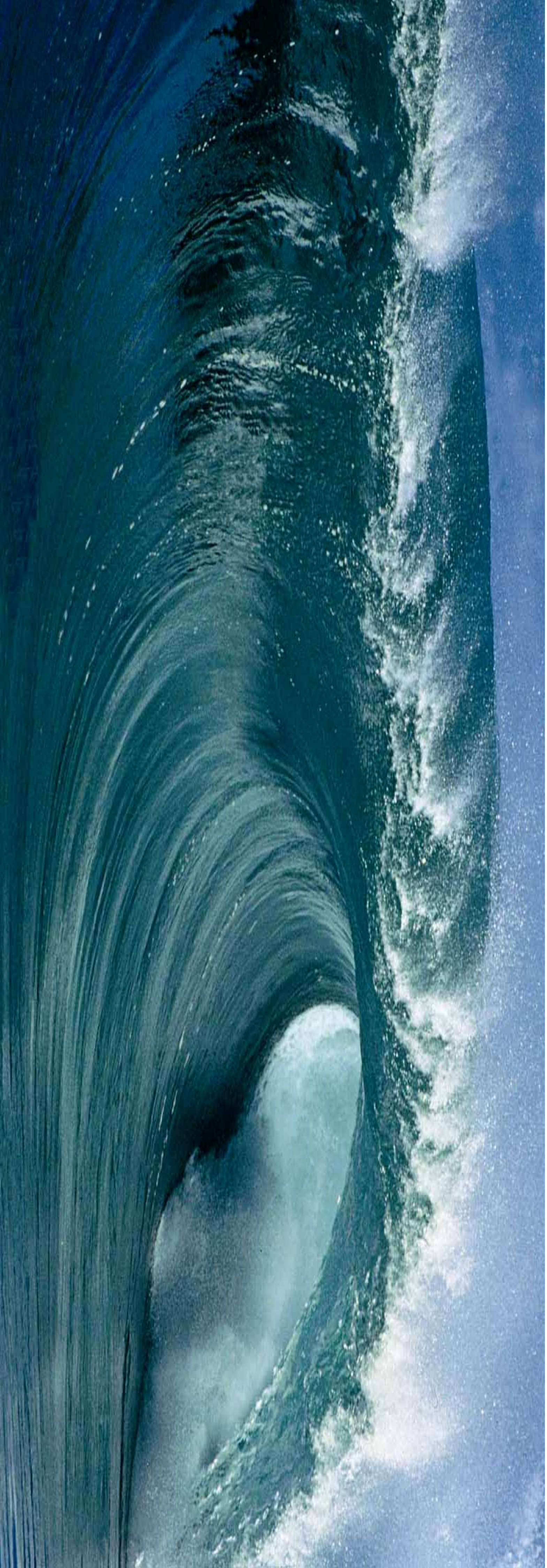

COASTAL ENGINEERING SOLUTIONS

COASTAL PROCESSES STUDY OF ADELAIDE BEACHES

FINAL REPORT

Prepared by
Coastal Engineering Solutions

For
Department for Environment & Heritage
Natural & Cultural Heritage
Coastal Protection Branch

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Section 1

INTRODUCTION

Coastal Engineering Solutions Pty Ltd was commissioned in April 2003 to update coastal process modelling for the entire metropolitan coastline of Adelaide - from Kingston Park in the south, to Outer Harbor in the north. Figure 1.1 shows the locality of the study area within Gulf St Vincent. As well as modelling the coastal processes currently influencing these foreshores, past and future scenarios were investigated.

Mathematical modelling of coastal processes has been undertaken previously to address coastal processes on specific foreshores - primarily at North Haven, Semaphore Park, West Beach, Glenelg and Brighton. Various modelling exercises have been undertaken periodically from about 1984 through to 2000. However the coastal processes influencing the entire Adelaide metropolitan coastline had not previously been mathematically modelled. Some regional studies were undertaken prior to 1984 - such as those by Culver (1970) and Kinhill Stearns/Riedel & Byrne (1983). However robust mathematical models had not been developed at that time, so those earlier investigations relied largely on available historical data to derive sediment budgets.

The erosion problems being experienced along Adelaide's foreshores can primarily be attributed to a deficiency in the amount of sand being supplied naturally from the south. The volume of sand entering the beach system at Seacliff is of the order of 5,000 m^3/year, whereas the capacity of waves to move sand along the shoreline from south to north is an order of magnitude greater, variously estimated to be in the range of 30,000 m^3/year to 80,000 m^3/year.

To further compound the erosion problems, it is generally thought that the rate of longshore sand movement has increased over the last 50 years as a consequence of diminishing nearshore seagrass meadows.

The coastal reach in the vicinity of Hallett Cove was also included in the study area to investigate a strategy of possibly exploiting the predominant northerly sand transport processes to naturally supply sand to the downdrift metropolitan beaches whilst improving the beach amenity at Hallett Cove.

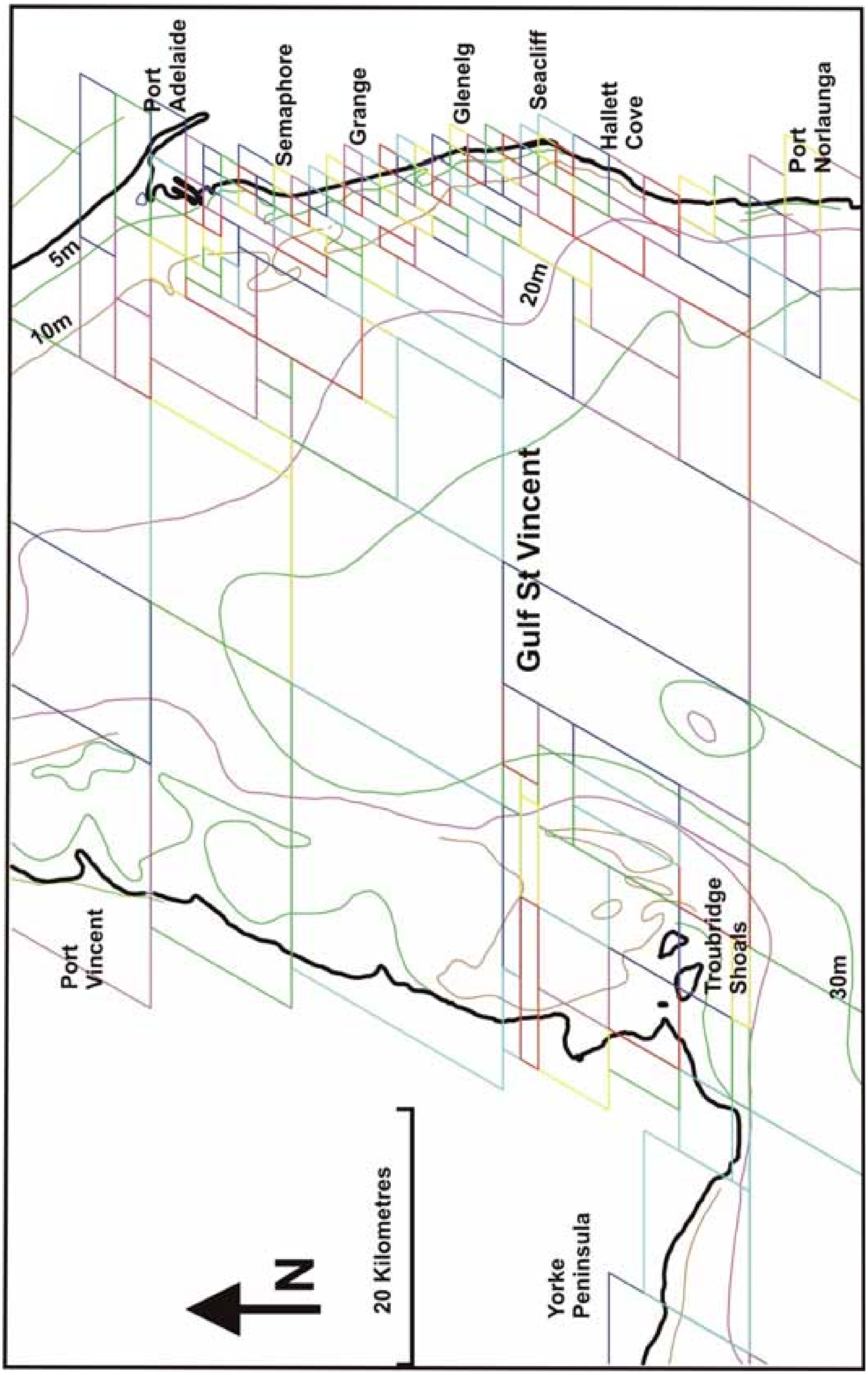


FIGURE 1.1: **Locality plan - with modelling grid overlain**

Any future changes to the seagrass meadows and sea levels (as a consequence of climate change) have the ability to alter the nearshore wave conditions and as a result the amount of sand being transported along the coast.

In order to provide ongoing protection to the Adelaide beaches, the South Australian Government's Coastal Protection Branch has initiated a review of the coast protection strategy for this region. The scope of the current review includes identifying future sources of sand along with the environmental impacts associated with the extraction of sand from these sites. The review is also focussed on reducing the long-term reliance on external sand sources for coast protection at Adelaide.

This Coastal Processes Study of Adelaide Beaches was commissioned to assist in the prediction of sand movement scenarios into the future, thereby providing technical support to the development of appropriate sand management strategies. As well as addressing the existing situation, the study includes modelling of the processes affecting the beaches as they might have been 100 years ago and are likely to be experiencing in 20, 50 and 100 years time.

Section 2

PREVIOUS STUDIES

2.1 Beach Erosion Assessment Study - 1970

Adelaide had been experiencing increasingly severe storm damage along the coast throughout the 1950's and 1960's. This led to the formation of the Metropolitan Seaside Councils Committee which in turn lobbied the State Government for remedial action. In 1965 State and Local Governments jointly funded a study by the University of Adelaide to identify causes of the beach erosion problem and to propose remedies. The investigations culminated in a report published in 1970 by the University's Department of Civil Engineering, now known as the "Culver Report". That report made several key recommendations, namely:

1. *Stop any further encroachment (of development) on to the beach or dune areas as a matter of urgency.*
2. *Rehabilitate (replenish or protect) low areas as a temporary measure NOW, particularly Brighton, North Glenelg and Henley South areas.*
3. *Declare and hold all known coastal reserves of sand for preservation of the beaches in the future.*
4. *Establish a Beach Protection Authority forthwith.*
5. *Under the jurisdiction and technical direction of (4) begin the detailed appraisal of the best restorative measures. Continue the further study of beach behaviour elsewhere as required.*

These recommendations were acted upon with the proclamation of the *Coast Protection Act* in 1972 and the subsequent formation of the Coast Protection Board. The coast protection strategy subsequently pursued by the Board involved beach replenishment, supplemented by seawalls where necessary as a last line of defence to protect existing foreshore development and infrastructure.

2.2 Adelaide Coast Protection Alternatives Study - 1983

In 1982, Kinhill Stearns Pty Ltd and Riedel & Byrne Consulting Engineers Pty Ltd were jointly commissioned by the Coast Protection Board to undertake the *Adelaide Coast Protection Alternatives Study*. This was the first comprehensive coast protection study undertaken since the completion of the Culver Report in 1970. It included the development, appraisal and costing of various methods for protecting Adelaide's coastline between Kingston Park and North Haven. The study included an appraisal of environmental and social effects.

Assessments of local inshore wave climates and calculations to determine the resulting longshore sand transport rates were not undertaken. Instead, the adopted approach was to utilise historical data relating to computed volumes of sand on the beaches (in conjunction with beach replenishment work undertaken subsequent to the Culver Report) to infer the following sand movement patterns:

- an average of 30,000m^3 of sand was accumulating each year in the Outer Harbor / Semaphore Park section of coast as a consequence of the northerly littoral drift. (The North Haven development was not completed at that time).
- However, due to a assumed sea level rise of 2mm / year, there would be an effective volume loss of 5,000m^3 / year from the beach system – relative to sea level – so that the net gain of sand was only 25,000m^3 / year.
- From Semaphore Park to West Beach the foreshore was considered stable, with the 5,000m^3/year loss attributable to sea level rise being counterbalanced by a 5,000m^3/year deposition of sand supplied from southern beaches.
- For the West Beach to Kingston Park section there is an erosion of 35,000m^3 / year. This assumes that there is an incoming 5,000m^3 / year from the south of Kingston Park and there is an offshore loss from the Adelaide coast of 5,000m^3 / year. Adding in the effective loss of 5,000m^3 / year for sea level rise, the effective total loss of sand is 40,000m^3 / year.

These inferred rates were used to evaluate a number of foreshore protection strategies. The relative implementation costs for the various alternatives was based on a 5% discount rate. The following conclusions were reached:

- *Alternative 1 – **No foreshore protection measures*** – would incur substantial loss of property and a significant reduction of beach amenity (with no beaches remaining after 50 years along an approximately 11 kilometre length of coast ie. by the year 2033).

- *Alternative 2 –* ***Continuation of the policy of beach maintenance through beach replenishment and seawall repair*** – would be the least expensive option to provide for both the protection of property and the improvement of beach amenity. However it would have the greatest potential adverse social impacts as a consequence of materials handling activities and the carting of sand by trucks.

- *Alternative 3 –* ***Seawall construction without beach replenishment*** – would be the cheapest option to implement if the objective was to only provide protection for foreshore property. There would be substantial degradation of beach amenity for this alternative (even more severe than that for Alternative 1).

- *Alternative 4 –* ***Major beach replenishment with continual topping up of sand*** – would be marginally the cheapest of the major replenishment options and achieves a rapid improvement in beach amenity but still has the potential adverse impacts due to truck cartage and materials handling activities. The costing for this option was based on the extraction of sand from an area offshore of Port Noarlunga, which had not been proven, and further assumed that sufficient sand would be available from this source for a period of 50 years. [*This is an assumption that has subsequently been found to be incorrect*].

- *Alternative 5 –* ***Major beach replenishment with groynes to reduce long term replenishment*** – would marginally have the greatest overall economic benefit, but would involve slightly greater construction expenditure. Truck cartage effects and maintenance dredging would be markedly reduced, as would materials handling impacts.

- *Alternative 6 –* ***Major beach replenishment with offshore breakwaters to reduce long term replenishment*** – would be very similar in overall terms to Alternative 5 except it would involve higher implementation costs. It would also potentially affect the greatest area of seagrass.

- Alternative 7 – ***Major beach replenishment with groyne/offshore breakwater combination*** – would also be very similar to Alternative 5, but with higher implementation costs.

The proposed solutions involving groynes and/or offshore breakwaters would require eleven new structures between Brighton and Semaphore Park. For completeness Figure 4.9 of the 1983 report is included herein as Figure 2.1.

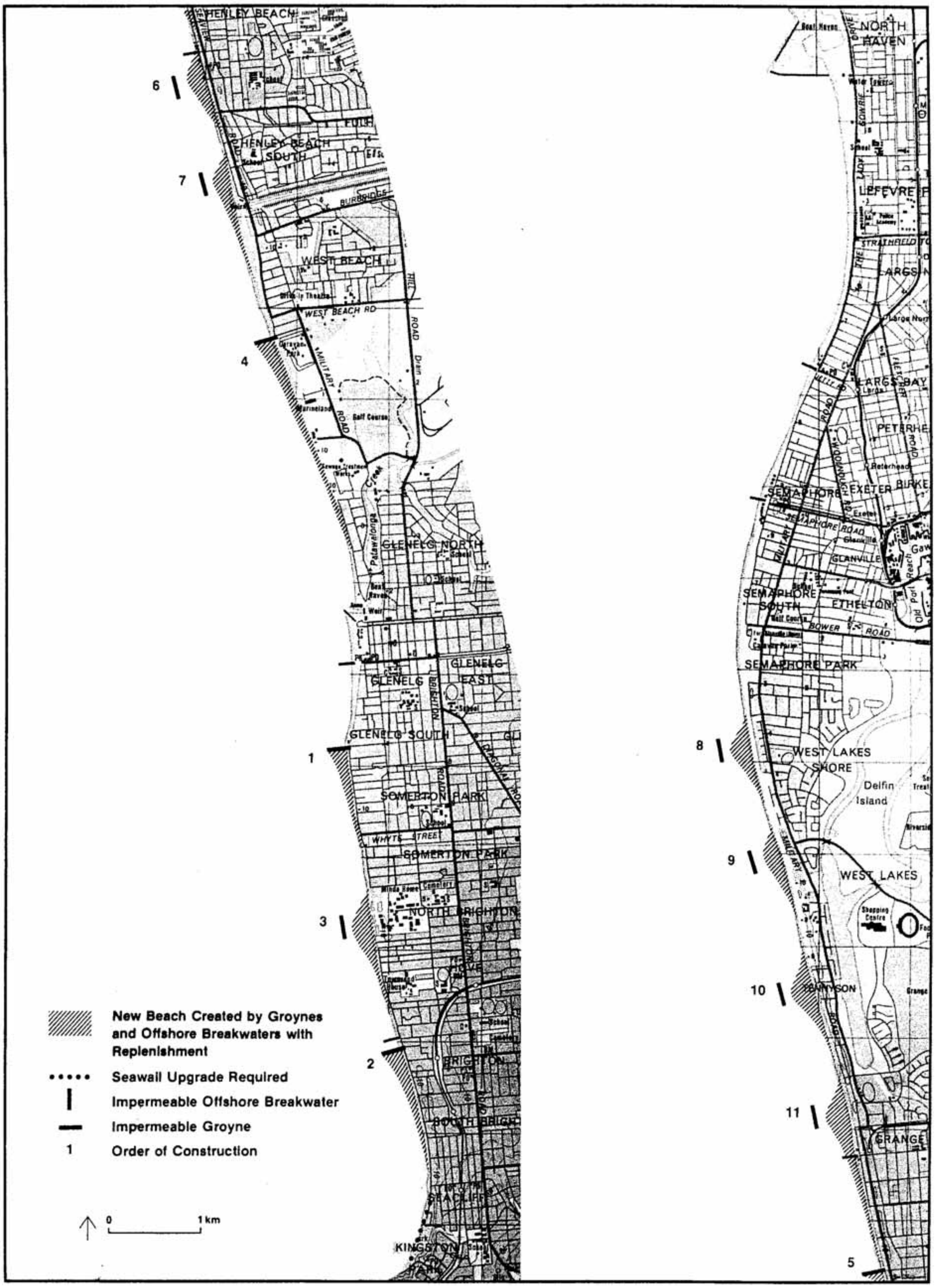


FIGURE 2.1: **Suggested location of groynes/offshore breakwaters (*taken from Fig 4.9 of 1983 report*)**

The Coastal Management Branch used information from this study and others undertaken for the Coast Protection Board and produced the Adelaide Coast Protection Strategy Review 1984, which led to the adoption of the strategy presented as *Alternative 2* which has been implemented between 1983 and 2003. New coastal structures (offshore breakwaters and groynes) have also been constructed, but not at the locations shown in Figure 2.1, nor at the scale envisaged in 1983.

