waves impacting the boat ramp.

DEWNR and Adelaide Shores chose to test the following breakwater modification options in the hydrodynamic and wave models:

- Option 0: Base Case, i.e. existing conditions.
- Option A: Removal of the 'heel' on the southern breakwater;
- Option B: Lengthen the southern breakwater whilst maintain minimum 50m entrance width;
- Option C: Extension the seaward end of the northern breakwater.

Figure 10-1 shows the existing layout of the harbour and Figure 10-2, Figure 10-3 and Figure 10-4 display the respective layouts for Option A, B and C.

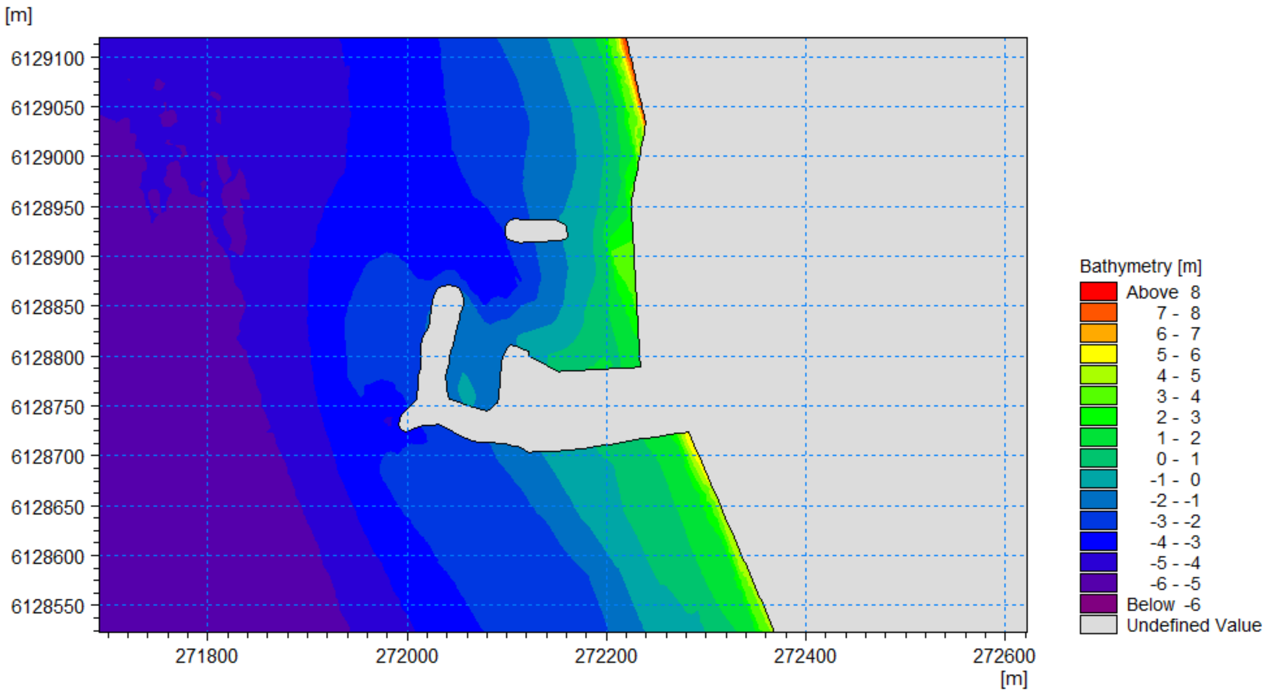


Figure 10-1: Harbour layout for Base Case (Existing).

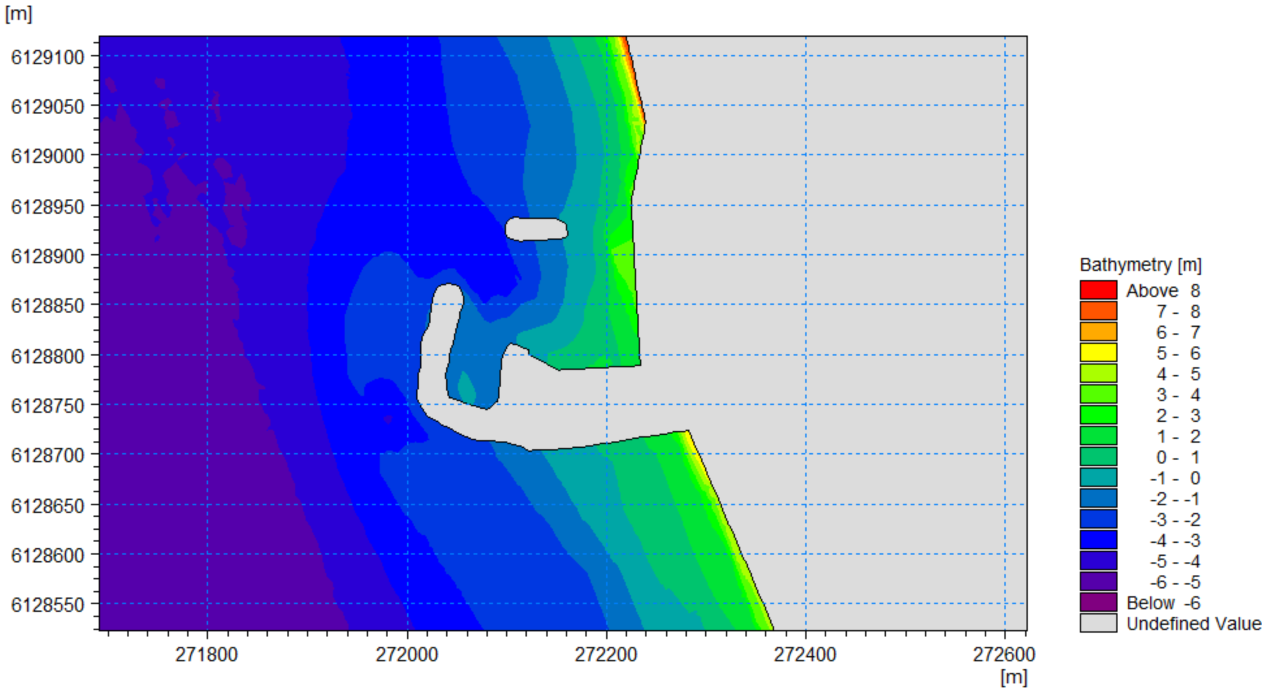


Figure 10-2: Harbour layout for Option A

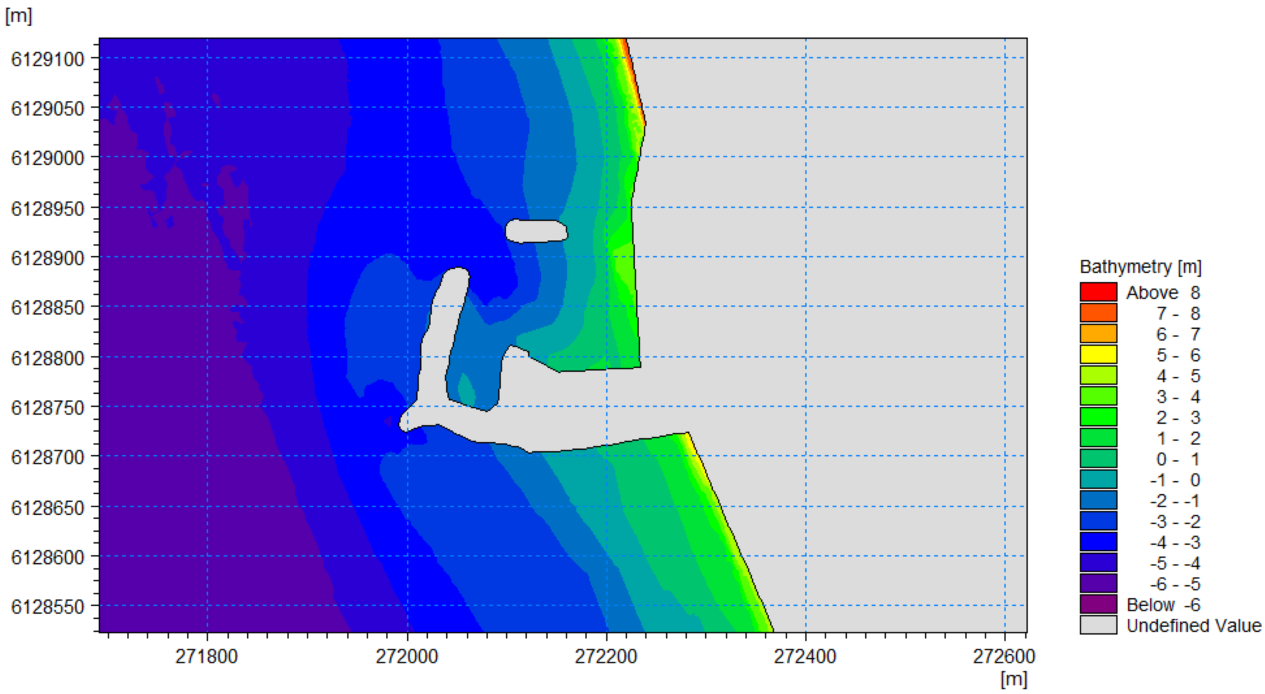


Figure 10-3: Harbour layout for Option B.

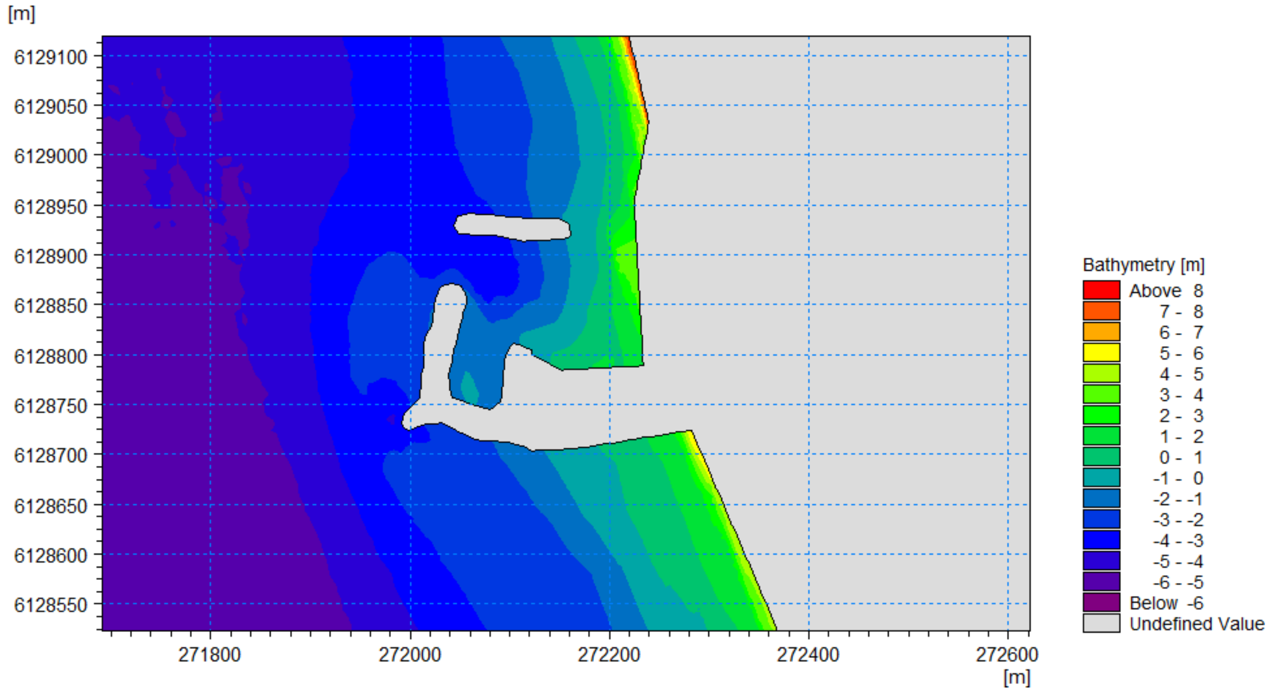


Figure 10-4: Harbour layout for Option C.