2.3 North Haven Siltation & Jubilee Point Coastal Processes Studies (1984 - 1985)

In late 1983, the first mathematical models for wave transformation and longshore sediment transport were produced and applied to the Adelaide foreshore under two separate commissions completed by *Riedel and Byrne Consulting Engineers*. The two studies investigated siltation at North Haven and the coastal processes associated with a proposed development at the entrance of The Patawalonga at Glenelg. Both modelling exercises and the subsequent reports were undertaken in 1984-85.

The models incorporated the following:

- Swell wave hindcasting for one “typical” year (1980 was chosen) for an offshore location at the ocean entrance to Investigator Strait; and three years of sea wave hindcasts for those waves generated within Gulf St Vincent. Waves were hindcast at six-hourly time steps;
- Wave transformation (again at six-hourly time steps) of the swells and seas from their respective areas of generation, up through the Gulf to nearshore sites at Glenelg and North Haven. The schematic model of the seabed bathymetry was achieved by representing water depths across a grid having almost 10,000 intersection points. The wave transformation aspect of the modelling included a representation of wave energy attenuation caused by seabed friction:
- A representation of seabed “roughness” was applied which enabled a spatial variation in seabed types (ie. sand, seagrass or reef) to be included in calculations of wave transformation effects. Wave attenuation by seabed friction is very strongly dependent on the bedform. If the seabed under the approaching waves was sand, the modelling determined whether the waves could create ripples on the seabed or whether the seabed was smooth. The “roughness” of a smooth seabed is an order of magnitude less than the roughness of a rippled seabed and therefore does not attenuate the waves to the same extent. At the time of these modelling studies, a fixed roughness factor was applied whenever the model determined that ripples would form - the factor was not dependent on the size of the ripples.

- The CERC formula for longshore sediment transport (CERC,1977) was applied to compute the sediment transport potential at each six-hourly time step and the volumes were aggregated on a seasonal and yearly basis. The term "*sediment transport potential*" is used to define the sediment transport that would occur if there is a sandy beach over the entire intertidal and wave run-up zone. In fact, seawalls truncate the active beach region along many of Adelaide's foreshores; therefore the full sediment transport potential cannot be achieved in these areas. A calibration factor of 0.4 was applied to the computed sediment transport in order for the modelling to produce a net northerly longshore transport of 40,000m^3/year.

For these two studies completed in 1984/85, it was assumed that the sediment transport rate of 30,000m^3/year established by the earlier *Adelaide Coast Protection Alternatives Study* (Kinhill Stearns / Riedel & Byrne,1983) did not include any factor of safety. Consequently it was decided that (from a planning perspective) it would be appropriate to allow for 40,000m^3/year when considering the North Haven and the Jubilee Point developments.

2.4 West Beach / Glenelg / Brighton Coastal Processes Studies

The Jubilee Point project did not proceed, however two connected projects were subsequently proposed:

- The *Holdfast Shores* development at the entrance to The Patawalonga. This included an extension of the southern Patawalonga training wall, modifications to the beach to the south of The Patawalonga and the introduction of long term sand by-passing of The Patawalonga entrance;

- A development at West Beach to accommodate public boating access, much of which was to be relocated from the entrance to The Patawalonga. The main component of the development was the construction of breakwaters to protect the boat ramp and to allow all-weather use of the ramp. Again long term sand by-passing was an integral component of the project.

Coastal Engineering Solutions Pty Ltd (1997a, b, c) undertook the coastal process studies for both of these projects and extended the study area to model the longshore sediment transport potential at Brighton as well. The same computer programs that had been used for the earlier North Haven and Jubilee Point projects (with 10 years of upgrades and technical refinements) were applied for this work.

The main differences in methodology from the earlier modelling studies were:

- The seabed was schematised in greater detail and incorporated the results of more recent nearshore surveys in project areas (wherever available). The computational grid used to represent the seabed extended from the project sites out into the open ocean beyond Investigator Strait. In total it used some 70,000 grid points, in comparison to less than 10,000 points used to schematise the seabed for the 1985 modelling.

  The better resolution achieved by using a greater number of points became practical since the depths at grid points could be extracted by computer programs directly from bathymetric surveys rather than be entered manually into a database, as was necessary for the earlier studies. Furthermore, the computing power of the mid-1990's could accommodate a 70,000 point schematisation within a reasonable computation time.

- New wave hindcasts were produced utilising wind data from the years 1991 through to 1994. Both the offshore swell waves and the sea waves generated within Gulf St Vincent were modelled. Coincidently 1994 had been one of the stormiest years recorded for the Adelaide coast.

- The numerical representation of the attenuating effects of seabed friction had been further advanced so that the "roughness" associated with ripples on the seabed was variable and dependent on the ripple height and shape.

- GENESIS beach morphology modelling was undertaken to assist with the prediction of beach plan-forms at Holdfast Shores and West Beach.

The CERC formula was still used to compute longshore sediment transport. However, with the combination of more detailed wave hindcasts over four years, in association with the improved seabed schematisation and the refinements made to the friction algorithms in the models, there was no longer a need to apply a calibration coefficient to the sediment transport rates determined by the models.

A conclusion drawn with respect to longshore sediment transport was that the net annual transport potential was about 40,000m^3 northward in a "mild" year (1991); whereas in a "stormy" year (1994) the longshore transport could be about 100,000m^3.

The modelling results estimated the average longshore transport potential at Glenelg /West Beach to be 60,000m^3 per year - which was consistent with revised estimates of longshore sediment transport computed from surveys and quantities of sand imported during beach replenishment works.

2.5 Semaphore Park Protection Strategy Review - 2000

Severe erosion had occurred at Semaphore Park in the years preceding this 2000 study. Coastal Engineering Solutions undertook a coastal processes study as part of a coastal protection strategy review. Detailed survey data was available for the seabed extending north from Tennyson up as far as North Haven. Consequently the computational grid used for the earlier investigations of foreshores between Brighton and West Beach was extended northwards to Outer Harbor. The number of grid points used to represent the seabed increased to 197,000 (from the 70,000 for the 1996 modelling). Again the technical improvements in computer capabilities from 1996 to 2000 enabled this increased resolution to be achieved without compromising computing effort and time.

There was a significant improvement in the modelling methodology implemented for this project. The CERC formula which had previously been used to calculate sediment transport potential was replaced with the QUEENS formula. The QUEENS formula is a significantly improved algorithm and includes the following aspects - which are not considered by the CERC formula when calculating longshore sediment transport:

1. density of sand
2. porosity of the sediment
3. wave period
4. sand grain size
5. beach slope

Items 3, 4 and 5 can be readily determined by field observations and measurements. Each has a significant impact on the rate of sediment transport. By way of example:

- A wave having a period of 15 seconds and a breaking height of 0.5m will move 10 times more sand along the beach than a 3 second wave of the same height (all other parameters being identical).
- Fine sand moves along the beach quicker than coarse sand - sand with an average grain size of 0.2mm will move about 25% more rapidly than a 0.5mm sand.
- With all other parameters being identical, the sediment transport along a beach with a slope of 1:9 is three times as great as for a beach with a slope of 1:30.

Results obtained from the QUEENS formula for the relative contribution of sea and swell to the overall sediment transport potential differed dramatically from that previously assumed.

Previously it had been thought that the swell only accounted for about 25% of the net northward sediment transport along Adelaide's beaches. In effect this premise had evolved from consideration of the results yielded by the long established CERC formula. The application of the QUEENS formula suggested that the contribution to net sediment transport was approximately 50% by swell waves and 50% by the sea waves.

In order to produce a total net sediment transport rate that was consistent with the "*Report of the Review of the Management of Adelaide Metropolitan Beaches"* (Reference Group, 1997), the seabed friction assigned to local seagrass meadows was reduced from that applied for the earlier modelling using the CERC formula. A net northward sediment transport rate of the order of 50,000m^3/year approaching Semaphore Park was cited in that reference.

Section 3
STUDY OBJECTIVES

A 50 year planning period has been nominated for the comparison of alternative approaches to select a new strategy for the management of the Adelaide metropolitan beaches. As such, predictions of sea level rise, land subsidence, future seagrass loss and changed climate conditions need to be taken into account (to the extent possible bearing in mind the limited information on the likely changes).

3.1 Estimates of Sediment Transport Potential

Qualitative and quantitative information on across and alongshore sediment transport potential for the Adelaide beaches is required. Rates of sediment transport potential will assist when developing concept designs and costs for various foreshore protection schemes. The volumes of sand that may be required for beach replenishment can be readily inferred from the results.

The sediment transport potential will also assist when comparing the robustness of various protection strategies to inter-annual variability, severe storms and periods of limited funding for beach management. The estimates of sediment transport potential therefore need to include:

- Monthly-averaged and annual-averaged gross and net longshore sediment transport potential rates;
- Extreme range of monthly and annual gross and net longshore sediment transport potential rates;
- Cross-shore transport rates under extreme conditions;
- An assessment of the angle difference between the coastline's plan alignment and the equilibrium alignment;
- An indication of the confidence in the estimates;
- Variations in the above predictions along the coastline between Kingston Park and Outer Harbor breakwater at sufficiently small intervals to identify the variation in sediment transport potential along the coast.

3.2 Shoreline Scenarios

In order to gain confidence with respect to projections for a 50 year design period, it was agreed that modelling and assessment should be undertaken for a range of scenarios:

- Conditions that existed prior to the loss of seagrass, nominally this was chosen as 100 years ago and termed throughout this report as the *Minus 100 Year Scenario*.
- Present day conditions - nominally as the year 2002, as this was the date for which the latest nearshore survey data was available.
- Predicted conditions for 20 years in the future – termed the *Plus 20 Year Scenario*.
- Predicted conditions for 50 years in the future – termed the *Plus 50 Year Scenario.*
- Predicted conditions for 100 years in the future – termed the *Plus 100 Year Scenario*.

3.3 Sensitivity to Variables That May Change Between Scenarios

Aspects that may change between scenarios and therefore need to be considered are:

- Sea level
- Land subsidence
- Storminess and its effect on waves
- Hydraulic groyne effect of the Torrens Outlet
- Seagrass coverage
- Seabed elevation (mainly in relation to seagrass loss)
- Wave attenuation due to changed seabed conditions
- Sand size, which affects beach slope. Sand size may vary depending on the source of sand used for future replenishment.
- Coastal development.

Section 4
MATHEMATICAL MODELLING

4.1 Overview

A suite of programs has been used to mathematically model the waves and sediment transport processes affecting Adelaide's Beaches. The modelling exercise included application of the programs listed below. A discussion of the approach and methodology applied to each module and phase of the modelling is offered in the sections following this overview.

Wave Hindcasting Module

- **WISWAVE** is a spectral energy split model used for hindcasting open ocean swell waves. A spectral energy spilt model hindcasts waves from independent fetches and assigns a separate direction to the wave generated from each fetch. There may be up to 3 independent wave trains at any one time step and a direction, period and height is assigned to each. Prior to January 2000 the resolution was based on a 2.5 degree latitude / longitude grid, however it has subsequently been refined to offer a 1.0 degree grid.
- **NOAA Wave Watch3**, is also used for open ocean swell hindcasting and has a database available from 1997, but it does not provide a directional energy spilt. That is, only one wave direction is assigned at each time step.
- **HINDADEL** used for hindcasting sea waves generated by winds blowing across fetches within Gulf St Vincent.
- **COTIDSEE** used to combine the hindcast sea time series with the water level data measured at Outer Harbor, so as to insert real time ocean levels into the wave hindcasts.
- **COTIDSWE** used to combine the hindcast swell time series with the water level data measured at Outer Harbor, so as to insert real time ocean levels into the wave hindcasts.

Wave Transformation Module

- **CES350** is a reverse ray refraction/shoaling algorithm that also accounts for diffraction effects. It tracks ray orthogonals from nearshore sites out into deep water locations. The output of this model for each site of interest is typically about 2000 reverse rays covering all likely wave periods and directions. Each ray depicts the reverse path that a wave orthogonal takes between deepwater (ie. the generation area) and the nearshore site.
- **SPECREF** uses the output of CES350 to compute inshore wave coefficients and inshore wave directions for the refraction/shoaling component of the wave transformation process.
- **WAVETISW** used to transform the deep water swell waves to the Adelaide foreshore.
- **WAVETISE** used to transform the deep water sea waves generated in Gulf St Vincent to the Adelaide foreshore
- **COMBSHAL** used to combine the sea and swell wave components for each nearshore site of interest once they have been transformed into shallow water, a depth of about 2.5 metres to Low water datum. The output is used in the sediment transport program.

Sediment Transport Module

- **QUEENSED** used to transform the nearshore waves (output of COMBSHAL) at each inshore site to the point of wave breaking - where longshore sediment transport rate is computed using the QUEENS formula.
- **SBEACH** used to compute the cross-shore sediment transport under storm conditions.

4.2 Wave Hindcasting Module

4.2.1 Swell Waves

The WISWAVE model was applied to replicate the wave generation processes which operate across the open waters of the Indian and Southern Oceans. The model provides data that distinguishes between waves generated from different regions / fetches of the oceans.

WISWAVE allows for up to three swell wave “trains” to be simulated simultaneously and provides significant wave height (H_s) , spectral peak period (T_p) and wave direction values for each of these three directional components at three-hourly time intervals. Applying this degree of resolution, in particular the directional aspect, is vital when undertaking studies to determine the sediment transport processes produced by waves.

The specialised modelling for swell wave hindcasting has been undertaken for this study by the firm of WNI. Swell wave data was produced for the ten year period of 1993 to 2002 for a location in a depth greater than 200 metres offshore of Kangaroo Island. This data was requested from WNI as a three-hourly time series.

At each time step, there may be up to three wave components (or “wave trains”) arriving simultaneously at the deepwater site, namely:

- A component due to those waves having been generated across the Great Australian Bight and the Indian Ocean;
- A component due to waves generated across the Southern Ocean; and
- A component due to waves generated across Bass Strait.

Global wave generation models used by scientists and engineers worldwide are evolving as better boundary conditions and wind data become available to drive them. In all previous coastal model studies undertaken for Adelaide foreshores, the WISWAVE model was applied with a latitude / longitude grid resolution of 2.5 degrees.

In recent years a finer resolution WISWAVE model has been developed, but it cannot be used to hindcast those waves generated prior to January 2000. This later modelling refinement offers a latitude / longitude grid resolution of 1 degree. For comparison purposes, hindcast data was also obtained from this finer resolution model for the years of 2000 to 2002.

One of the more recent developments in wave hindcasting is the *NOAA Wave Watch3* model. Engineers and scientists working in professions associated with the ocean and coastal environments are tending to apply this model more frequently when determining wave climates. However this model does not distinguish between different directional wave trains, and is therefore not as appropriate as WISWAVE for generating wave data to be used for sediment transport computations. Due to availability of appropriate input data, it can only be used to hindcast waves from 1997 onwards.

For this study of Adelaide’s beaches, the *Wave Watch3* model was used to hindcast waves for the years 1997 to 2002 so that the results could then be compared to the waves determined by the multi-directional WISWAVE model over the same timeframe.

Figure 4.1(a) presents a comparison of the wave exceedance from the three deep water swell wave hindcasting models for the period of 2000 through to 2002. The three models are those discussed above, namely:

- WISWAVE at 2.5 degree lat / long resolution,
- WISWAVE at 1.0 degree lat / long resolution, and
- NOAA Wave Watch3

The highest significant wave heights predicted to have occurred during this period were less than 9 metres. By comparison the highest significant wave height predicted during 1994 was nearly 11 metres.

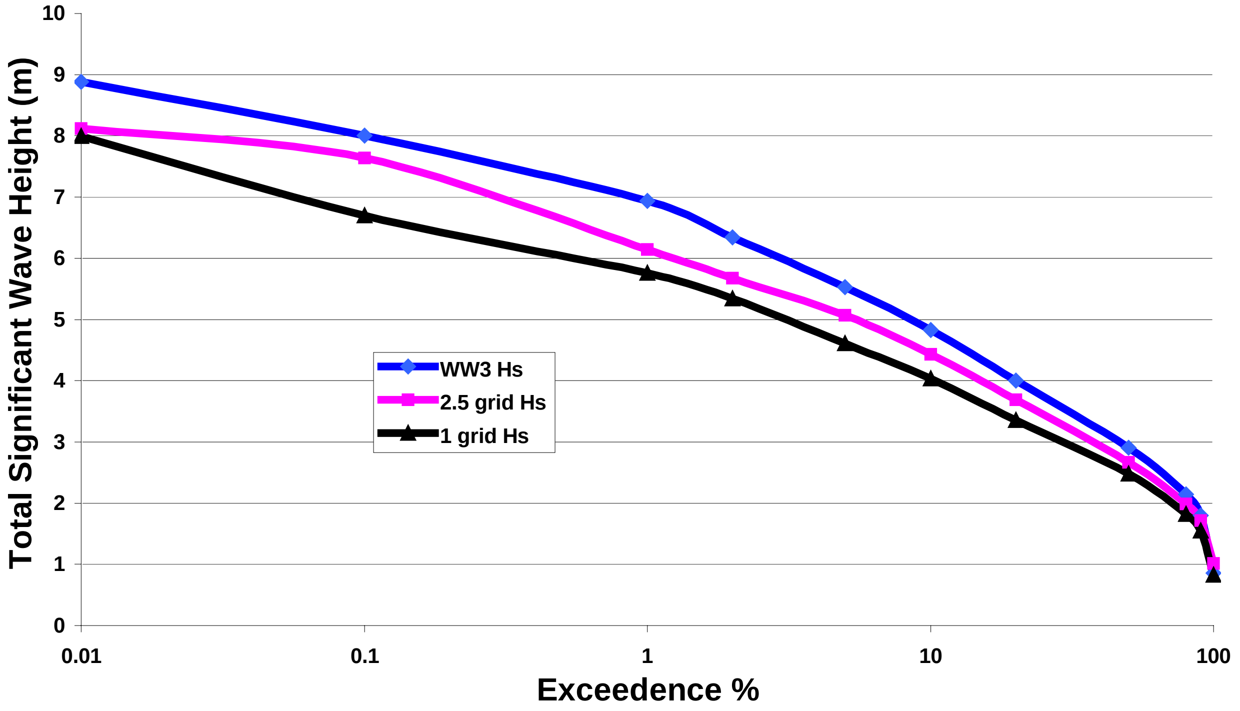


FIGURE 4.1(a): Comparison of wave exceedence characteristics for three swell hindcast models

Later during the study the Coastal Protection Branch provided measured Waverider Buoy data at a water depth of 80 metres off Kangaroo Island, about 4.2 nautical miles west of Cape du Couedic Light (36.07°S, 136.62°E). The measurement period was from late 2000 to the end of 2002. This measured data is compared with the hindcast (WISWAVE at 2.5 degree lat / long resolution) for the same period of time in Figure 4.1(b).

The hindcast waves are in a water depth of about 500 metres whilst the wave measurements were taken in a water depth of 80 metres. For ocean swell waves there is considerable shoaling that occurs as waves move into shallower water. The deep water measured data has been corrected for shoaling. The correlation with this shoaled wave data is excellent.

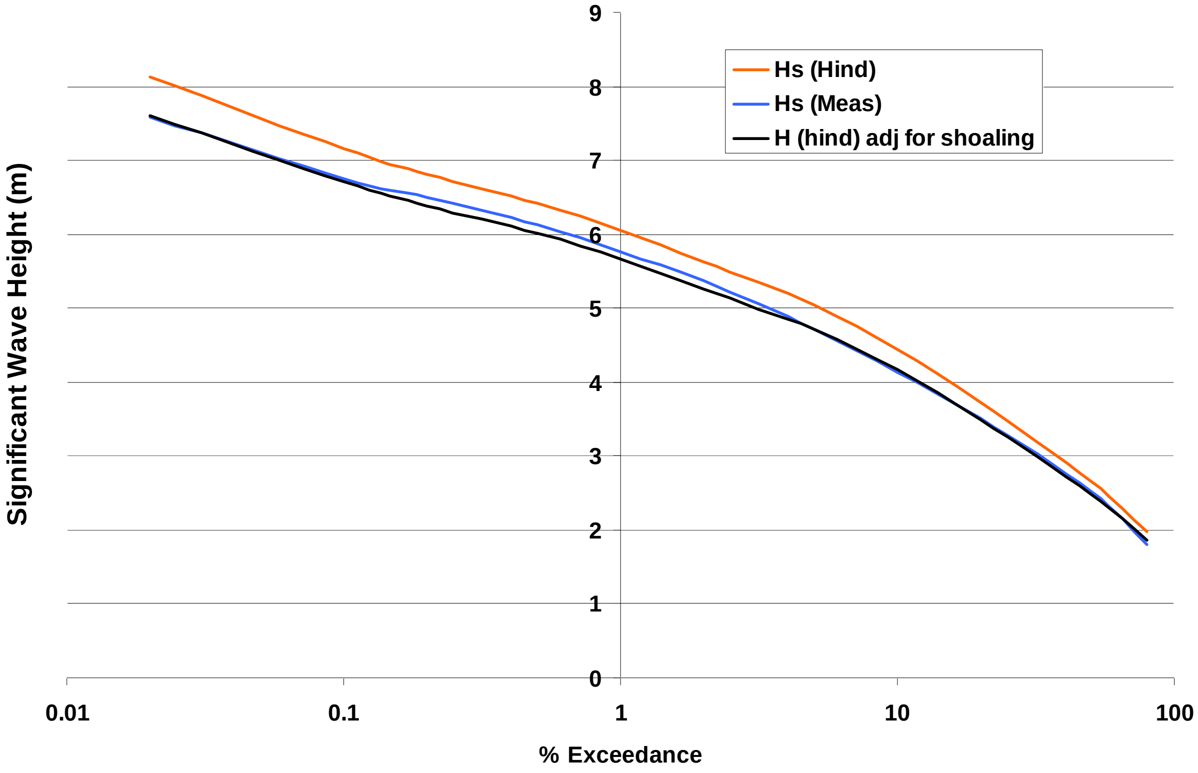


FIGURE 4.1(b): Comparison of measured and hindcast wave exceedence off Kangaroo Island

The swell wave hindcasts generated from the 2.5 degree resolution WISWAVE model have been used because:

- unlike the others, ten years of data is available for computations of sediment transport. This incorporates the most severe storm to occur in recent times; namely that which occurred in May 1994;
- The directional resolution of the wave data is very relevant to the Adelaide region and this model provides this resolution; and
- The wave exceedence statistics correspond almost exactly with the measured waves off Kangaroo Island.

The swell wave hindcast for the ten year data base is separated into three data files for each of the three wave direction trains. This facilitates better subsequent processing of the hindcast by the wave transformation programs. Figure 4.2 shows a sample of the total deep water swell wave hindcast for the year of 1994, during which the largest waves occurred.

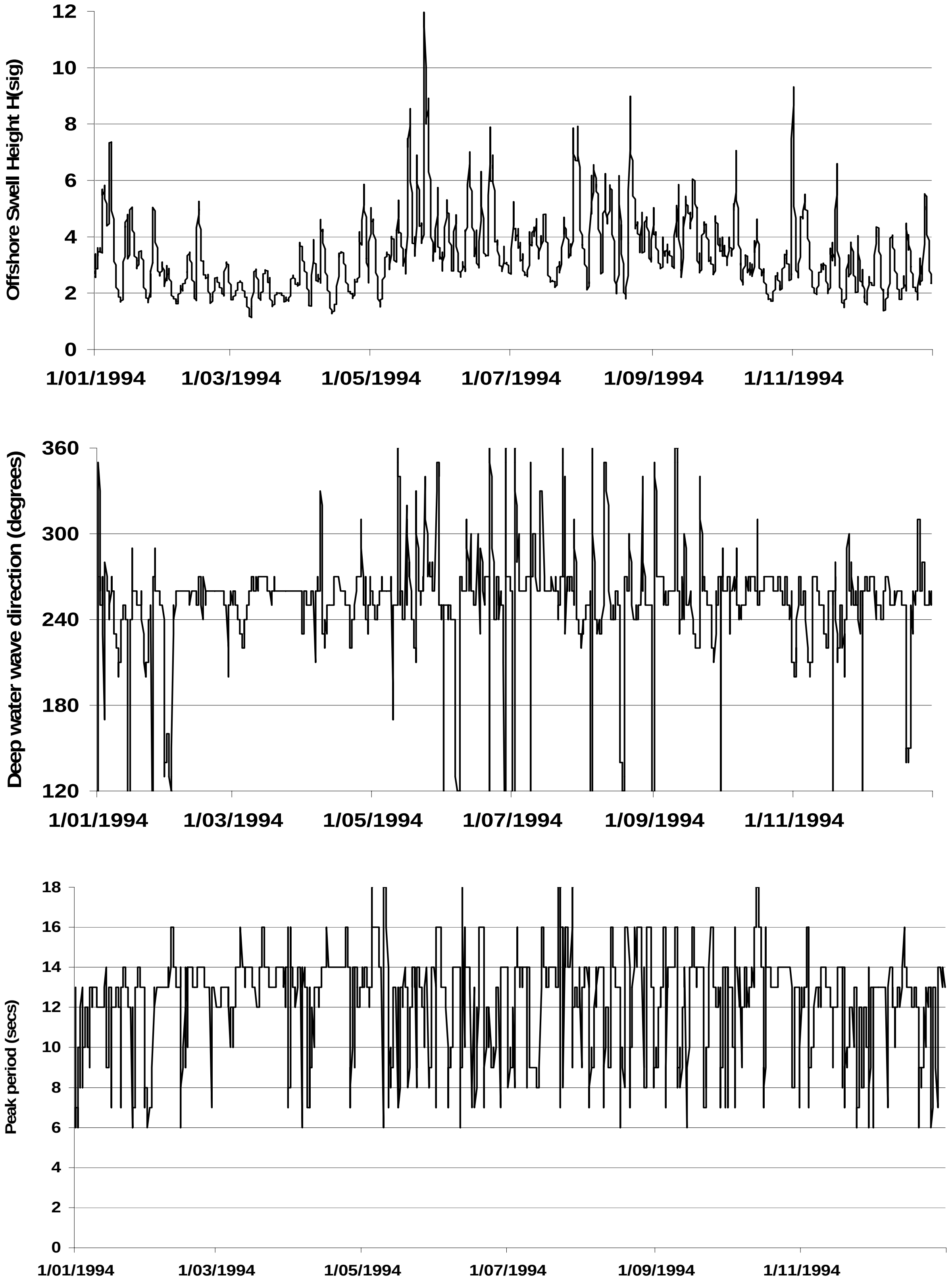


FIGURE 4.2: **Deep water swell wave hindcast for 1994**

4.2.2 Sea Waves

Hindcasts for those waves generated by winds blowing across the open water fetches within Gulf St Vincent itself have also been produced. Given that the primary objective of the study is to model the waves and sediment transport processes which occur along the entire length of the metropolitan beaches, it was necessary to select 94 locations along the length of the Adelaide foreshore. The spacing between each was some 250 to 300 metres. Separate hindcasts are required for each site because the exposure of the almost 30km long foreshore to waves generated within the Gulf varies significantly along its length.

The wind data recorded by the anemometer station at Adelaide Airport was used to hindcast sea waves across the various fetches affecting the study foreshore. However some corrections to the data was necessary to account for the fact that the airport location is not necessarily recording wind speeds and directions indicative of those blowing across the open waters of Gulf St Vincent. For example, O'Halloran Hill (the high area behind Hallett Cove) appears to shield the Airport location from S to SSE winds - thereby potentially misrepresenting the winds blowing across these important fetches.

When determining appropriate corrections to the airport winds, reference was made to previous general experience of overland / overwater corrections in coastal locations - supplemented by comparisons with a shorter duration of recorded winds from an anemometer at Outer Harbor (which itself is affected by topographic features). The factors applied to correct the measured 10 minute winds to 3 hour duration winds over water were:

Wind direction	**Factor applied**
Less than 210°	1.27
210° to 240°	1.03
250° to 310°	1.14
Greater than 310°	1.17

The mathematical techniques of *Sverdrup - Monk - Bretschneider* (SMB) as presented in the 1977 edition of the Shore Protection Manual (CERC, 1977) have been applied to determine the wave heights resulting from winds blowing across the open water fetches of the Gulf St Vincent. It is universally acknowledged that the empirical steady-state wave prediction methods given in the subsequent 1984 edition of the Shore Protection Manual (which uses an adjusted wind speed factor based on friction velocity) tends to over-predict wave height. The SMB techniques presented in the later edition are appropriate for determining wave period, and have therefore been applied.

That is, the 1977 formula has been used to determine wave height and the 1984 formula has been used to determine wave period.

The sea wave hindcasts are in the format of three-hourly time series and correspond to the same ten years (of 1993 to 2002) as the swell wave hindcast. The 94 sea wave data files (one for each of the 94 inshore locations selected along the metropolitan beaches) are then combined with measured tide levels for the corresponding timeframe and stored for subsequent processing by the wave transformation programs.

Figure 4.3 presents a typical example of sea hindcast output for a site located off Semaphore Park for the year 1994. The wave characteristics shown in the figure are those hindcast in deep water, prior to their propagation onto the Semaphore Park beach. As a further example of the results of the sea wave hindcast, Figure 4.4 provides a more detailed description of sea wave and water levels off Semaphore Park for the month of November 1994.