Each of the above three options were trialled in isolation under the following two steady forcing scenarios:

1. West-northwest wave condition (Hs = 1.5 m, Tp = 9 s and MWD = 300);
2. Southwest wave condition (Hs = 1.5 m, Tp = 9 s and MWD = 235);

For each scenario, numerical particles were introduced into the flow fields at three cross-shore locations up-drift of the harbour, the release position are shown in Figure 10-5. One particle is released every 3 seconds at each of the six (6) locations. The particles were introduced to provide a proxy for the transport and fate of individual seagrass leaves in the coastal waters at the study area.

The drift profile of the particles was formulated such that they simulated a suspended, conservative and mass-less (no decay or settling) substance that was transported by the mean flow and without significant influence from wind (no surface drifting). The particles were also not enabled to beach when in contact with the shoreline. The drift profile description is a simplification of the behaviour of seagrass transport however it is considered to represent a quite reasonable proxy for assessing the likely mechanisms by which seagrass wrack is transported into the Adelaide Shores boat harbour for these preliminary assessments.

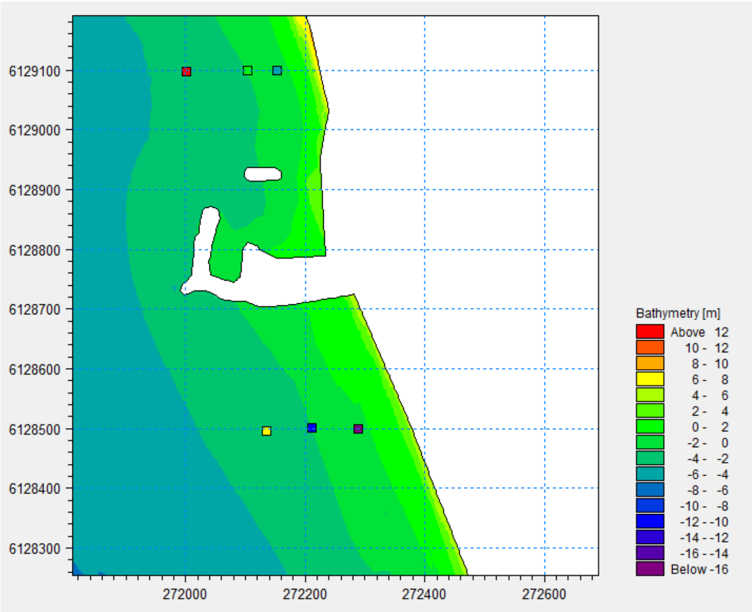


Figure 10-5: Release positions for particles.

10.1 Results

For each of the simulated scenarios, firstly, the flow field is shown. Next, the particle tracks are shown. The tracks have been coloured according to whether they enter the harbour or not. Green tracks do not enter the harbour and red tracks do enter the harbour. Tracks which enter the harbour and then leave the harbour again have been terminated before they leave the harbour as it is most likely that seagrass wrack which enter the harbour will get stuck on either the breakwater rocks or on the beach and this process is not included in the model.

10.1.1 Option 0 (Base Case)

The flow conditions during the NW event is shown in Figure 10-6 while Figure 10-7 shows the flow condition during the SW event. It is observed that the present harbour layout promotes the forming of eddies both inside and around the harbour. During the NW event the longshore current along the beach flows straight into the harbour. During the SW event eddies are formed both along the outer breakwater and north of the northern breakwater. These eddies are problematic as seagrass wrack can get trapped in the eddies and subsequently be washed into the harbour.

In many cases seagrass wrack is washed onto the beach. This seagrass wrack is often taken by the waves during wave events and transported along the beach by the longshore current. For this reason, the concentration of seagrass wrack in the water is often very high close to the shoreline during wave event. Thus, the longshore current flowing along the beach and straight into the harbour through the opening at the shoreline is expected to bring a large amount of seagrass wrack into the harbour.

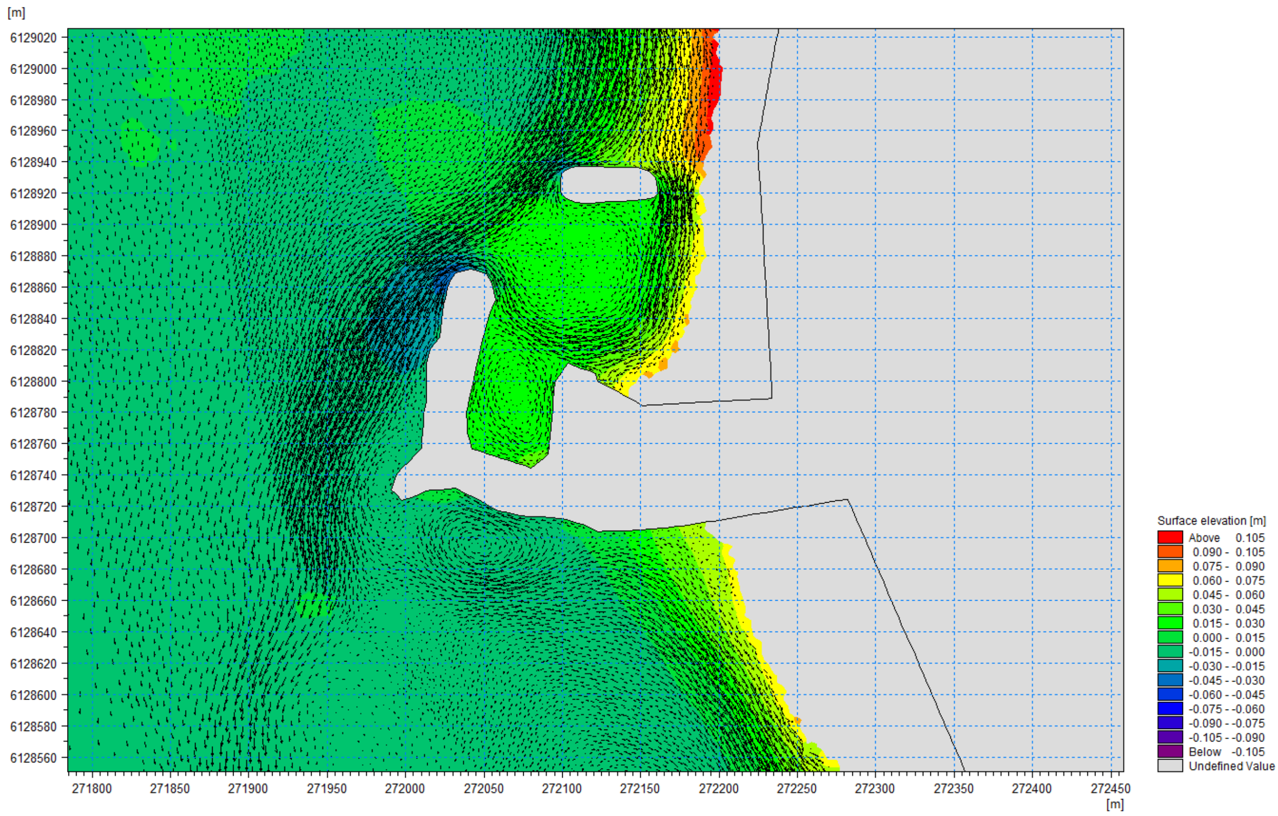


Figure 10-6: Flow conditions for Base Case during NW event.

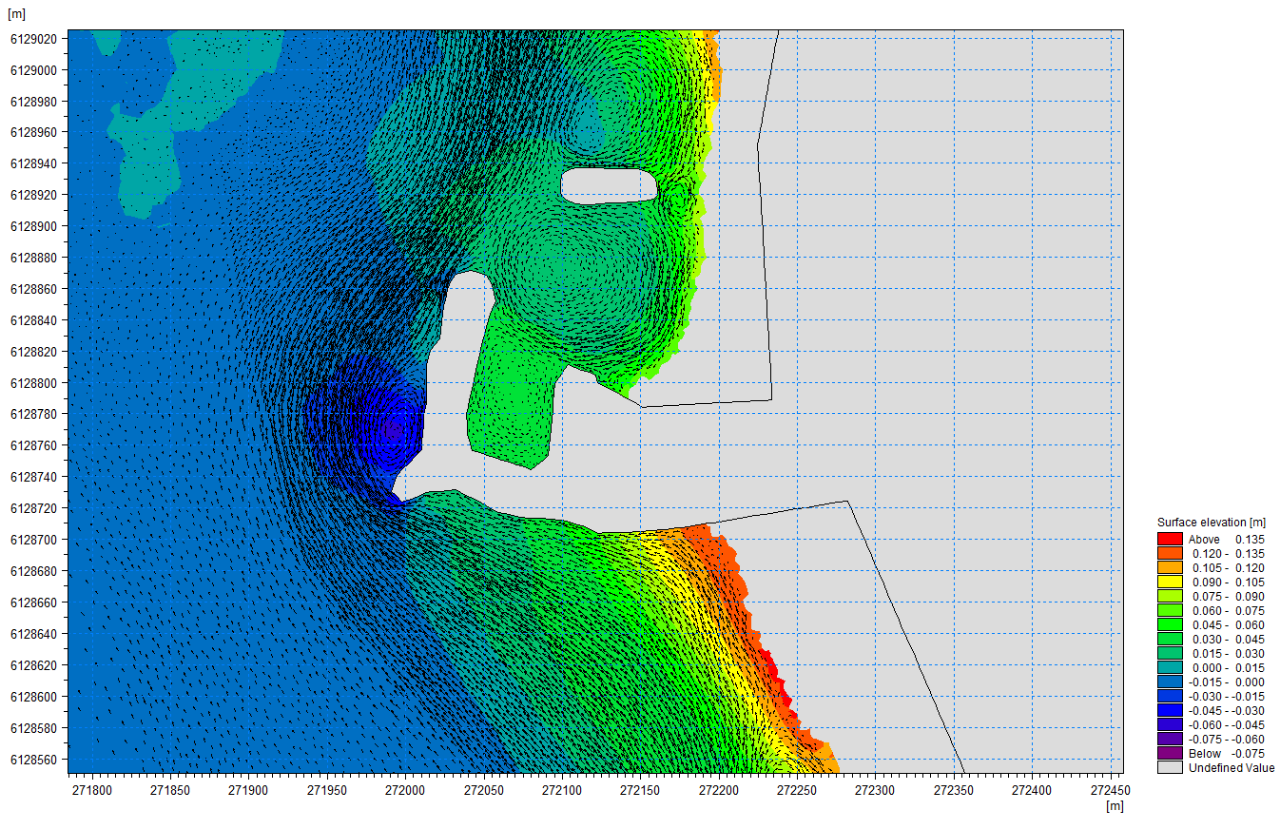


Figure 10-7: Flow conditions for Base Case during SW event.

The particle tracks for the Base Case NW event is shown in Figure 10-8 for the up-drift release positions, the down drift release positions did not result in any particles going near the harbour. It is seen that none of the particles released at the off-shore location enter the harbour, a few of the particles release at the middle position enter the harbour while almost all the particles release at the nearshore point enter the harbour.

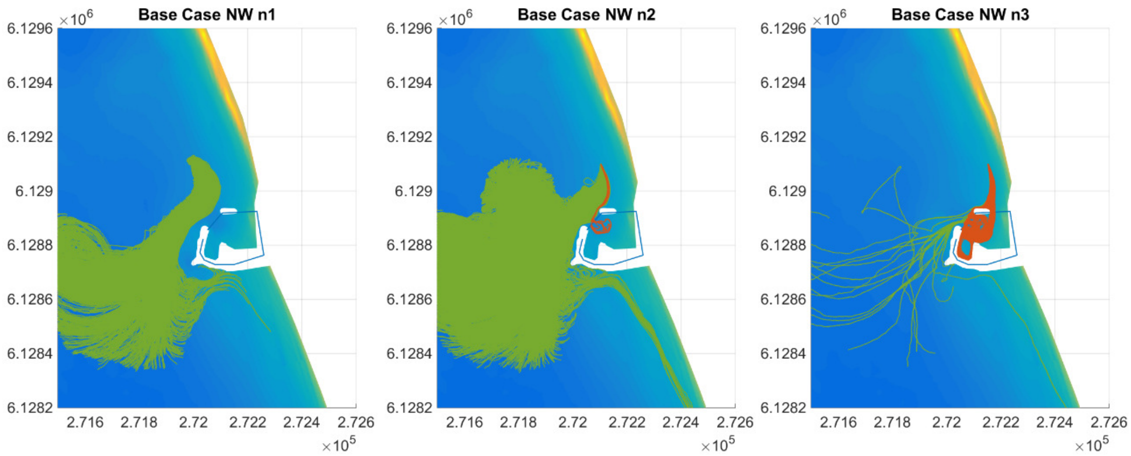


Figure 10-8: Particle tracks for the Base Case NW event.

Figure 10-9 shows the particle tracks for the SW event. It is seen that none of the particles release at the off-shore point enters the harbour while many of the particles release at the middle and nearshore points enters the harbour. It is observed that many particles are trapped in the eddies around the harbour before entering the harbour.

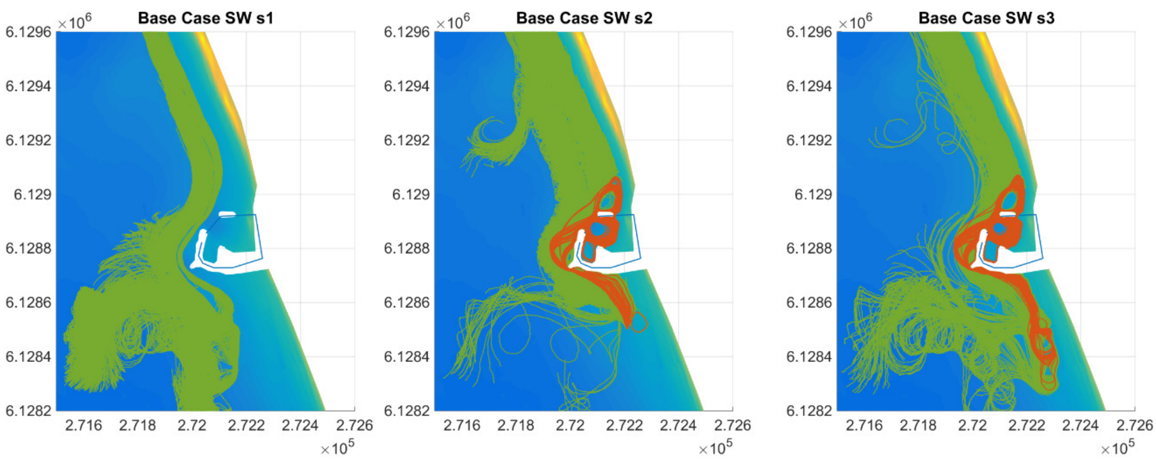


Figure 10-9: Particle tracks for the Base Case SW event.

The modelled particle tracks look similar to the measured drogues tracks shown in Figure 10-10 validating the model, most notably is the eddy on the offshore side of the offshore part of the southern breakwater observed in both the measurements and the model during the SW Event.

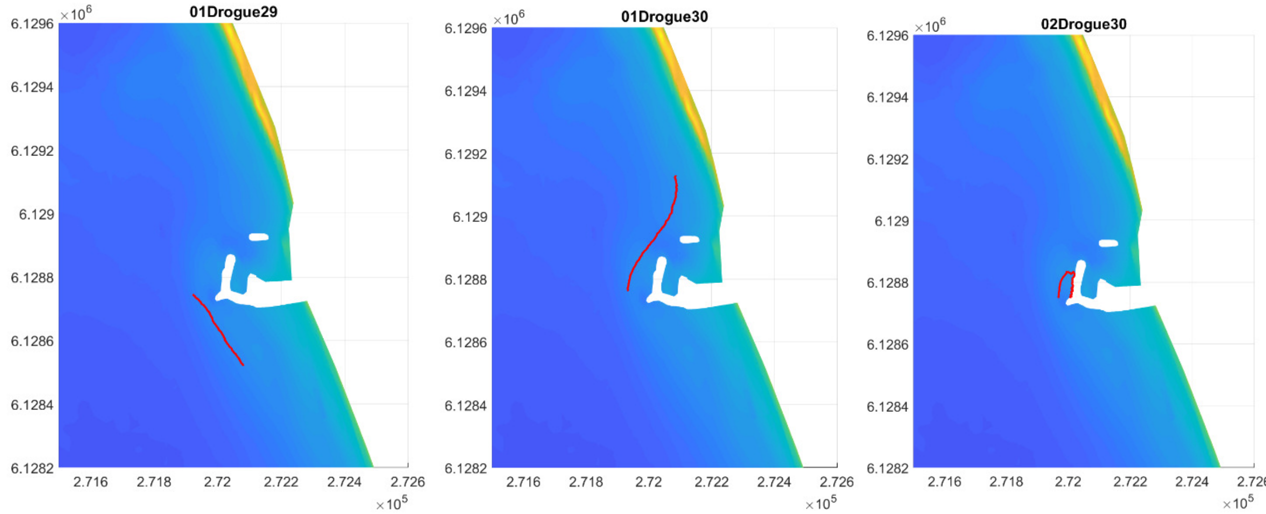


Figure 10-10: Measured drogues tracks around the harbour.

10.1.2 Option A (Removal of ‘Heel’)

The flow conditions during the NW event is shown in Figure 10-11 while Figure 10-12 shows the flow condition during the SW event. It is noted that for the SW event, the eddy offshore of the outer breakwater is gone and the eddy north of the northern breakwater looks smaller compared with the Base Case. For the NW event the flow looks similar to the Base Case.

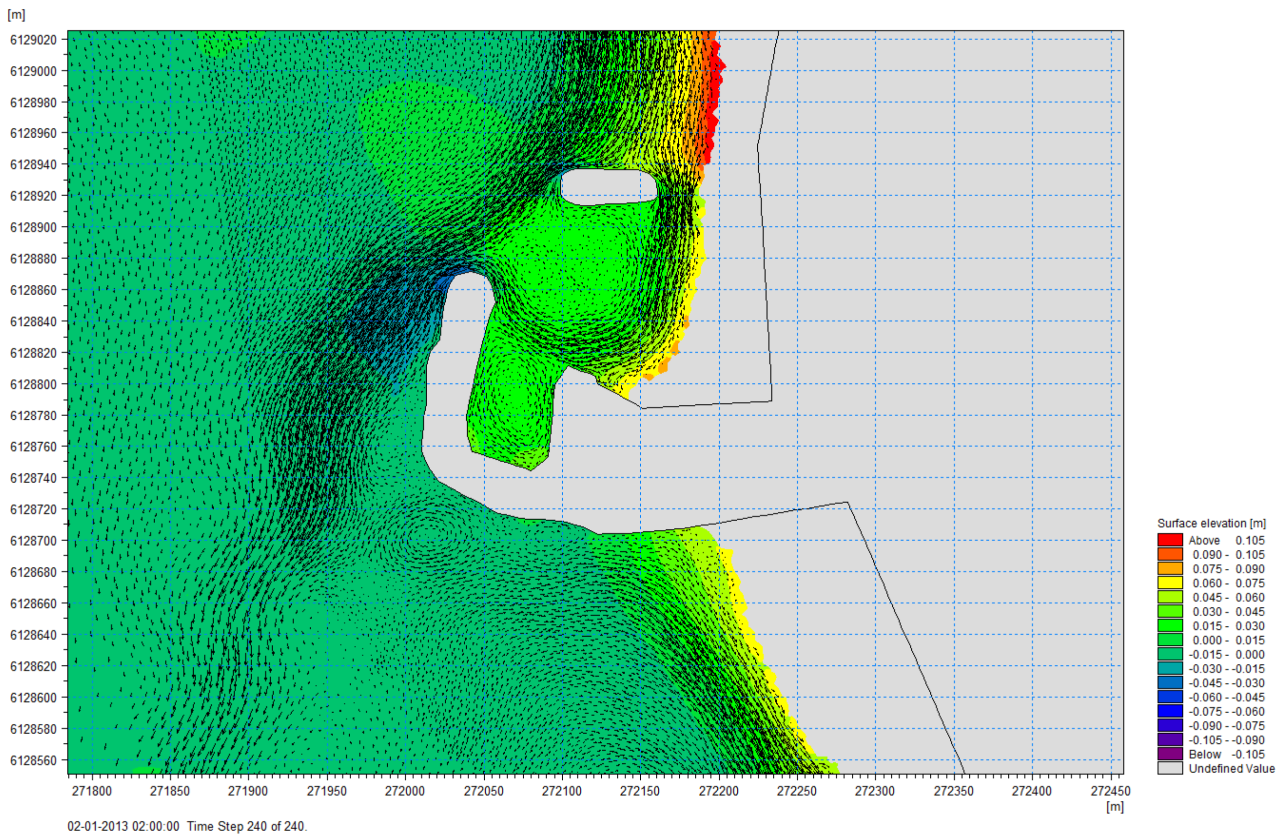


Figure 10-11: Flow conditions for Option A during NW event.