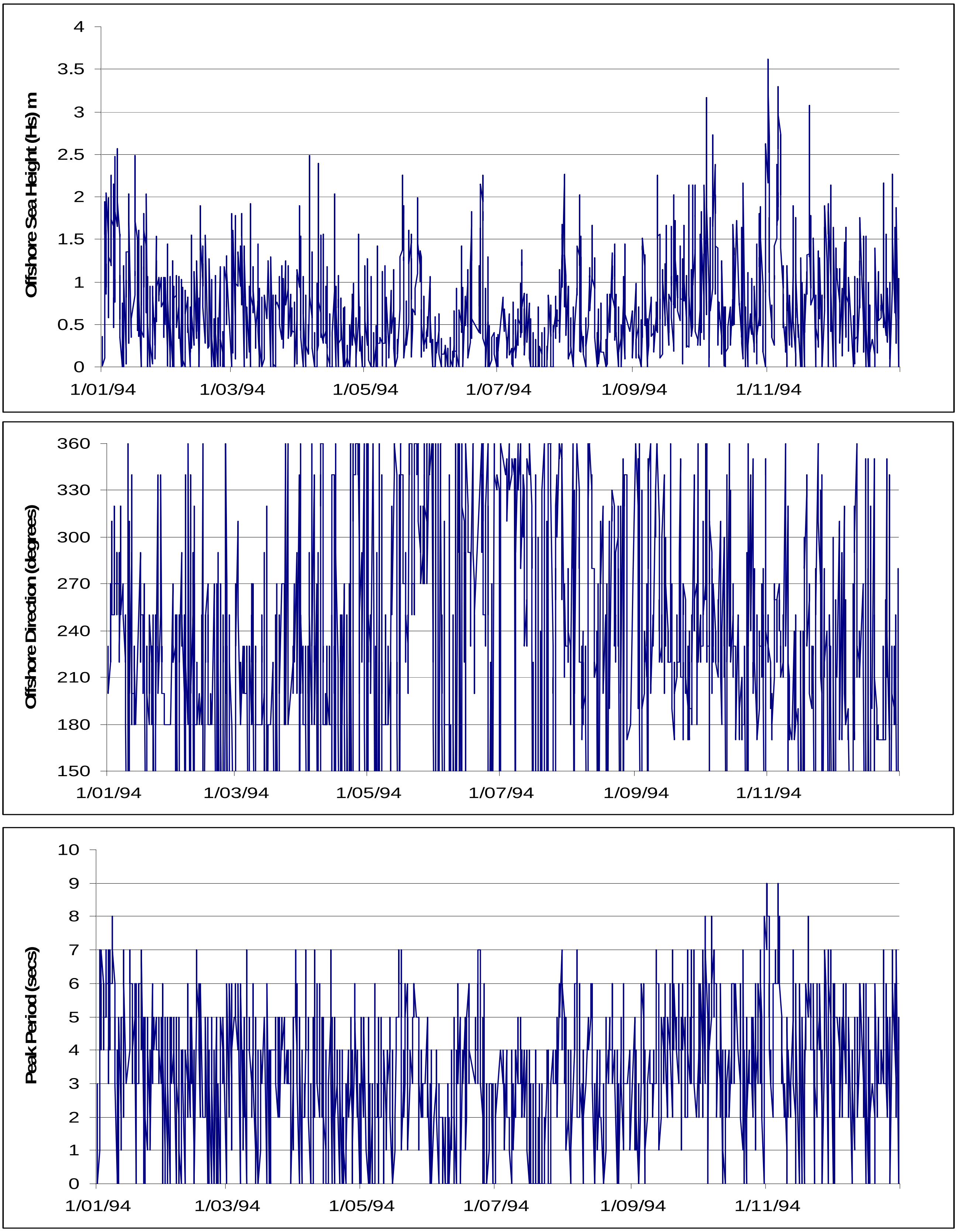


FIGURE 4.3: **Sea wave hindcast for 1994 offshore of Semaphore Park**

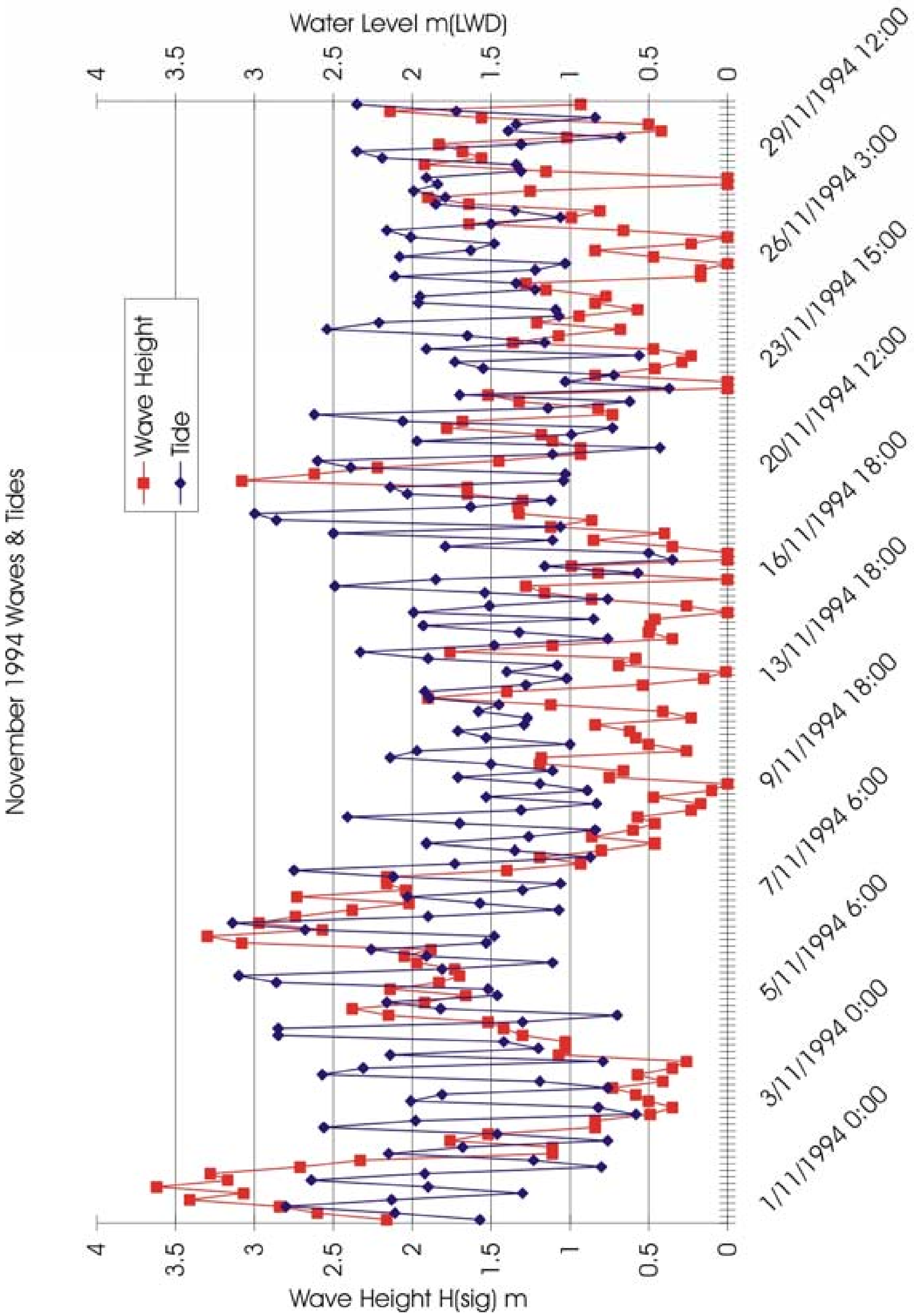


FIGURE 4.4: **Sea waves and water levels off Semaphore Park – November 1994**

4.3 Wave Transformation Module

As waves propagate shoreward from deep offshore waters they are modified significantly by the effects of wave refraction, diffraction, wave shoaling, breaking and seabed friction.

These complex wave transformation processes are replicated by application of the various mathematical modelling techniques discussed in the following sections. When applied together, these various techniques constitute the *Wave Transformation Module* of the entire modelling procedure.

4.3.1 Generation of Reverse Rays for Spectral Refraction Analysis

Swell waves

The program CES350 is used to determine the wave refraction and wave shoaling effects as swell propagates shoreward from the deep waters beyond Kangaroo Island onto the Adelaide Beaches. In order to undertake the complex wave transformation computations, it is necessary to define the seabed bathymetry over which all such waves can propagate. A computational grid system is therefore established to schematise the form of the seabed. This is achieved by assigning a depth to each of the intersecting points on the grid.

The grid system established for this study covered the entire Gulf St Vincent, Investigator Strait, Backstairs Passage and extended out into the deep waters of the Southern Ocean around Kangaroo Island. The system actually consists of a series of adjoining grids (termed “zones”). The spacings within each of these zones can be made variable - with a fine spacing chosen to properly define the seabed in areas of complex or rapidly changing bathymetry, and a wider spacing where the seabed is relatively flat and unchanging.

A total of 344 zones containing 829,447 grid points were used to represent depths to the seabed across the extent of the grid system.

The grid system used maximum spacings of 1600 metres in areas where the seabed is relatively flat - typically this is in the deep waters off Kangaroo Island. In the shallower inshore waters (and around steep sloped seabed features), the grid spacing has been reduced to 25 metres. In fact the 25 metre grid spacing is applied to all of the nearshore waters off Adelaide’s beaches.

Figure 4.5 shows the extent of the seabed covered by the computational grid system. The parallelograms shown on the figure represent the various zones - within which different grid spacings are assigned.

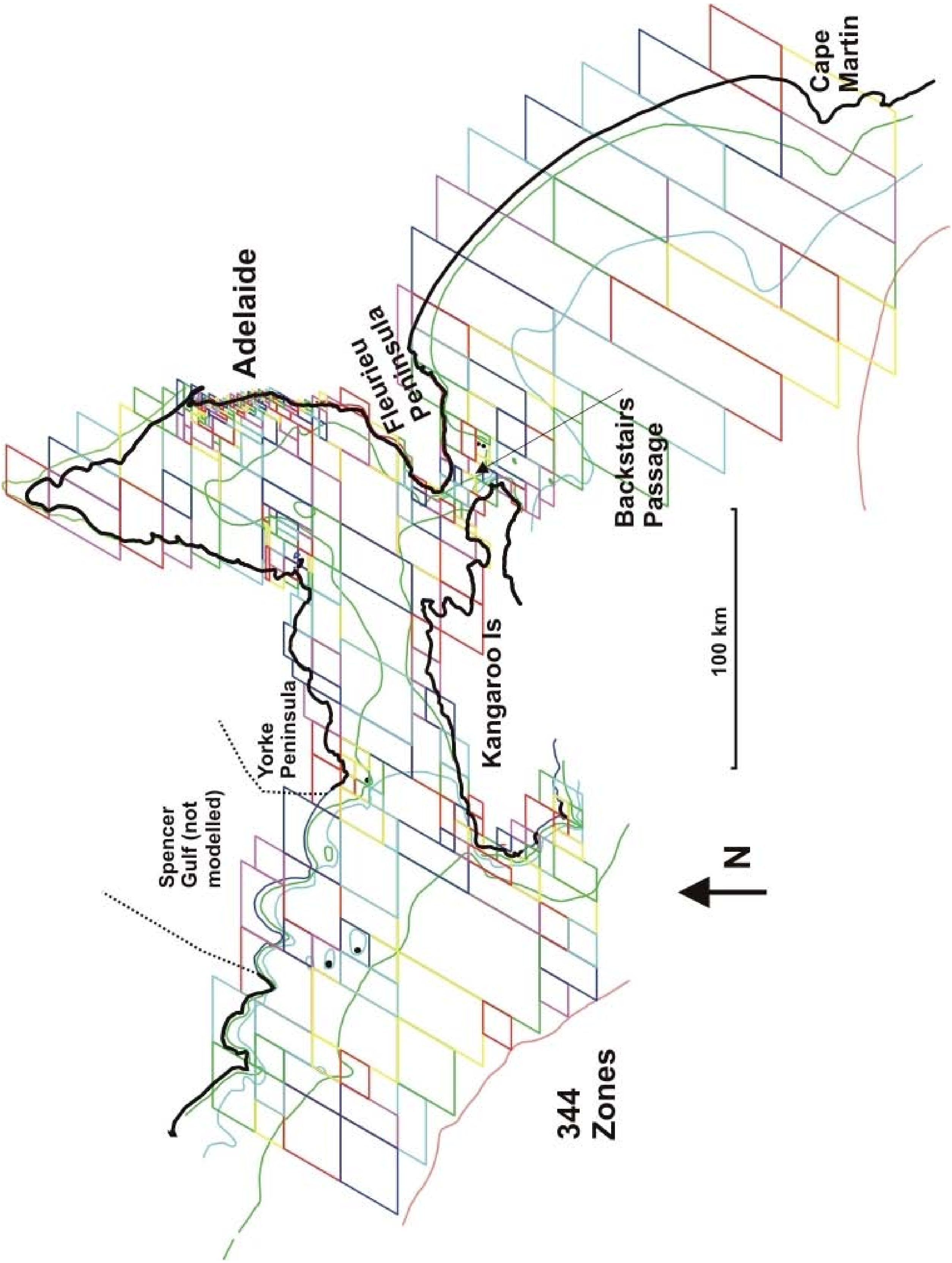


FIGURE 4.5: **Overall extent of seabed schematisation for swell waves**

To further assist in the appreciation of the grid's resolution, Figure 4.6 shows in closer detail the extent and arrangement of the various zones used to schematise the seabed within the Gulf St Vincent itself, and within the nearshore waters of the metropolitan beaches. Each of the equal-sided parallelograms shown linked along the eastern shoreline of the Gulf represents an area of 1600 x 1600 metres, each subdivided into 65 x 65 = 4,225 grid points to which the appropriate depth is assigned. This resolution is considered more than adequate to define the complex nearshore bathymetry.

CES350 is a "*reverse ray refraction*" algorithm. This model tracks wave orthogonals across the computational grid from selected nearshore locations out into deep water. A wave orthogonal is basically a "ray" drawn perpendicular to the alignment of the wave crests and therefore defines the approaching path of the wave. Each ray depicts the reverse path that a wave orthogonal takes between deepwater (the generation area) into each inshore site.

The output from this component of the Wave Transformation Module is typically about 2,000 reverse ray orthogonals covering all likely wave periods and directions which could conceivably occur for any particular site near the shoreline. Consequently the reverse rays from sites in the vicinity of the Adelaide beaches tracked out across the Gulf St Vincent, through either Investigator Strait or Backstairs Passage, into the water depths where the swell wave hindcast was determined.

For the purposes of defining the inshore swell wave characteristics along Adelaide's metropolitan beaches, 94 sites were selected along the foreshore. The sites were selected so as to be in 3 to 3.5 metres depth of water (at mid-tide) and are at approximately 300 metre intervals along the entire shoreline between Kingston Park and the Outer Harbor breakwaters. This depth was chosen because most waves will not yet have broken. Additional sites were chosen in deeper offshore areas so that wave refraction processes could be determined for subsequent use by other algorithms in the suite of wave transformation programs. These additional sites were spread along the 20 m and the 35 m depth contours offshore from the 94 sites.

FIGURE 4.6: **Nearshore zones**

Sea Waves

The program CES350 is run separately to determine the refraction and shoaling processes associated with the seas generated within Gulf St Vincent. However in this case, the orthogonals are computed from the nearshore site out to a water depth of about 20 metres. The computational grid used for sea waves need not extend further into the Gulf St Vincent, since the shorter period sea waves are no longer significantly affected by refraction and shoaling effects at this depth.

Figures 4.7 to 4.10 show the locations of the 94 sites selected for investigation by the mathematical modelling of wave transformation processes. Two additional sites are shown in the vicinity of Hallett Cove. These additional sites were selected to assist in later determining the rate of sand transport towards the metropolitan beach system.

These 94 locations represent the position of the inshore sites used to determine the wave climate and sand transport rates under present day climate conditions. The scope of work necessary to address the objectives of the study also requires an assessment of wave and sediment transport processes for a historical shoreline scenario (ie. 100 years ago) and three possible future shoreline scenarios (ie. in 20 years, in 50 years and in 100 years time).

For each of these various scenarios, some of the 94 locations depicted on Figures 4.7 to 4.10 needed to be re-positioned either further inshore or further offshore. This was necessary so as to accommodate the different position of the eroded / accreted shoreline under each scenario.

As stated, the CES350 program was run separately for swell and sea waves. It was also run for each inshore site and for each of the five shoreline scenarios. Consequently the number of base output files created was very substantial, being 94 (sites) x 5 (scenarios) x 2 (wave types) = 940 datafiles in total. Each output datafile contains approximately 2,000 ray “pairs” – consisting of the angular bearing of the orthogonal (in degrees) at the inshore site along with its corresponding bearing out in deep water at the edge of the computational grid.

The output from the CES350 modelling step is used as input to the spectral refraction analysis program SPECREF.