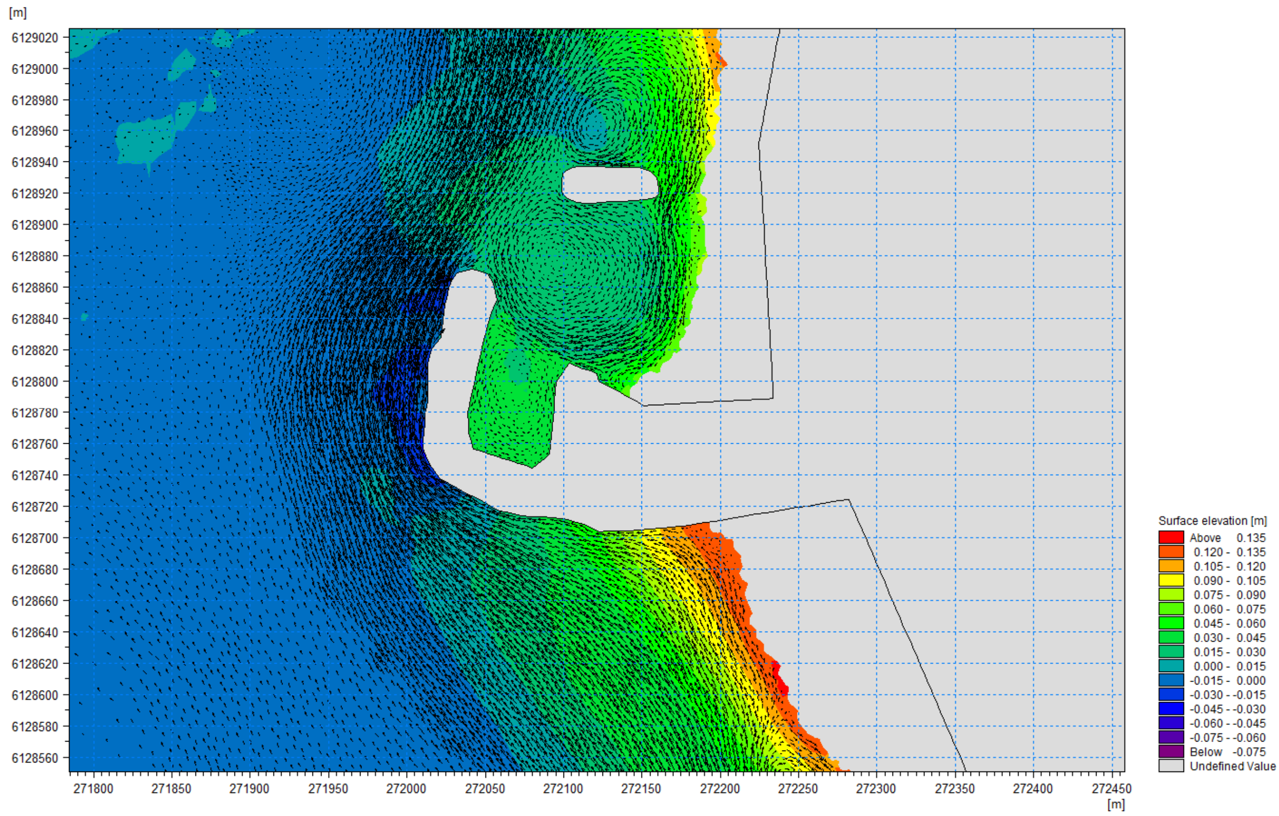


Figure 10-12: Flow conditions for Option A during SW event.

The particle tracks for Option A are shown in Figure 10-13 and Figure 10-14. It is noted that particles enter the harbour from the middle and nearshore release locations for both the SW and NW events.

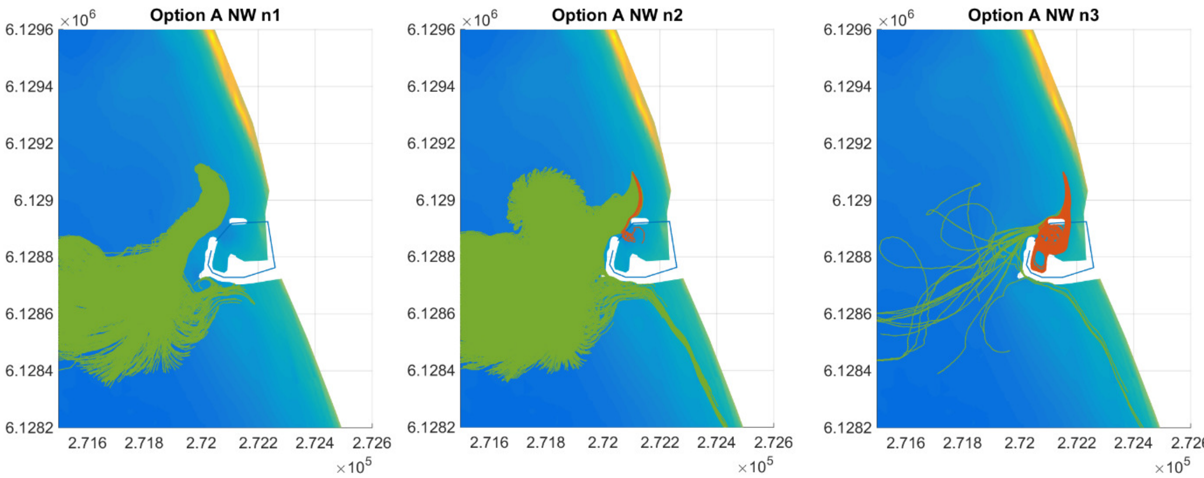


Figure 10-13: Particle tracks for the Option A NW event.

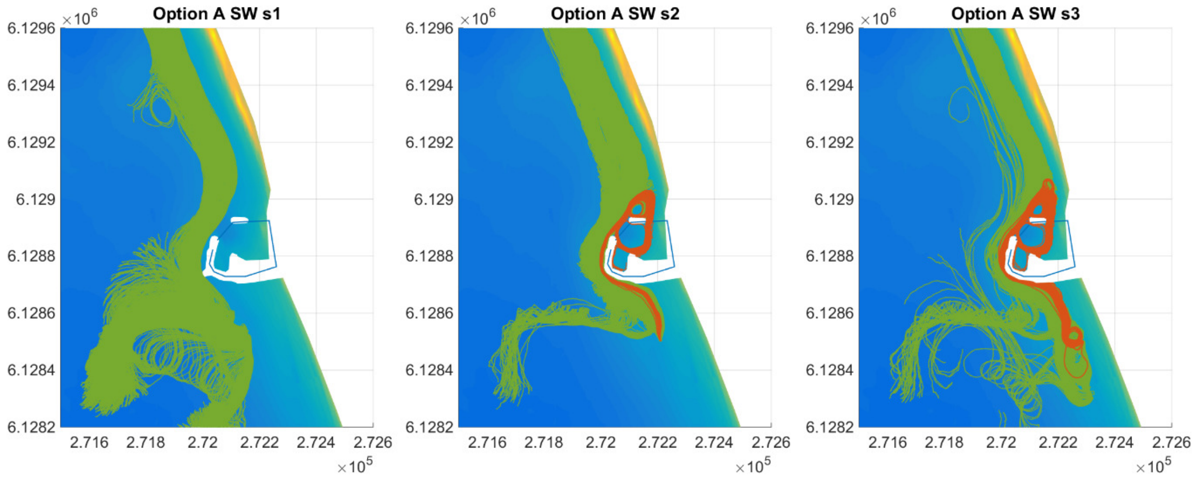


Figure 10-14: Particle tracks for the Option A SW event.

10.1.3 Option B (Lengthen Southern Breakwater)

The flow conditions for the two events are shown in Figure 10-15 and Figure 10-16. These look quite similar to the flow conditions for the base case, but the eddy north of the northern breakwater looks weaker for Option B than for the Base Case during the SW event.

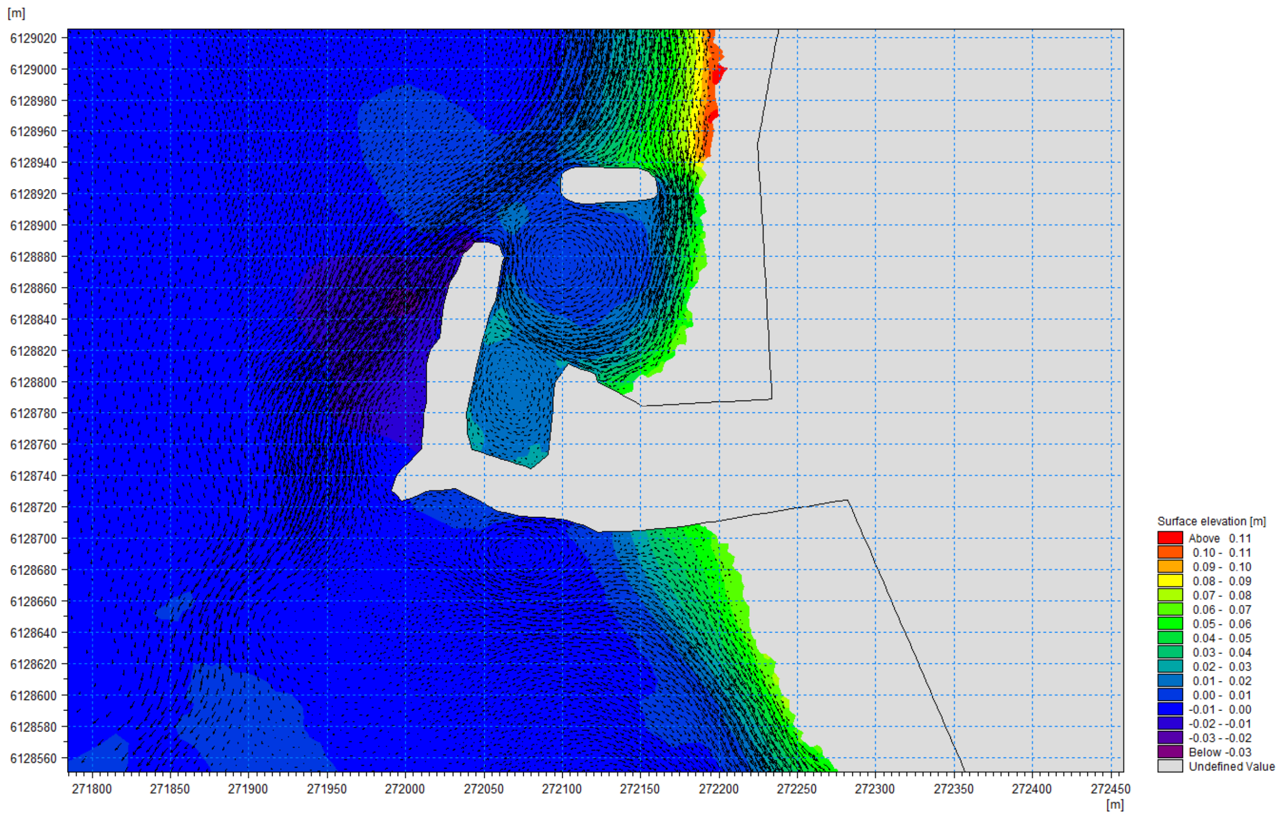


Figure 10-15: Flow conditions for Option B during NW event.

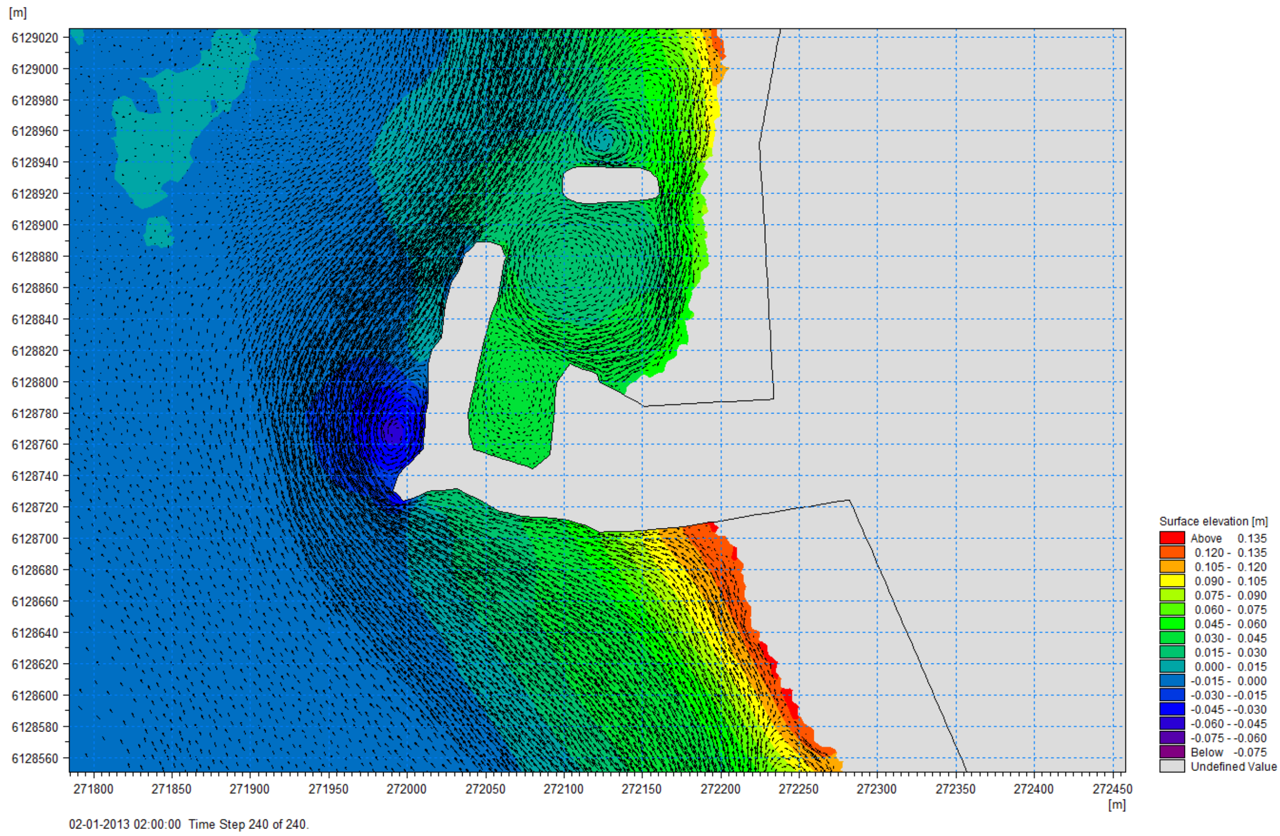


Figure 10-16: Flow conditions for Option B during SW event.

The particle tracks for Option B are shown in Figure 10-17 and Figure 10-18. It is noted that particles enter the harbour from the middle and nearshore release locations for both the SW and NW events.

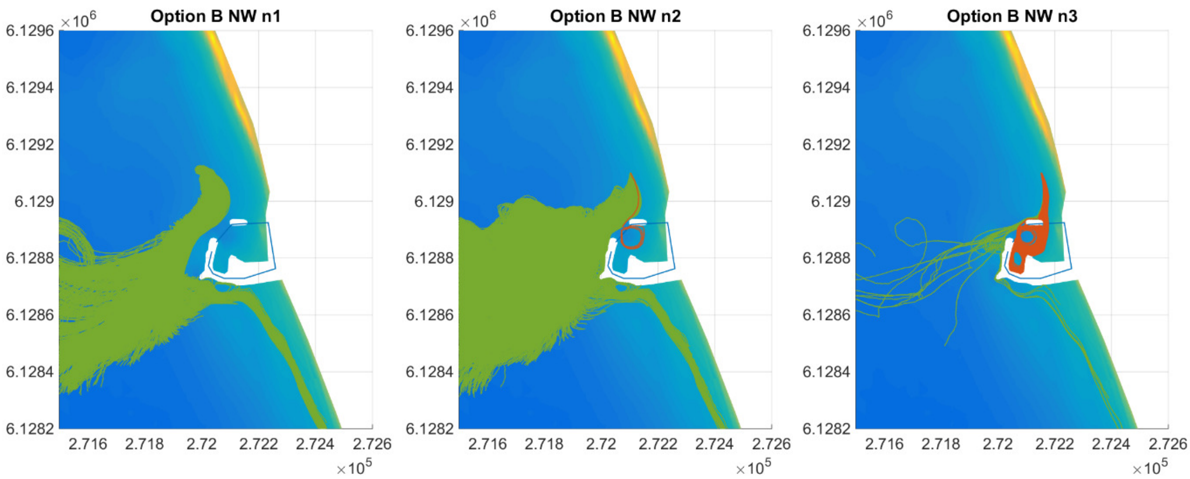


Figure 10-17: Particle tracks for the Option B NW event.

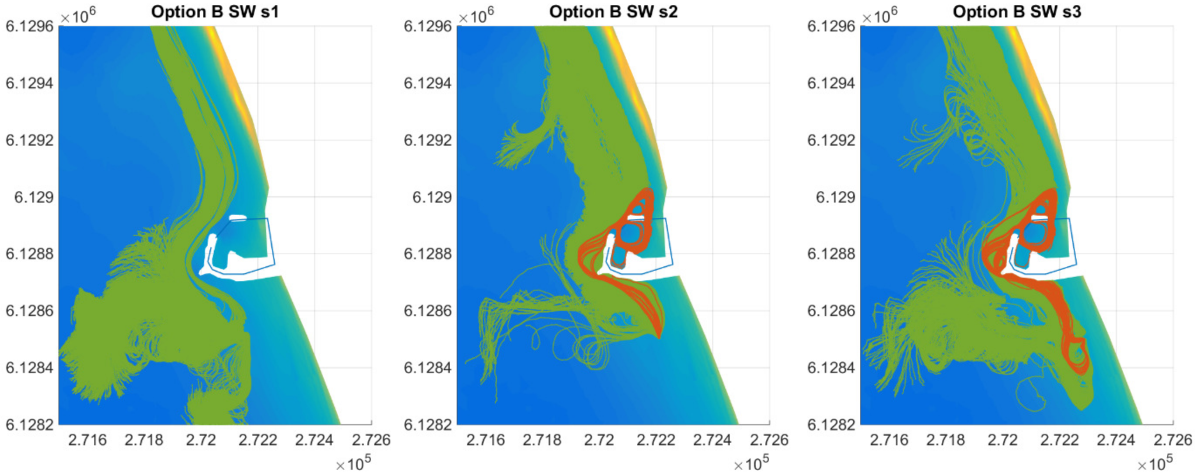


Figure 10-18: Particle tracks for the Option B SW event.

10.1.4 Option C (Seaward Extension of Northern Breakwater)

The flow conditions for the two events are shown in Figure 10-19 and Figure 10-20. For the NW event the flow is directed more towards the offshore by the extended northern breakwater, but still the longshore current along the beach flows straight into the harbour. The flow through the harbour meets the flow along the northern breakwater to generate the strong offshore directed flow.

For the SW event the extended northern breakwater seems to have increased the size of the eddy north of the northern breakwater.