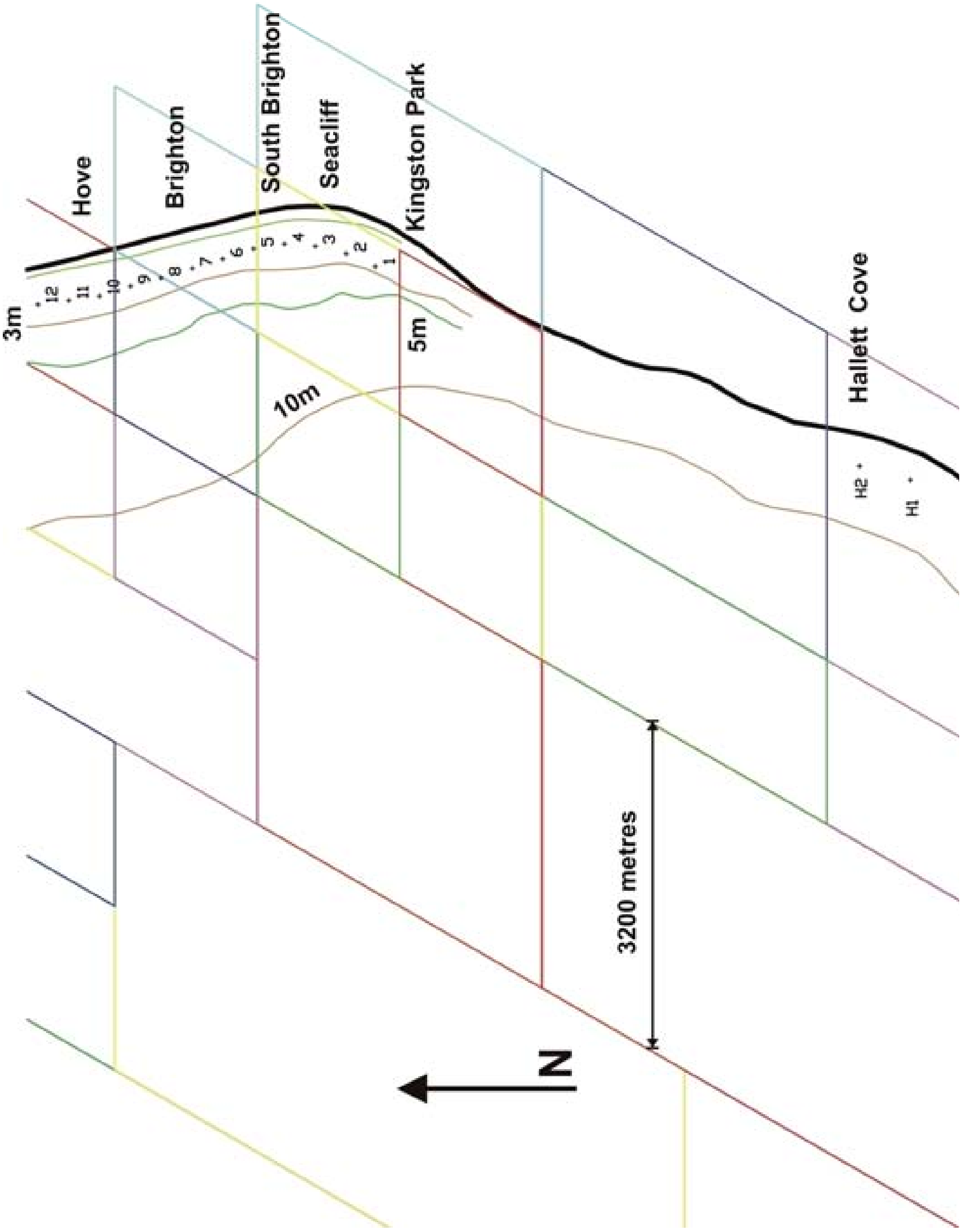


FIGURE 4.7: Nearshore sites from Hallett Cove to Hove

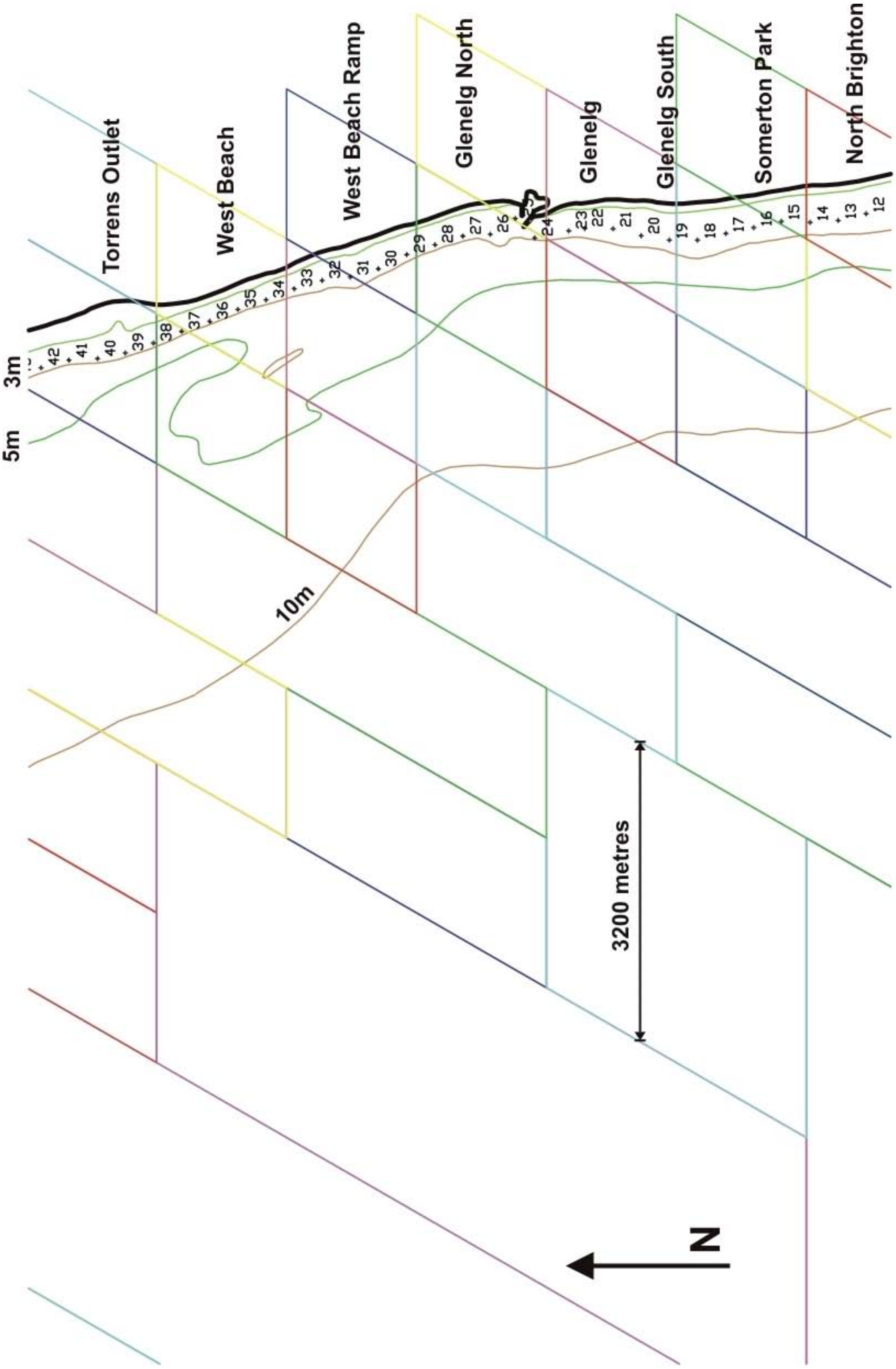


FIGURE 4.8: Nearshore sites from Brighton to Torrens Outlet

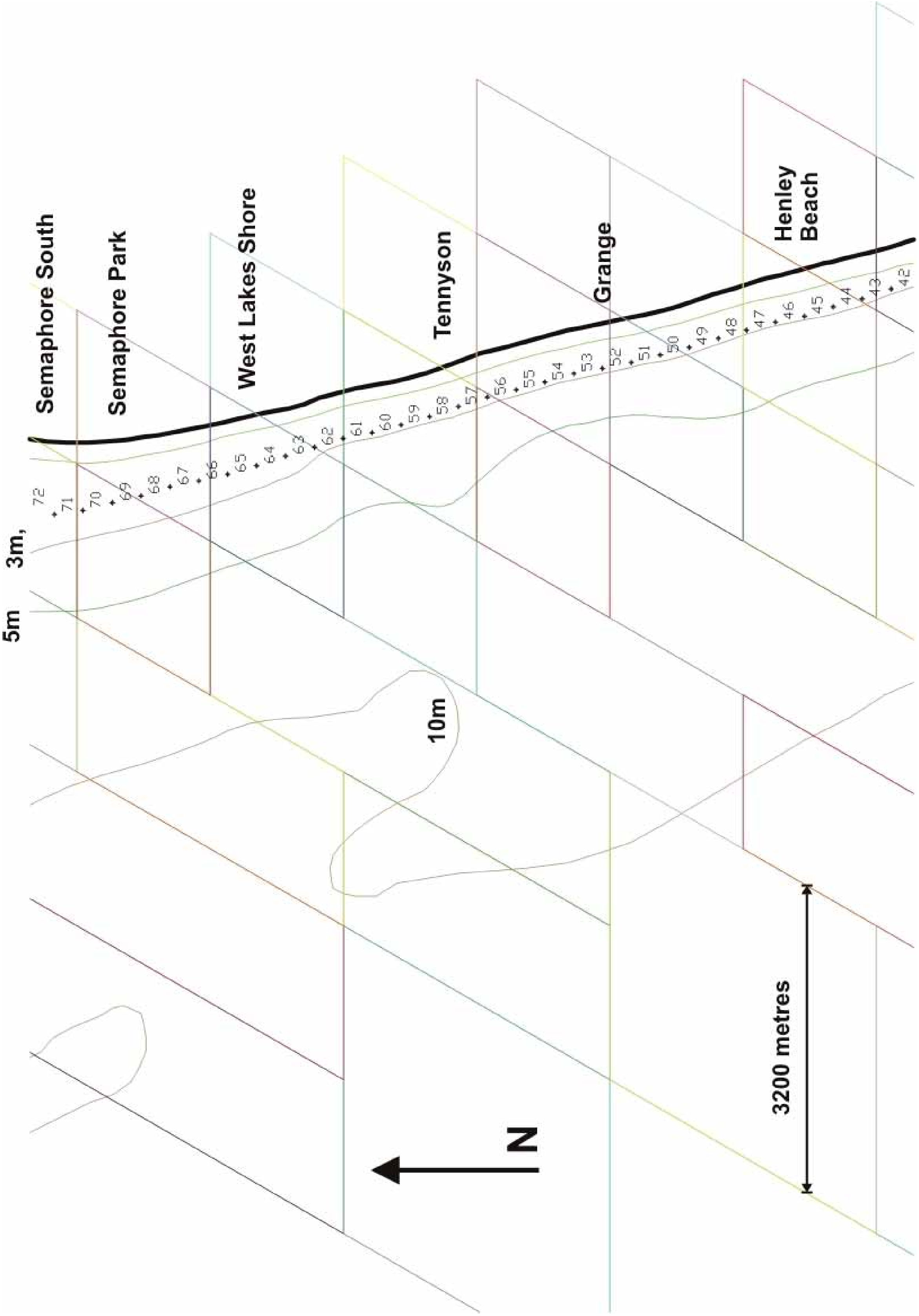


FIGURE 4.9: Nearshore sites from Henley Beach to Semaphore South

FIGURE 4.10: Nearshore sites from Semaphore to Outer Harbor

4.3.2 Computations of Wave Refraction and Shoaling Effects

SPECREF is a computational routine used to determine the wave coefficients (ie. the ratio of inshore to offshore wave heights), and the relationship between the deepwater wave direction and the corresponding wave directions inshore. These calculations are completed on a spectral basis for the complete range of possible offshore wave directions and periods.

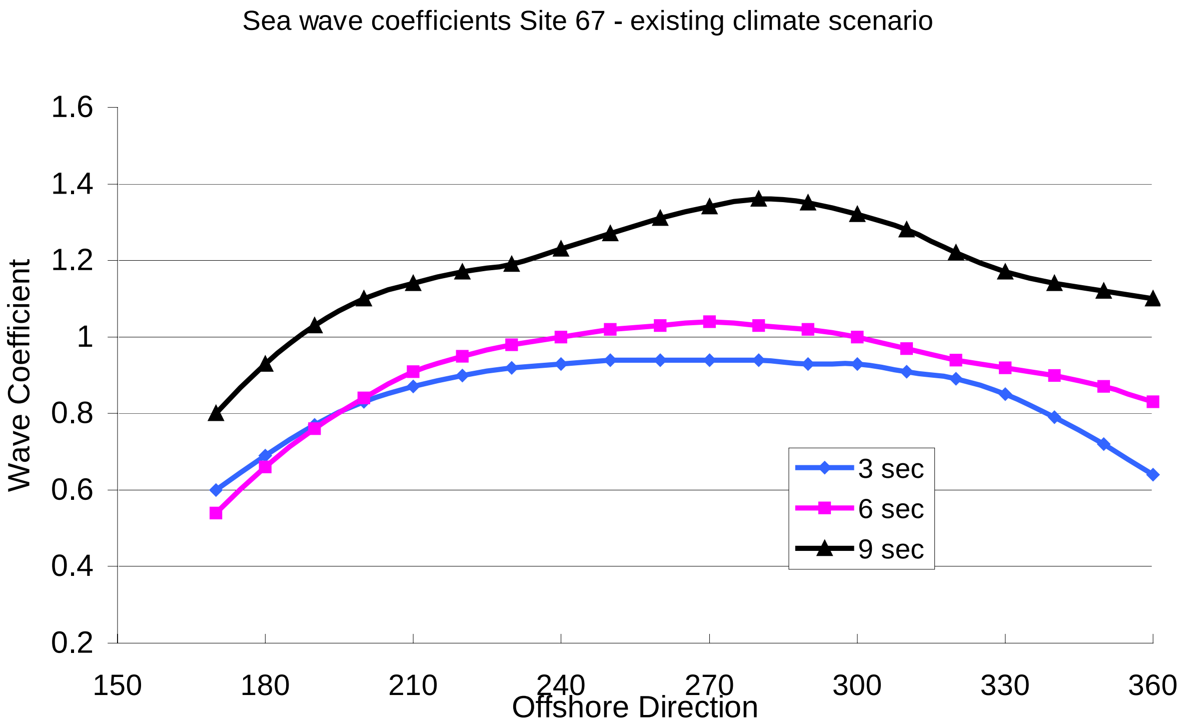
This routine uses the data output files from CES350. Offshore wave directions used in the analysis are specified in 10 degree increments. As well as including the effects of wave refraction, the resulting wave coefficients also account for wave shoaling - but not seabed friction or wave breaking, as these are completed by subsequent modelling routines as required.

The 10 degree resolution is required for accurate sediment transport modelling. Sediment transport rates are quite sensitive to the orientation of the waves as they break with respect to the plan-alignment of the beach. Separate transformation coefficients pertaining to swell and sea waves are determined.

Figure 4.11 shows an example of the output from SPECREF. Sea wave coefficients and inshore wave directions are shown in this figure for a location just offshore of Semaphore Park (Site 67). As an example of how to interpret the results presented in Figure 4.11, for an offshore sea wave of 1.0 metres height having a period of 9 seconds and approaching from 270 degrees, the corresponding wave height inshore at Site 67 (neglecting seabed friction effects) is 1.35 metres. In other words, the wave height has been amplified by a factor of 1.35.

Reference to the lower half of the figure indicates that as a consequence of the transformation processes, the same wave will be arriving at the site on a bearing of approximately 263 degrees (360 degrees being north).

Figure 4.12 shows similar relationships for swell waves at site 67 off Semaphore Park.



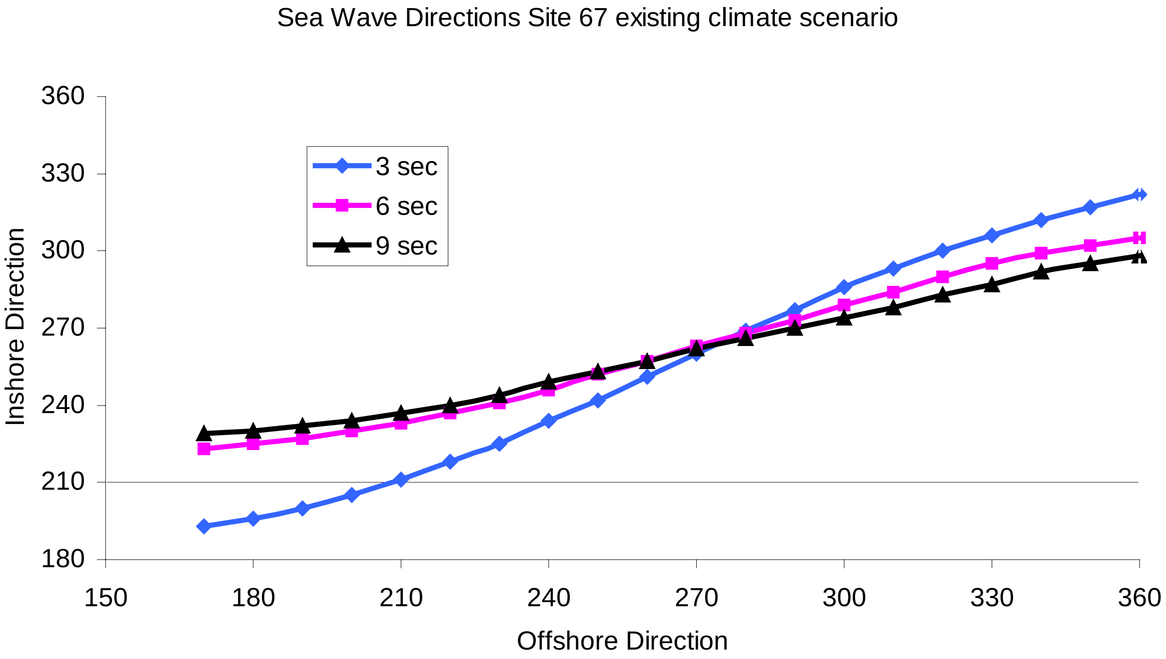
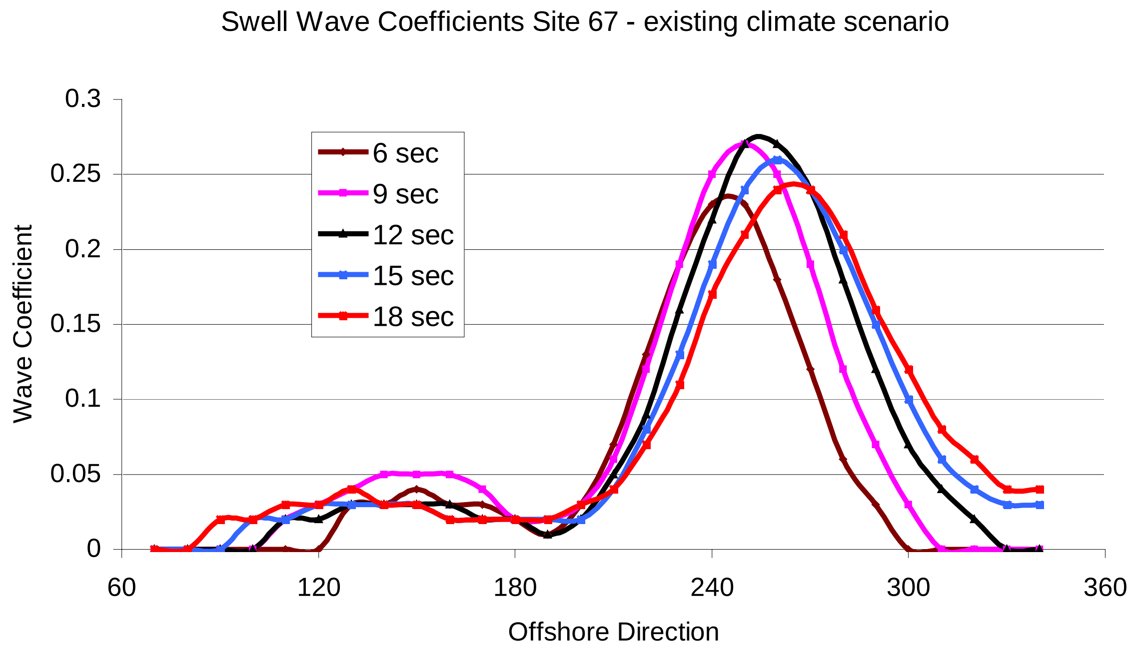