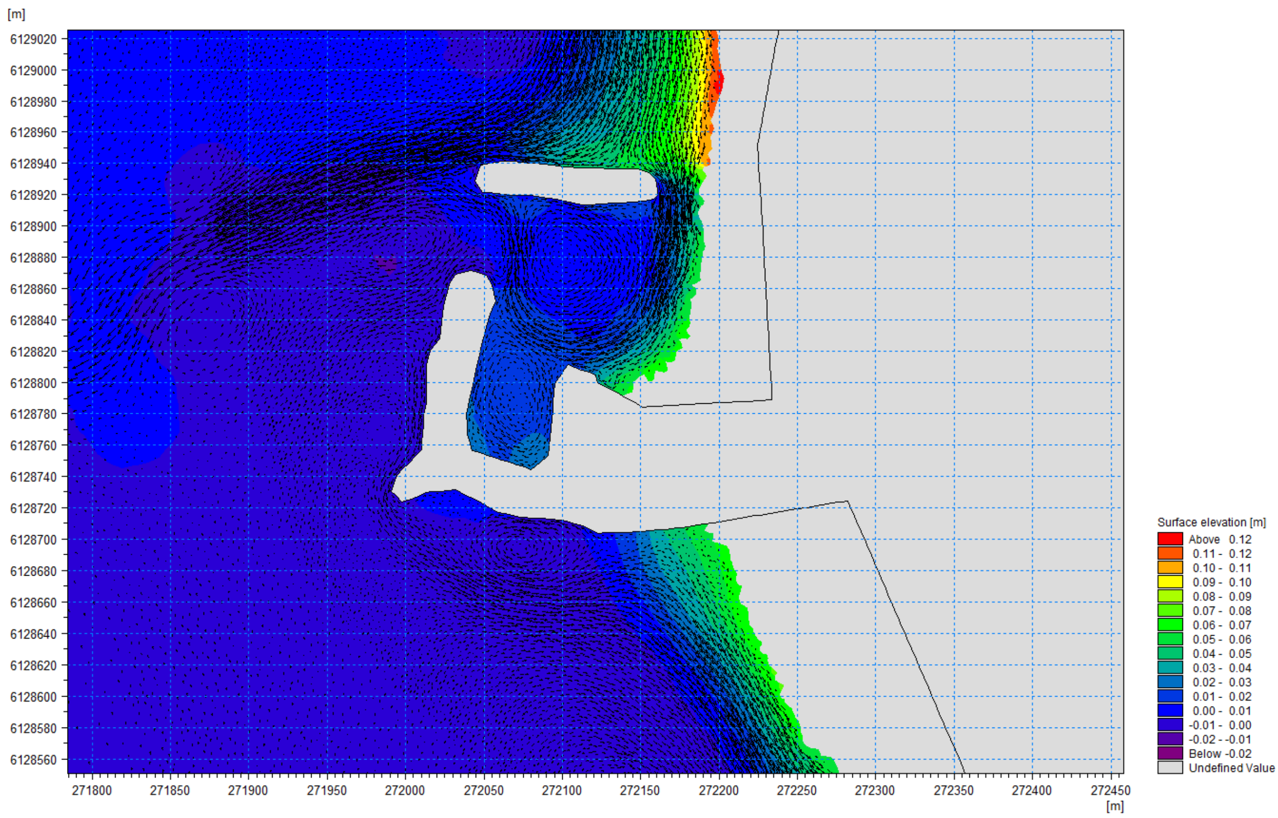


Figure 10-19: Flow conditions for Option C during NW event.

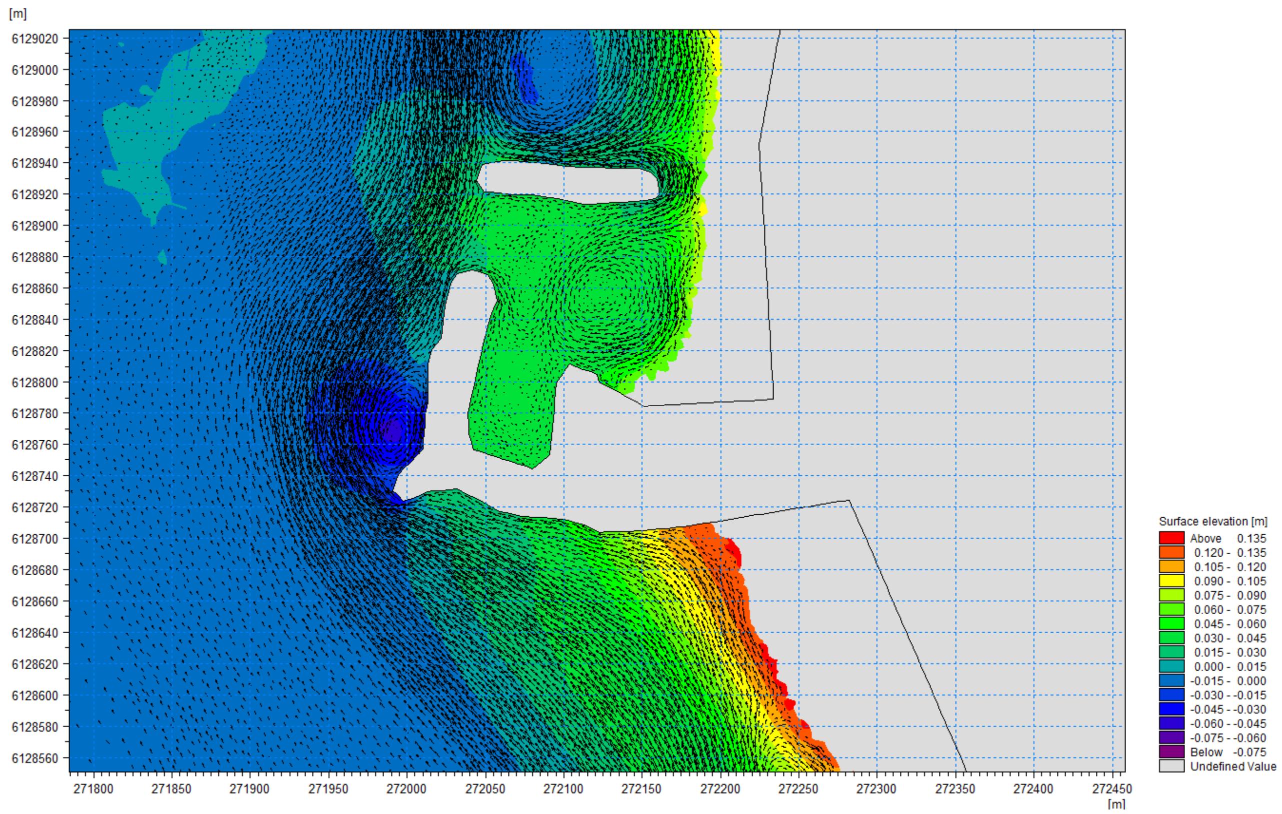


Figure 10-20: Flow conditions for Option C during SW event.

The particle tracks for Option C are shown in Figure 10-21 and Figure 10-22. It is noted that particles enter the harbour from the middle and nearshore release locations for the SW events. For the NW event, the strong offshore directed flow along the northern breakwater prohibits particles released at the middle point to enter the harbour, but most of the particles released from the nearshore point enter the harbour.

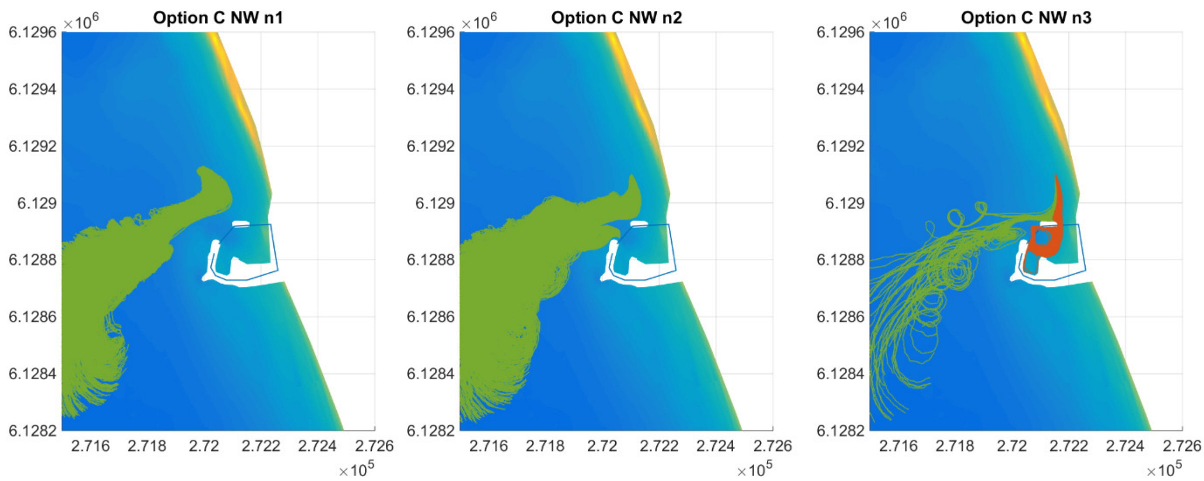


Figure 10-21: Particle tracks for the Option C NW event.

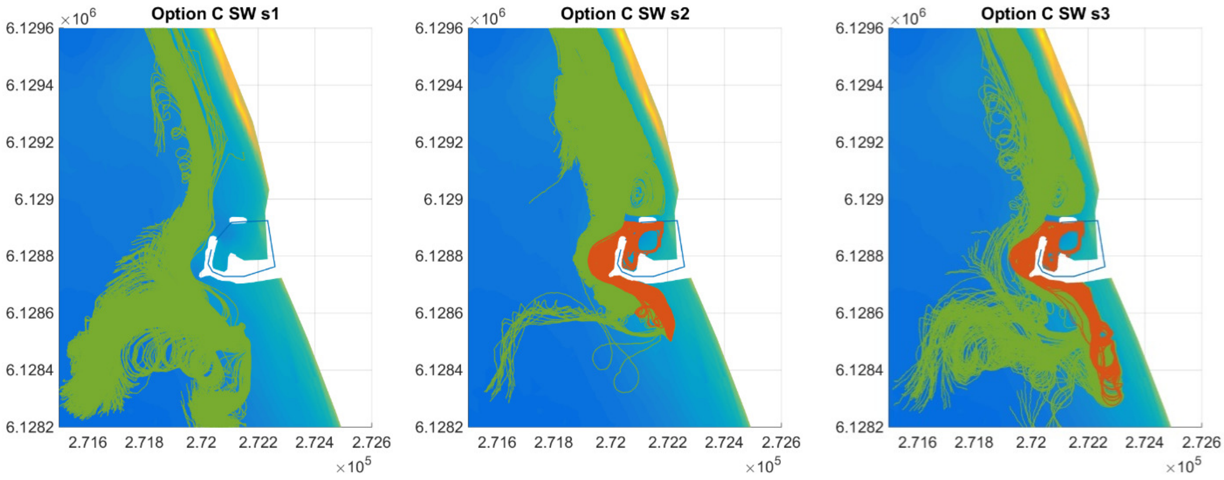


Figure 10-22: Particle tracks for the Option C SW event.

10.1.5 Quantitative Impact Assessment

The number of particles entering the harbour from each release point have been counted and Table 10-1 compares the three options with the base case. Table 10-2 summarises the relative percentage increase in the number of particles entering the harbour compared to the base case.

It is noted that almost all particles released at the nearshore location enter the harbour for all layouts with no improvement for Option A and B and only insignificant improvement for Option C.

For the SW event Option B shows a reduction in the number of particles entering the harbour, while the two other options increase the number of particles which enter the harbour.

Based on the present results, none of the options are recommended from a seagrass wrack intrusion perspective. To significantly reduce the amount of seagrass wrack in the harbour, the opening between the northern breakwater and the shoreline is recommended to be closed.

Table 10-1: The number of particles which enter the harbour during each event for each harbour layout. 2401 particles were released at each position during each simulation.

	NW event			SW event		
Release point	Offshore	Middle	Nearshore	Offshore	Middle	Nearshore
Base Case	0	5	2273	0	38	71
Option A	0	4	2270	0	26	119
Option B	0	1	2277	0	20	39
Option C	0	0	2250	0	253	621

Table 10-2: Percentage of the particles which enters the harbour in the base case.

	NW Event		SW Event	
Release point	Middle	Nearshore	Middle	Nearshore
Option A	80%	100%	68%	168%
Option B	20%	100%	53%	55%
Option C	0%	99%	666%	875%

10.2 Wave Height at Boat Ramp

DEWNR requested DHI to extract the significant wave height (H_s) from the simulation used for the seagrass wrack ingress study at a point in front of the boat ramp. Figure 10-23 shows the result from this extraction, i.e. the significant wave height in front of the boat ramp for both the NW Event and SW Event.

Figure 10-24 shows how much the extracted wave height has been reduced by each of the options compared with the Base Case.

The significant wave height for the two events for the base case and all options is shown in Figure 10-25 and Figure 10-26 and also show the location of the extraction point used for the analysis described above.

It is noted that diffraction which is a very important wave process responsible for wave spreading in harbours is not described by the SW model used in the sea-weed ingress modelling. Therefore, the results presented in the present section is an indication at best and should not be used to make any final decisions regarding the best layout of the harbour. Before deciding on a final layout it is recommended to study the reduction in wave disturbance using a Boussinesq Wave model or similar phase resolving wave model.

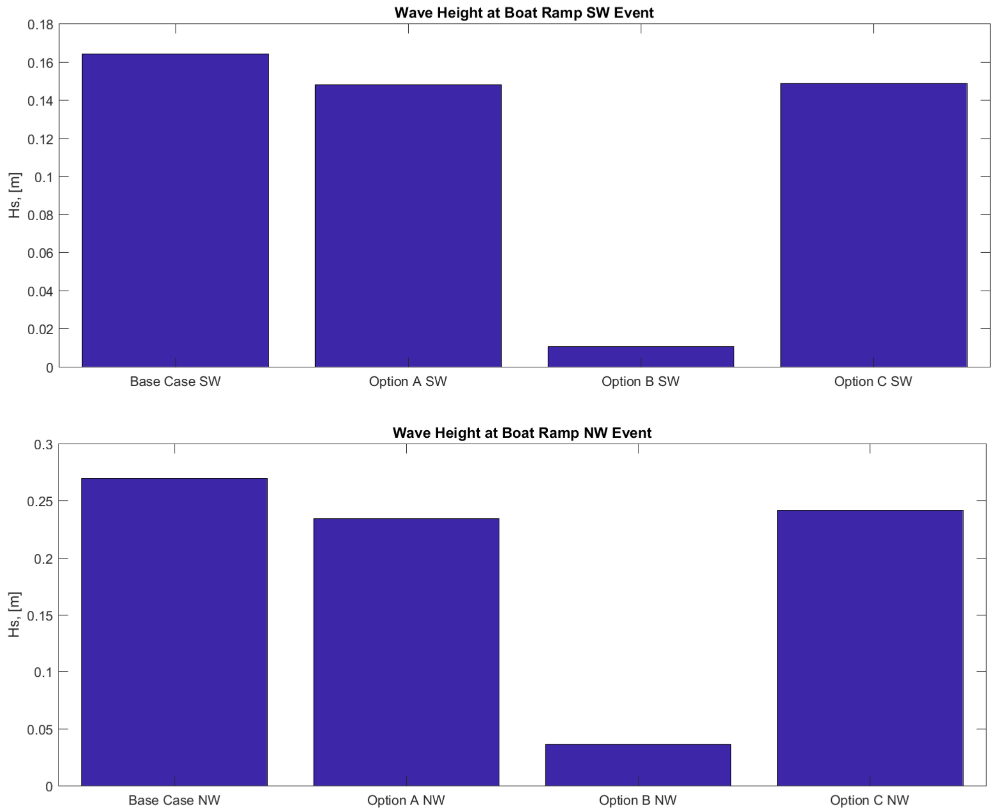


Figure 10-23: Significant wave height at boat ramp for SW Event (Top) and NW Event (Bottom).

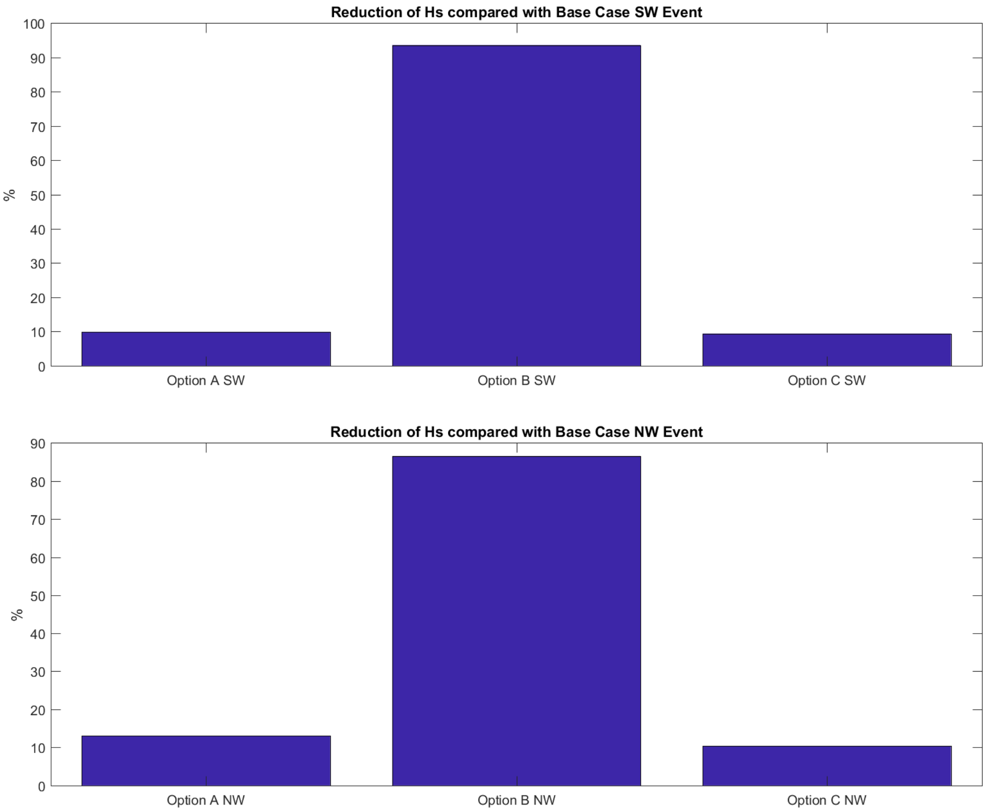


Figure 10-24: Reduction in H_s at boat ramp for SW Event (Top) and NW Event (Bottom).

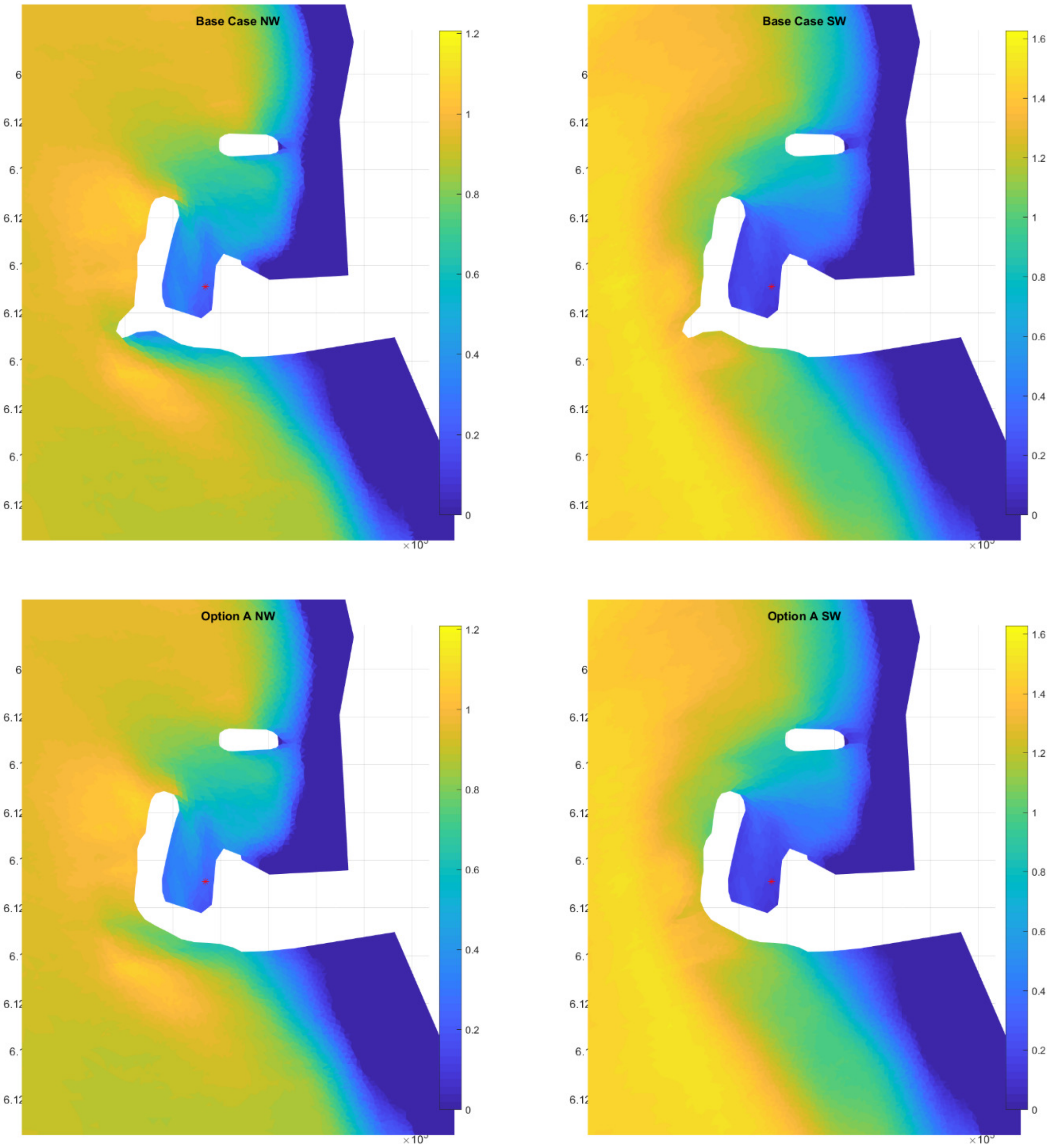


Figure 10-25: Significant wave height (H_s) in the harbour for the base case and Option A. The location of the extraction point is shown with a red dot.