FIGURE 4.11: Sea wave coefficients and inshore directions for Site 67 (off Semaphore Park)



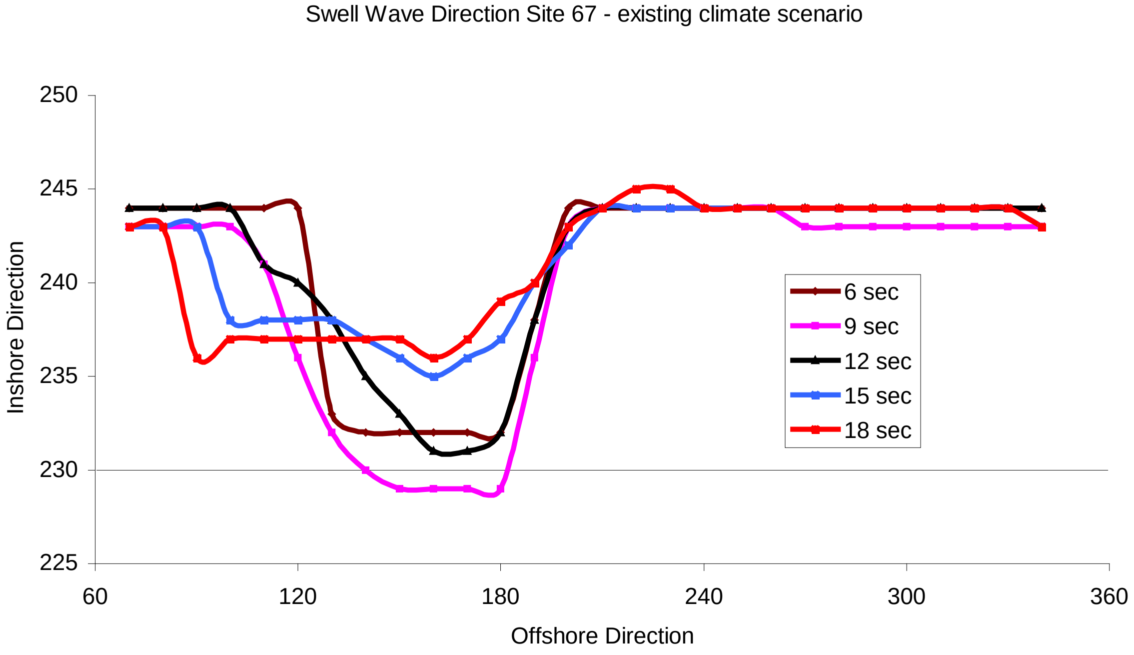


FIGURE 4.12: Swell wave coefficients and inshore directions for Site 67 (off Semaphore Park)

The results presented in Figure 4.12 lead to the following observations:

- There are potentially two ways by which swell waves generated by distant weather systems out in the open ocean can propagate to Semaphore Park:
  - The first is illustrated by the small increase in the wave refraction coefficients (and the significant change in the inshore wave directions) for those waves generated from offshore directions between 70 and 180 degrees. These waves enter Gulf St Vincent through Backstairs Passage.
  - The second is illustrated by the larger increase in the wave coefficients, peaking at about 0.27, for waves generated in the open ocean from a bearing of 250 degrees. These waves enter Gulf St Vincent through Investigator Strait. These waves tend to be almost unidirectional by the time they reach Semaphore Park (arriving on a bearing of 244 degrees).

- The maximum wave coefficient for swell varies between 0.2 and 0.3 for offshore wave directions of 250 to 260 degrees. This is the direction from which the largest swell waves are generated in the open ocean south of Kangaroo Island. In the absence of significant seabed friction, the implication is that when a swell having a significant wave height (ie. H_s) of 10 metre occurs in the open ocean, the inshore swell wave height would be 2 to 3 metres at Semaphore Park. This does not happen. Even during a severe storm, the significant wave height for inshore swell does not exceed approximately 1 metre. This illustrates the importance of seabed friction in the attenuation of waves propagating to Adelaide beaches.

The results for the modelling of the sea and swell wave refraction are provided in tabular format on CD as Appendix A.

4.3.3 Seabed Friction

Seabed friction effects play a substantial role in the attenuation of both swell waves and locally generated sea waves. Figure 4.13 shows an overall schematic view of the various seabed forms in Gulf St Vincent. This interpretation of the seabed characteristics was derived from Shepherd & Sprigg (1976).

The most notable features of the seabed are as follows:

- In Investigator Strait immediately north of Kangaroo Island there is a bare reef area which for the purposes of determining seabed friction effects has been assigned a roughness height of 100mm;

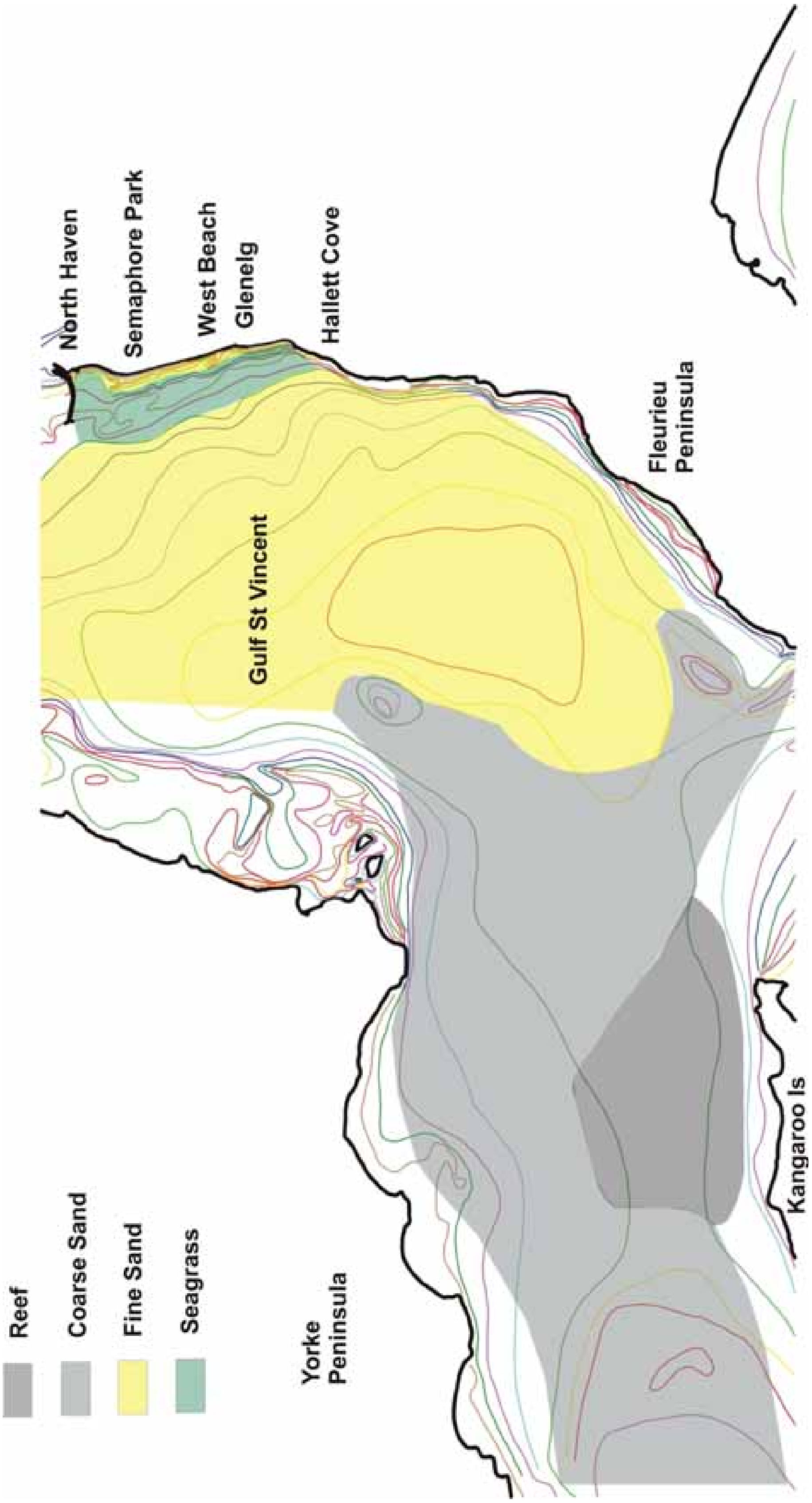


FIGURE 4.13: Seabed characteristics in Gulf St Vincent

- For most of the remainder of Investigator Strait, the seabed consists of coarse sediments. Calculations indicate that ripples are unlikely to form on this area of the seabed. The sand has been assigned an average grain size (ie. a D_{50} value) of 0.6mm.
- The deeper areas of Gulf St Vincent have a fine sand surface layer which calculations suggest can form ripples. A nominal sand grain size of 0.2mm has been adopted for modelling purposes.
- There are seagrass meadows off Adelaide's metropolitan coastline. It is generally accepted that the extent of the seagrass meadows has varied notably over the years. Consequently, when modelling the five different shoreline scenarios, the extent of the seagrass coverage has been varied for each. The seabed roughness assigned to areas of seagrass varies from 30mm in deeper waters where the coverage is sparse, to 120mm where there are dense seagrass meadows.
- Inshore of the seagrass meadows there is typically a sandy substrate consisting of fine sand varying in average grain size from 0.25mm in the south to 0.18 mm at North Haven. Ripples can form on such sandy seabeds.

The seabed roughness value assigned to reef and seagrass remains constant under all wave conditions. However, the roughness of a sandy seabed depends on whether or not there are ripples present. The roughness assigned to a rippled bed by the wave transformation modelling is determined to be 4 times the calculated ripple height, Hsiao & Shemdin (1978) and Nielson (1977). Where calculations indicate that the wave height is such that ripples do not occur, then the roughness assigned to the sand bed is 4 times the median sand diameter, Riedel (1972). Therefore the roughness of a rippled seabed tends to be some two orders of magnitude greater than that for a flat sandy bed. This has a significant influence on wave attenuation.

4.3.4 Wave Transformation

The wave transformation modelling basically assembles the various swell and sea wave hindcasts undertaken for the appropriate locations in deep offshore waters, then applies the effects of wave refraction / shoaling and seabed friction to determine the corresponding wave climate at selected nearshore sites.

As discussed in the preceding Sections 4.2.1 and 4.2.2, the hindcast database consists of a time series of offshore wave conditions at three-hourly intervals over the ten year period from 1993 to 2002. The offshore wave conditions for each three-hourly time increment is modified in accordance to the relationships determined by the reverse ray modelling described in the preceding Section 4.3.2.

The actual tide levels (as measured at Outer Harbor) corresponding to each time increment are adopted, thereby ensuring that the effects of real ocean tides are considered during the wave transformation computations.

The calculations for transforming the offshore wave conditions into shallow water for each three-hourly time increment are themselves performed in steps as the waves propagate shoreward. Should the advancing waves encounter what has been determined to be a sandy section of the seabed, a calculation is made as to whether or not ripples will form. If so, then the ripple height is computed. The appropriate roughness is assigned to that section of seabed and the resulting reduction in wave height is calculated. The attenuated wave is then propagated further shoreward into the next seabed section. The appropriate seabed roughness is again calculated, the attenuated wave height is determined for this section of the seabed approach, the resulting wave is then propagated shoreward into the next section and the process repeated.

This stepped computation procedure (as waves propagate across the variable seabed forms to the selected inshore site) is necessary because seabed friction reduces wave height - and the reduced wave height at the start of a new seabed section may or may not initiate ripples.

This computation procedure is undertaken separately for the swell waves and the sea waves for each of the 94 sites along the metropolitan coast - not only for present day conditions, but also for each of the other four shoreline scenarios. The outputs for each site consist of nearshore sea and swell wave data files - each containing the 10 year wave data set in three-hourly time series. The real tidal water level is used for each three hour time step over the 10 years of wave simulation.

An example of how wave transformation processes affect swell and sea waves propagating to Semaphore Park is given in Figures 4.14 and 4.15.

Figure 4.14 shows that comparatively, the smaller sea waves are attenuated more than the larger sea wave heights. This is because large sea waves will tend to “wipe out” ripples on the seabed - consequently the attenuating effects of seabed friction reduces. The largest Hs is about 3 metres and would have occurred near high tide. At low tide a wave with Hs of 3 metres would have broken.

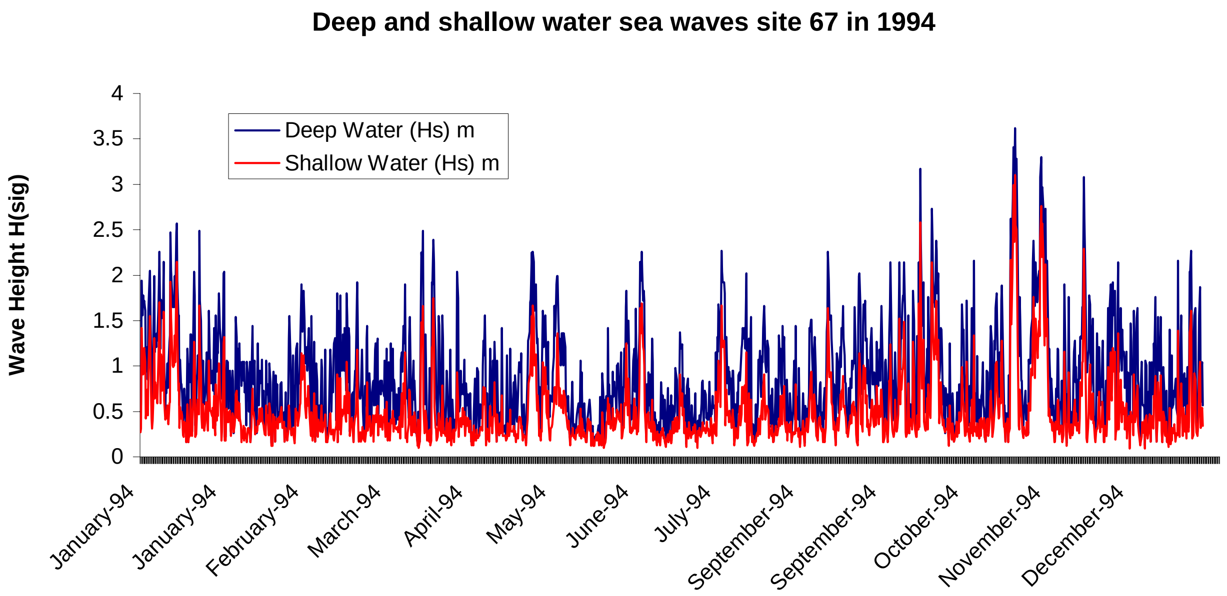


FIGURE 4.14: Sea waves in deep water and after transformation to Semaphore Park

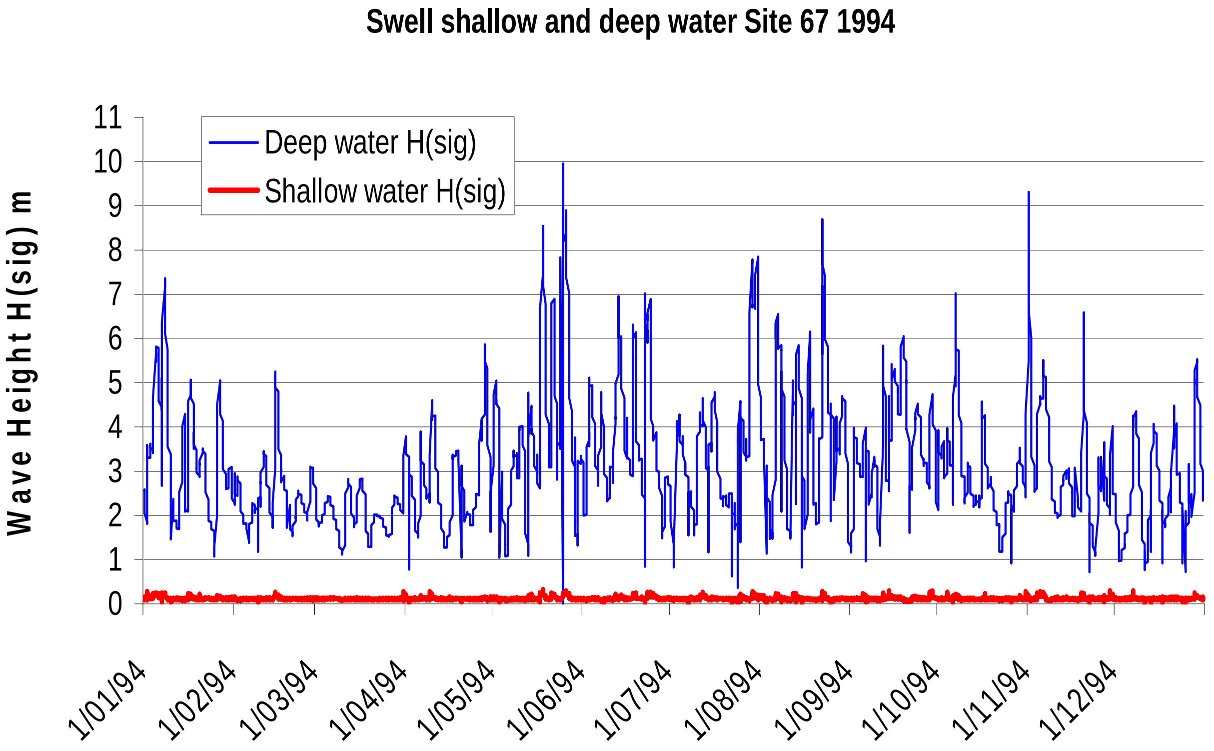


FIGURE 4.15: Swell waves in deep water and after transformation to Semaphore Park

Figure 4.15 shows that all swell waves are attenuated significantly. The larger waves are attenuated more (percentage-wise) than the smaller waves. It is interesting to note that there is always a small residual swell present at the inshore site, as shown by the continuous red line depicting shallow water swell wave conditions.