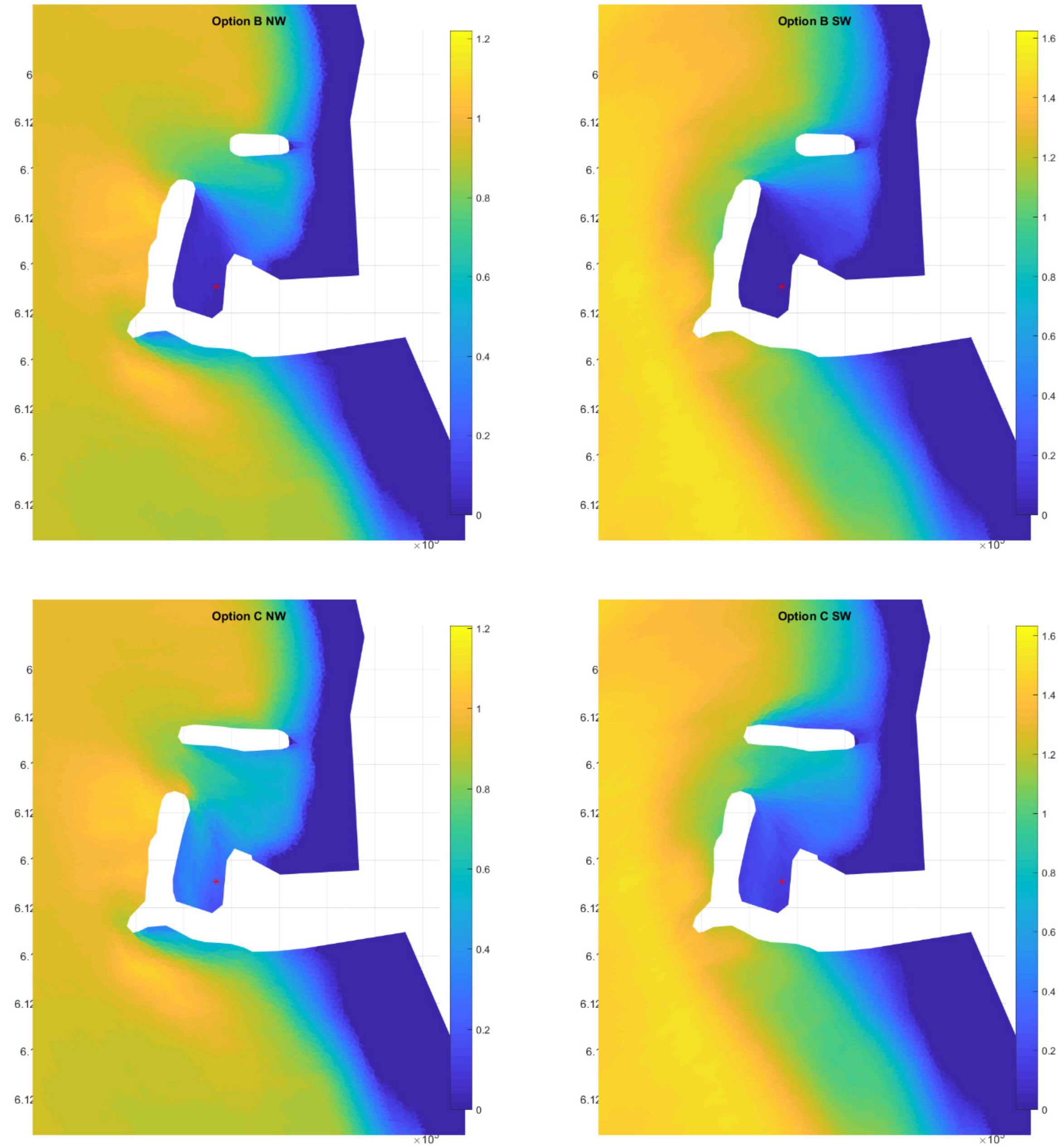


Figure 10-26: Significant wave height (H_s) in the harbour for Option B and C.

11 Conclusion

A comprehensive assessment of the coastal processes and observed erosion in the West Beach sediment cell has been undertaken using a combination of analysis of existing data sets and a state of the art numerical modelling framework for the modelling of long-term shoreline evolution.

Key conclusions developed from the review and analysis of the coastal processes at West Beach and the Adelaide Metropolitan beaches more broadly:

- The littoral transport along West Beach and further north is between 50,000 and 150,000 m^3/yr with an average rate of around 100,000 m^3/yr being derived from the analysis of available coastal profile data sets and also reproduced by the numerical shoreline modelling analysis. This rate is materially higher than previous estimate of ~50,000m^3/yr for West Beach.
- The West Beach sediment cell has lost in the order of 500,000m^3 of sand since the late 1990's and the rate of decline has accelerated since approximately 2011.
- The impact of the large external mass nourishment campaigns in the 1990's on the littoral volumes along the entire Adelaide Metropolitan coastline are evident in the historical profile data sets and likely underpinned the supply of sediment to northern cells (including West beach) for almost a decade following their completion in the late 1990's.
- No significant volumes of sand are being lost from West Beach to off-shore areas. Rather, significant volumes of sand are being transported from West Beach and to a lesser extent Henley Beach cells and accumulating in the northern most sediment cells, at the end of the littoral system.

Key conclusions developed from the modelling assessment of the coastal management options for West Beach include the following:

- A sustainable solution to the observed erosion problems at West Beach must include some form of long term nourishment at a rate of around 100,000 m^3/yr on average; otherwise, the erosion problems will continue to worsen and migrate northwards into the Henley Beach cell.
- A mass nourishment at West Beach of around 1.5 M m^3 will solve the erosion problems at West Beach and prevent erosion of Henley Beach cell for a period of at least 7.5 years. By back-passing sand from Torrens Outlet to the south end of West Beach it would be possible to extend the benefit of the mass nourishment solution up to 10 years. A sustainable solution could therefore be to mass nourish West Beach with around 1 million m^3 of sand approximately every 10 years.
- Back-passing sand at a rate of around 100,000 m^3/year from the northern sediment cells via a pumping system every year could also solve the erosion problems at West Beach. The advantage of this system is that it is more flexible and the back-passing rate can be managed every year based on the state of the beach in terms of volume of sand in the different cells. The main disadvantage is that recreational users and the environment would disturbed by significant periods (3-4 months) every year by the back-passing operation.

Key conclusions developed from the modelling assessment of potential modifications to the Adelaide Shores boat harbour breakwaters to limit the ingress of seagrass wrack into the harbour basin and to improve the attenuation of waves impacting the boat ramp include the following:

- None of the options which were investigated are recommended from a seagrass wrack intrusion perspective. To significantly reduce the amount of seagrass wrack in the harbour, the opening between the northern breakwater and the shoreline must be closed.
- Simple linear wave modelling shows a reduction in the wave heights at the boat ramp are possible for a number of tested modifications to the breakwater layouts. These results are

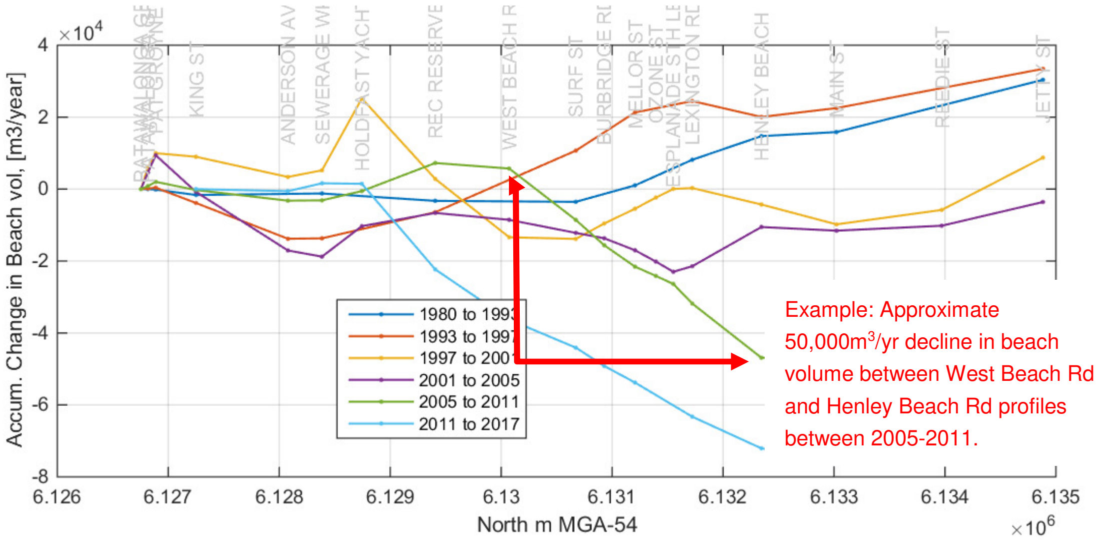
however only indicative and require a more advanced wave model such as a Boussinesq wave model confirm these findings before any recommendations can be made.

12 Recommendations

- Future decision making around the management of the West Beach and Henley Beach sediment cells should factor in the current best available estimate of the average littoral transport in these cells of approximately 100,000m^3/yr.
- Further analysis of the long-term mass nourishment and large scale backpassing options is undertaken to evaluate the full financial, social and environmental implications of these options to provide a long term, sustainable solution to the management of the West Beach sediment cell.
- The historical coastal profile data set owned by DEWNR is considered a very valuable data set for understanding the historical responses of the Adelaide Metropolitan beaches and for evaluating the impact of future management interventions. It is recommended that the use of this data set be standardised and formalised to ensure it is actively used to inform DEWNR's strategic and operational decision making for Adelaide's Metropolitan beaches.

Appendix A

Explanation of Accumulated Beach Volume Change Figures



- This figure displays results from the analysis of the accumulated changes in measured beach profile volumes from the Glenelg Marina, through the West Beach sediment cell and to Henley Beach South (The names of the profile locations are written vertically in grey at each profile location along the shoreline).
- The figures are constructed by calculating the annual change in profile volume at the southern most profile location (Patawalonga groyne) and then summing the annual profile volume changes along subsequent measured beach profile from south to north.
- The volume at each measured profile is calculated from the area under each profile between -5m AHD and +5m AHD, along the length of the entire profile;
- The calculation of the beach profile volumes between the measured profiles is conducted using a simple linear interpolation based on the distances between the surveys along the length of the shoreline.
- To ease the interpretation and visualisation of this analysis, the accumulated annual volume changes have been averaged across six relevant time periods.