All of the nearshore swell and wave files are presented in tables contained in Appendix A.

4.4 Sediment Transport Module

The major sediment transport processes acting on Adelaide's metropolitan beaches consist of:

1. Sand being swept along the coastline by wave action alone. This phenomenon is termed *longshore sediment transport*;
2. The transport of sand by waves in an offshore / onshore direction. Offshore sand movement tends to occur when storm wave activity attacks the beach, causing sand to be eroded from the beach face and deposited in sand bars offshore. Onshore sand movement tends to occur during mild wave conditions;
3. Sand transported within the nearshore area by currents. Often ocean currents on their own will not initiate the transport of sand grains along the seabed - it frequently requires waves to agitate the seabed, thereby initiating movement of the individual sand grains. Any currents that co-exist with the waves can then sweep the sediment that is already in motion;
4. Sand blown by onshore winds to form sand dunes at the rear of the beach. The wind may also blow sand along the beach.

It is difficult to quantify the rates of sand transported on Adelaide's beaches by ocean currents and wind (items 3 and 4 above). However sediment transport by waves can be readily estimated using mathematical modelling techniques (items 1 and 2 above). It is suggested that the accuracy achieved by such techniques is of the order of ± 20%. Mathematical modelling has been used for this study to determine the rates of sediment transported by waves. When applied together, these various mathematical algorithms constitute the *Sediment Transport Module* of the entire modelling procedure. A discussion of each algorithm is offered below.

4.4.1 Longshore Sediment Transport

The central component of Coastal Engineering Solutions' *Sediment Transport Module* is the QUEENSED mathematical model for longshore sediment transport. This model uses the algorithm developed at Queens University in Canada – ie. the QUEENS formula. It is used to assess the longshore sediment transport potential, the equilibrium beach-plan alignments and the seasonal rotations of beach-plan alignments along particular coastal reaches.

Longshore sediment transport rates are computed for Adelaide's foreshores as a three-hourly time series, over the entire 10 years of sea and swell wave hindcasts.

QUEENSED uses the output from the Wave Transformation Module (namely the inshore directional wave climate) to determine sediment transport rates. Nevertheless, there is a further wave transformation computation which is required to be undertaken as part of the calculations for longshore sediment transport. Typically the nearshore sites are selected some distance offshore of the beach and seaward of the breaking wave zone. For the modelling of longshore sediment transport on Adelaide's beaches, there are 94 nearshore sites along the coastline - each located in some 3 to 3.5 metres depth of water (at mid-tide).

However it is the characteristics of the breaking wave that must be used in the longshore sediment transport calculations - not the waves seaward of the breaking wave zone. Therefore the QUEENSED program determines the propagation of waves between each of the 94 nearshore sites chosen for investigation by the Wave Transformation Module to the point where wave breaking occurs. The characteristics of height, period and orientation (with respect to the plan alignment of the beach) of this breaking wave are then adopted by QUEENSED for longshore sediment transport calculations.

The program considers natural fluctuations in the ocean water level as a consequence of tides, as well as storm surge effects where appropriate. Given the flat foreshore/beach slopes and the approximate 2 metre astronomical tidal variations which occur along Adelaide's shoreline, it is vitally important that such water level variations, plus a storm surge of up to 1.4 metres during severe storms, are incorporated into computations of sediment transport rates.

The sediment transport modelling applied for this study utilised ocean water levels measured at Outer Harbor. Actual recorded ocean levels (including storm surge) corresponding to the three-hourly time steps throughout the 10 years of modelled wave conditions were considered by the QUEENSED model.

The QUEENS formula for determining longshore sediment transport rates includes several parameters which define the physical characteristics of the nearshore sediments as well as the wave conditions prevailing at the time. Some parameters have a greater effect of longshore transport rates than others. For instance the transport rate is strongly dependent on the incident wave period; the wave height; the average sand grain size; the slope of the seabed approach onto the beach and the orientation at which the wave breaks relative to the seabed contours. The other parameters in the formula have a lesser influence on sediment transport rates.

The QUEENS formula is as follows:

$$S = \frac{1.3\text{x}10^{-3}}{(1-p)\rho_s}\frac{\rho H_b^3}{T}\left(\frac{H_b}{L_o}\right)^{-1.25}\tan^{0.75}(\alpha)\left(\frac{H_b}{D_{50}}\right)^{0.25}\sin^{0.6}2\phi_b$$

in which:

- S = longshore sediment transport (m^3/s)
- ρ = density of sea water (1025 kg/m^3)
- ρ_s = density of the sand (2600 kg/m^3)
- p = porosity of the sediment (42%)
- H_b = significant wave height at breaking point (m)
- T = peak period of the spectrum (sec)
- D_{50} = median sand grain size (generally 0.0002 m)
- ϕ_b = wave angle at breaking to the seabed contours
- α = beach slope (measured at each site from survey data), and
- L_0 = deep water wave length (m)

The sediment transport output can be presented by the QUEENSED program in a number of ways. The basic raw output consists of a lengthy data file for each site and for each scenario, where for every three-hourly time step the direction and quantity of sand moved by waves is presented. This raw output data can then be assembled to produce either the longshore sediment transport which occurred specifically during a storm event, or on a monthly, or on an annual basis.

The model is also used to compute the extent of likely seasonal rotations within contained beach compartments/reaches. It is also used to determine the equilibrium beach angle – that is the local plan-alignment of the beach for which there would be no net longshore transport. This later information is very useful whenever foreshore stabilisation strategies involving beaches contained by groynes or offshore breakwaters are to be assessed.

Figures 4.16 to 4.18 show three typical time scales for longshore sediment transport. The present day conditions at Semaphore Park (Site 67) are again used for these examples. A brief commentary on each figure is offered below.

Figure 4.16 shows the longshore sediment transport potential over a 10 year period at Semaphore Park:

- Since there is no seawall or reef within the beach system which might otherwise restrict the amount of sand available to wave action, it is expected that the full potential for sediment transport (as calculated by QUEENSED) would be achieved at this location;
- Each bar represents the amount of longshore sand transport during one month. A positive value represents transport towards the north, a negative value represents transport to the south. The maximum amount transported in any month (almost by a factor of two) occurred in November 1994;
- There appears to be little variation in the net volume of sand moved along the beach from year to year, except for the large amount transported during the November 1994 storm.
- The rate of northerly sediment transport exceeds the rate of southerly transport during every month of the entire 10 years.
- The average annual rate of northerly transport is approximately 60,000 cubic metres at this site.

Figure 4.17 presents the sediment transport rate in more detail, this being on a monthly basis at the Semaphore Park site for the year 1994:

- The total net sediment transport for this year was computed at 85,000 cubic metres compared to the annual average over ten years of 60,000 cubic metres;
- 17,000 cubic metres of sand moved northward in November 1994 alone. This was due to the severe storm that occurred early in that month;
- There is significant variation in the sediment transport rate from month to month.

Figure 4.18 provides a further breakdown of the sediment transport rate at the Semaphore Park site, this being on a daily basis for November 1994. The most notable feature is that most of the longshore transport would have occurred over three days in the early part of the month.

Appendix A contains sediment transport files in tables for all 94 nearshore sites and for all five historical scenarios.

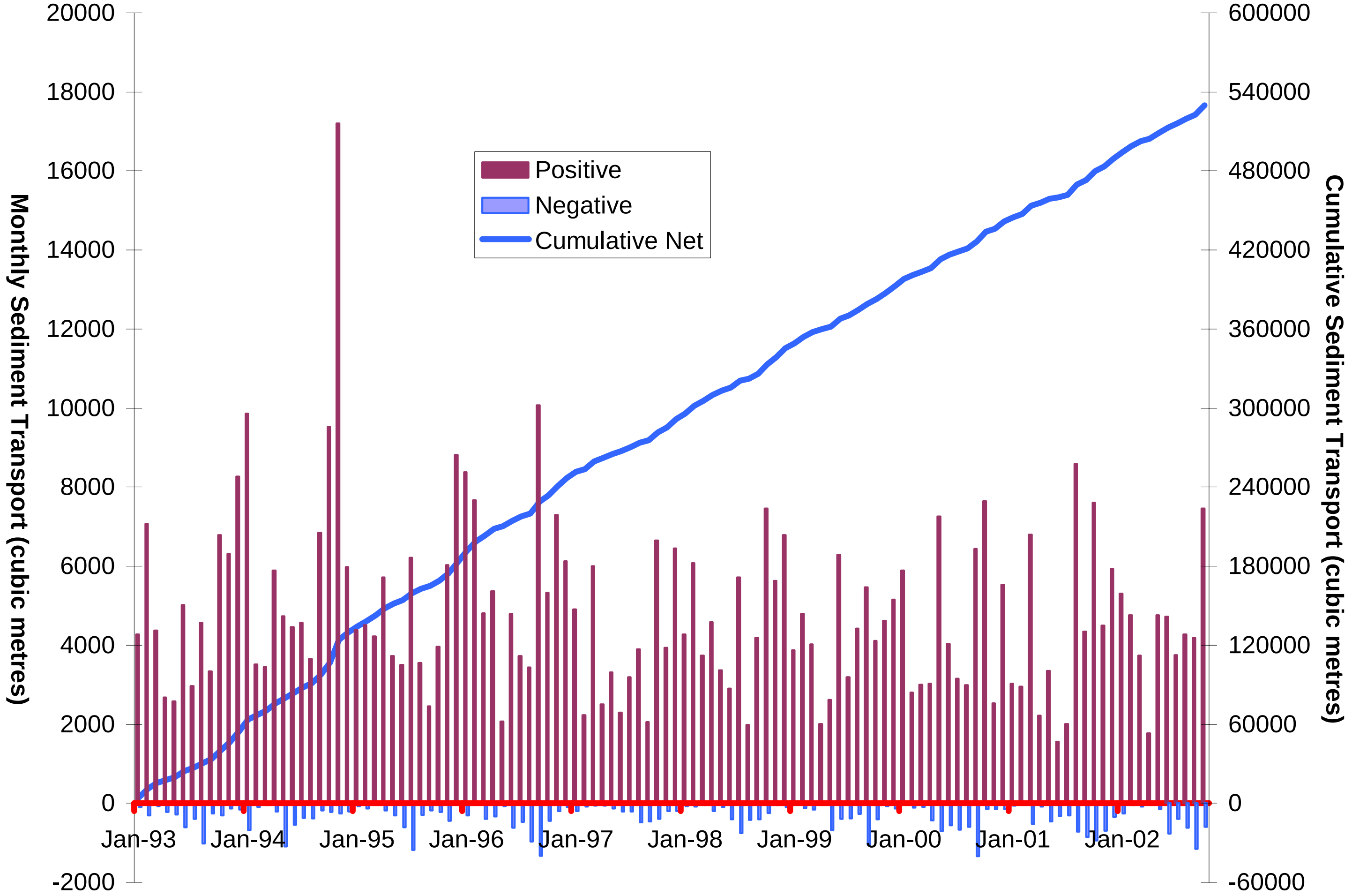


FIGURE 4.16: **Ten year longshore sediment transport potential – Semaphore Park**

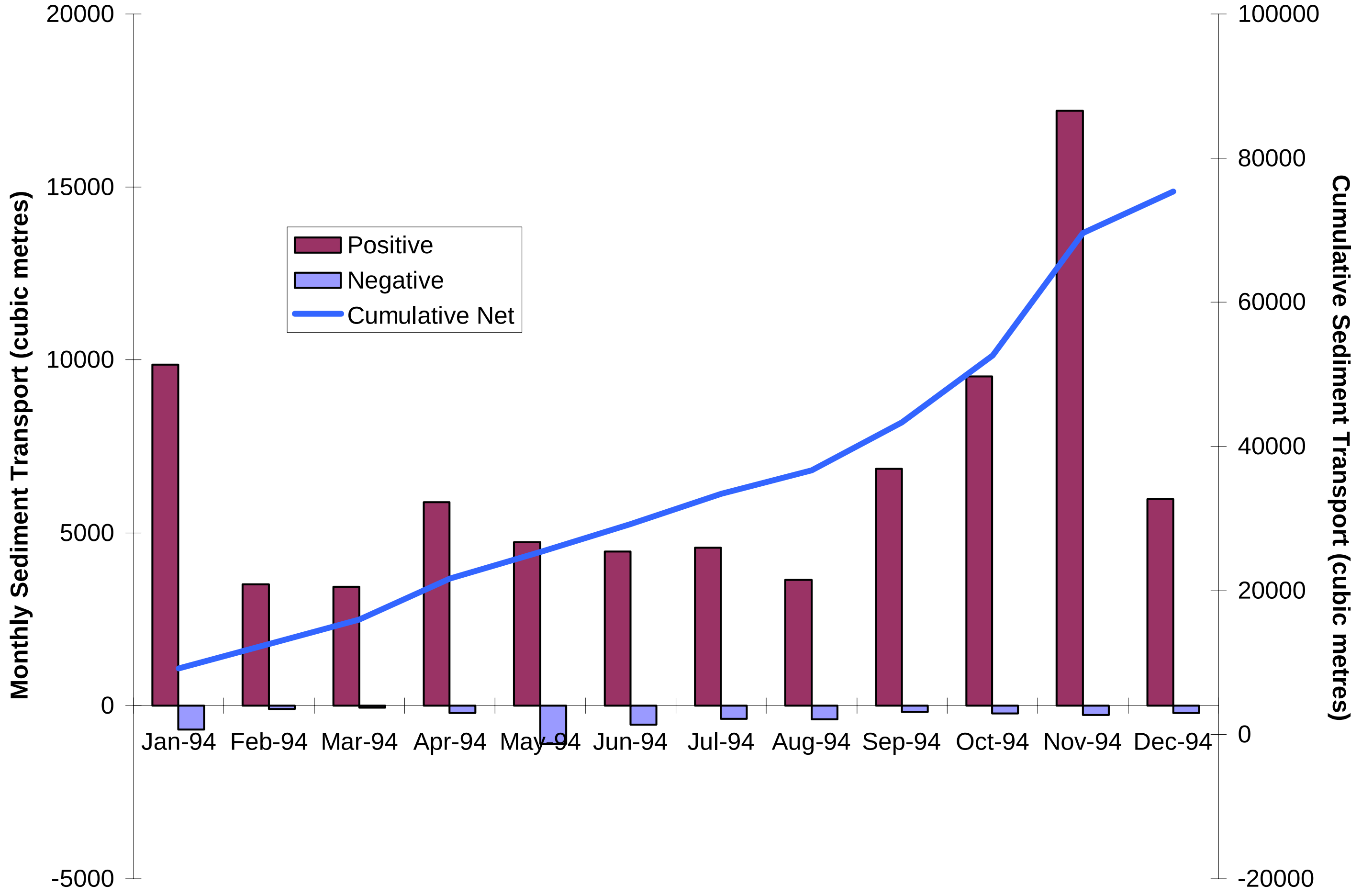


FIGURE 4.17: Longshore sediment transport potential for 1994 at Semaphore Park

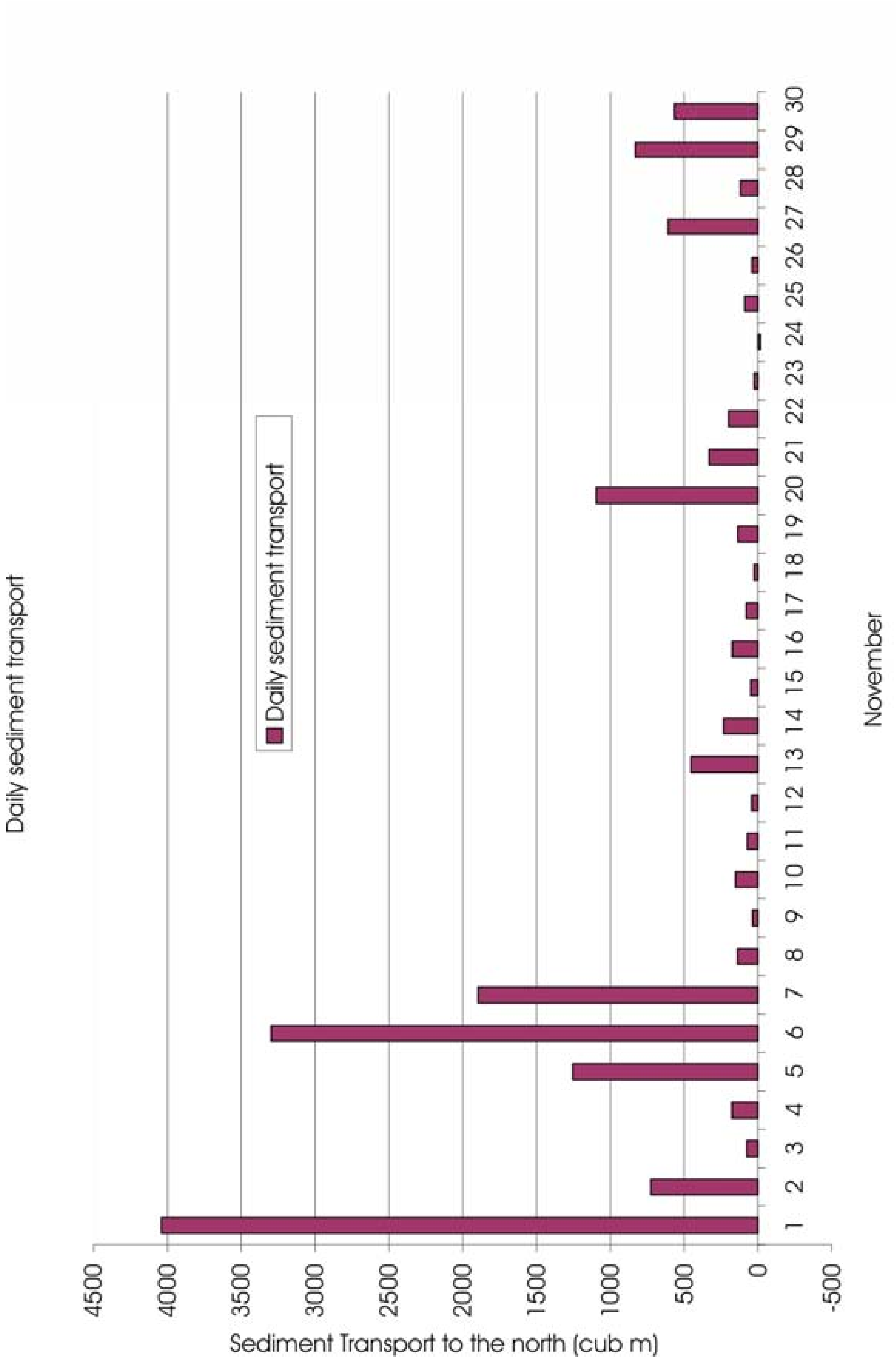


FIGURE 4.18: Longshore sediment transport potential in November 1994 at Semaphore Park

4.4.2 Offshore Sediment Transport

SBEACH is a model developed by the Coastal Engineering Research Center of the U.S. Army's Corps of Engineers specifically for examining the performance of beach systems subject to onshore/offshore sand movements under wave action. The program uses a Windows front-end with real-time modelling of sand movements. It also allows for the placement of a seawall in the active beach zone to investigate localised scour or accretion as a result of such a structure.

The severe storms identified for consideration by the offshore transport modelling include:

- April 1948, which anecdotally was the most severe storm to hit Adelaide's shoreline, was produced by a relatively short duration south-west change. However, the winds accompanying the change were 20 to 30 m/s, which are significantly higher than any other winds recorded for subsequent storms. The maximum storm surge during the storm was 1.1 metres.
- May 1953, is believed to have ranked closely behind the 1948 storm in terms of severity. However, it occurred at a time the wind anemometer was moved to a new site and wind data suitable for wave hindcasting could not be obtained. The maximum storm surge during the storm was 1.2 metres.
- April 1956 for which the significant wave height off the coast of Adelaide exceeded 1.5 metres for a duration of almost 5 days. The highest predicted significant wave height in offshore waters did not exceed 3 metres. The maximum storm surge during the storm was less than 1 metre.
- May 1960 - two storms occurred, separated by a calm period of 5 days. The cumulative storm duration was approximately 4 days and the largest significant wave height in offshore waters was over 3 metres.
- April 1985 - a severe short duration storm occurred with an offshore wave height of about 3.5 metres. The storm duration was only about two days.
- November 1994 - a severe storm occurred at the beginning of the month. The effective duration of the storm was approximately 4 days. The maximum storm surge during the storm was 0.9 metres.
- September 1996 - a short duration storm occurred but it produced the highest hindcast wave of the 1993 to 2002 period (of over 4 metres). The associated storm surge was 0.8 metres.
- June 1999 produced another severe short duration storm where the wave height exceeded 3.5 metres. It was accompanied by the highest storm surge on record of 1.5 metres.

Given that beach erosion is typically more sensitive to elevated ocean levels than to the height of the waves, it is not possible to confidently determine which of these storms would produce the most erosion without actually modelling the wave and tide/surge conditions for each event.

Modelling of offshore sediment transport processes has been undertaken for all of these storms except for 1953 (due to the lack of suitable wind data) using the SBEACH system.

Ten representative locations along the Adelaide foreshore were selected for investigation, namely:

- South Brighton : Site 4
- North Brighton : Site 8
- Minda Beach : Site 13
- Glenelg Jetty : Site 22
- West Beach Dunes : Site 33
- Torrens Outlet : Site 38
- Tennyson : Site 58
- Tennyson Dunes : Site 60
- Tingira Ave, Semaphore Park : Site 67
- Semaphore Jetty : Site 75

Further north of Semaphore Jetty, erosion during storms is not likely to cause a concern since the foreshore is generally accreting. The results of the SBEACH modelling of storm erosion are presented in Section 5.5, accompanied by a discussion of offshore sediment transport.

Section 5
RESULTS FOR VARIOUS SHORELINE SCENARIOS

In order to provide further confidence with respect to projections of likely coastal processes over a 50 year design period, the scope of the mathematical modelling undertaken for this study included consideration of a range of scenarios, namely:

- Conditions that existed prior to the loss of seagrass, nominally this was chosen as 100 years ago and termed throughout this report as the *Minus 100 Year Scenario*.
- Present day scenario - which is effectively the year 2002 since this is the date for which the latest nearshore survey data is available.
- Predicted conditions for 20 years in the future – termed the *Plus 20 Year Scenario*.
- Predicted conditions for 50 years in the future – termed the *Plus 50 Year Scenario.*
- Predicted conditions for 100 years in the future – termed the *Plus 100 Year Scenario*.

5.1 Present Day Scenario

The latest available surveys were used to schematise the form of the shoreline and the nearshore region for the present day scenario. The survey data included:

- Results of detailed nearshore surveys undertaken between Kingston Park and Outer Harbor over 2001-2. These typically extended to about the 10 metre depth contour with drawings produced at an approximate scale of 1:17,500. The survey drawings were provided by the Coastal Protection Branch, Department for Environment and Heritage.
- Admiralty charts:
    - Aus 343 – Whidbey Isles to Cape Du Couedic, approx scale of 1:300,000
    - Aus 345 – Gulf St Vincent and Approaches, approx. scale of 1:300,000
    - Aus 347 – Backstairs Passage to Cape Martin, approx. scale of 1:300,000
    - Aus 780 – Port Adelaide to Backstairs Passage, approx. scale of 1:150,000
    - Aus 781 – Gulf St Vincent, approx. scales of 1:75,000 for the southern portion and 1:150,000 for the northern portion.

When establishing the computational grid that schematises the seabed, a gap was identified in the nearshore seabed survey data in the vicinity of Kingston Park. The recent survey (completed in 2001and presented at a scale of 1:17,500) did not overlap with the seabed depicted on the Admiralty Chart Aus 781 (presented at a scale of 1:75,000). Unfortunately the resolution of the nearshore data in Aus 781 is quite poor, consequently considerable estimation and manual “smoothing” of contours had to be undertaken to link these two survey data sources. This may have some effect on the results of the wave and sediment transport modelling for the Kingston Park to Brighton coastal reach.

Further, the resolution of the data seaward of the limit of the 1:17,500 scale data (2001), again on AUS 781 is limited. The best interpretation of Chart 781 implies that the offshore contours from the 10 to the 30 metre contour are quite sinusoidal in plan form. This can be seen in Figure 4.6. Theses sinusoidal contours will have a considerable effect on swell wave refraction to Adelaide’s beaches. If this sinusoidal contour form is an artifice of how the data was analysed, and the contours are in fact much straighter lines, then errors would result in both the nearshore swell wave direction and height.

The extent of seagrass coverage was ascertained from inspection of the most recently available aerial photographs for the entire metropolitan beaches (ie. those taken in 2002).

Figure 5.1 shows the net longshore sediment transport potential determined by the mathematical modelling. The results are presented for all of the selected nearshore sites - from Kingston Park (Site 1) to the Outer Harbor breakwater (Site 94). The rates shown are the net amounts of northerly transport over the entire 10 year timeframe considered by the sediment transport modelling.

The longshore sediment transport due to swell waves is shown separately to the transport attributable to sea waves. This was done so as to better appreciate the contribution of both types of waves to the longshore sediment transport potential on Adelaide’s beaches. This separation of sea and swell contributions has not been carried out for other shoreline scenarios. The following observations and conclusions can be inferred from examination of the results summarised in Figure 5.1:

1. South of the Torrens Outlet (Site 38), the swell waves contribute more to longshore sediment transport than do the sea waves generated with Gulf St Vincent. This trend reverses to the north of the Torrens Outlet. This type of response seems reasonable since the shoreline south of the Torrens Outlet is more directly exposed to swell waves than the shoreline further north. However, near North Haven the trend reverses again. This suggests that the swell waves are very sensitive to the form of the nearshore bathymetry.

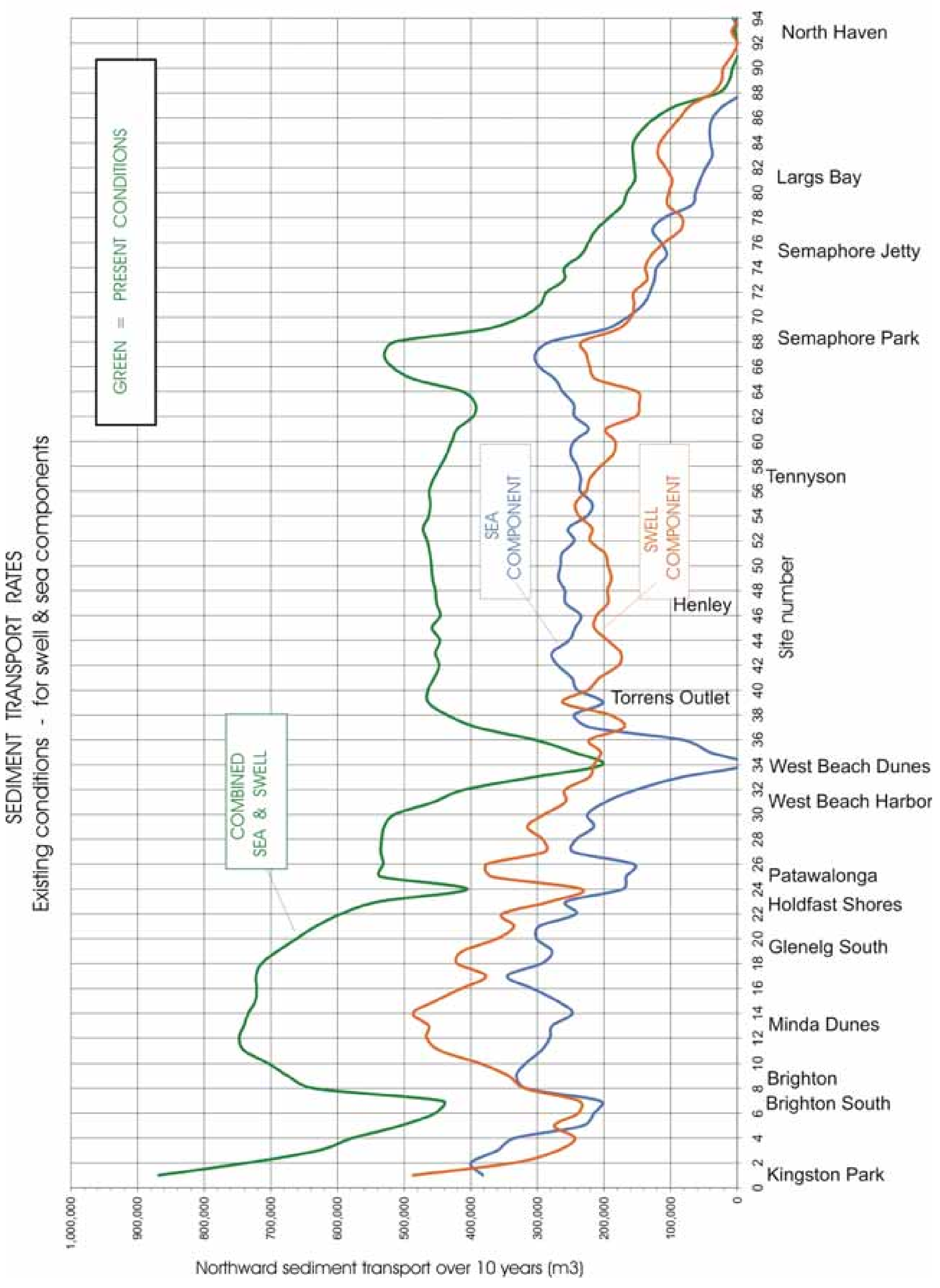


FIGURE 5.1: Longshore sediment transport potential – Existing Conditions

2. There is a rapid diminishing in the sediment transport potential to 450,000 cubic metres (over the 10 years modelled) between Kingston Park and Brighton South. However at Brighton (Site 8) the sediment transport potential has again increased to over 600,000 cubic metres for the 10 years. This is likely to be a real phenomenon. There is a continual need for intermittent trucking of sand from Brighton back to Seacliff because little sand is supplied from the south (only of the order of 5,000 m^3/year). The trend suggested by the model may also be accentuated somewhat due to the need to assume bathymetric features in this area because of a gap in the available survey data.
3. The sediment transport leaving the Brighton coastal precinct at about Site 18 matches the natural migration of sand northward out of this same precinct (as determined by the Department's Coastal Protection Branch). That determination was based on interpretation of nearshore / foreshore mapping undertaken for a *Beach and Seabed Stability Analysis* completed by the Branch. In essence this is the only data which is available for model verification.
4. Another drop in sediment transport potential occurs south of The Patawalonga. This induces a discontinuity in the plan-form of the shoreline. The slowing down of sediment transport potential is a consequence of the breakwater and offshore breakwater. The induced response is to cause the plan-form of the beach south of The Patawalonga to rotate anti-clockwise (relative to the adjacent coastline). It also reflects a sand deposition area. The accumulated sand is partly by-passed by pumping to north of The Patawalonga and partly back-passed by trucks to the Brighton-Seacliff area.
5. North of The Patawalonga, the sediment transport potential is greater than 500,000 cubic metres over the 10 years modelled. The actual quantity of sand moved depends on the rate at which by-passing of The Patawalonga occurs.
6. There is a significant reduction in the longshore sediment transport potential north of West Beach Harbor (Sites 32 to 37). Theoretically this would imply that sand accretes at West Beach Dunes and this does not happen. The reason for this reduction and anomaly in beach behaviour is not certain and is probably due to a combination of factors:
   - The reduction in longshore sediment transport rate is primarily the result of the sand movement north by locally generated sea waves diminishing to zero.
   - There is an offshore shoal / trough feature (refer to Figure 5.2) which refracts the sea waves in such a manner that they approach the local foreshore of the West Beach Dunes precinct from a more northerly direction. Consequently the component of longshore sediment transport capacity caused by sea waves is expected to reduce significantly in this area.

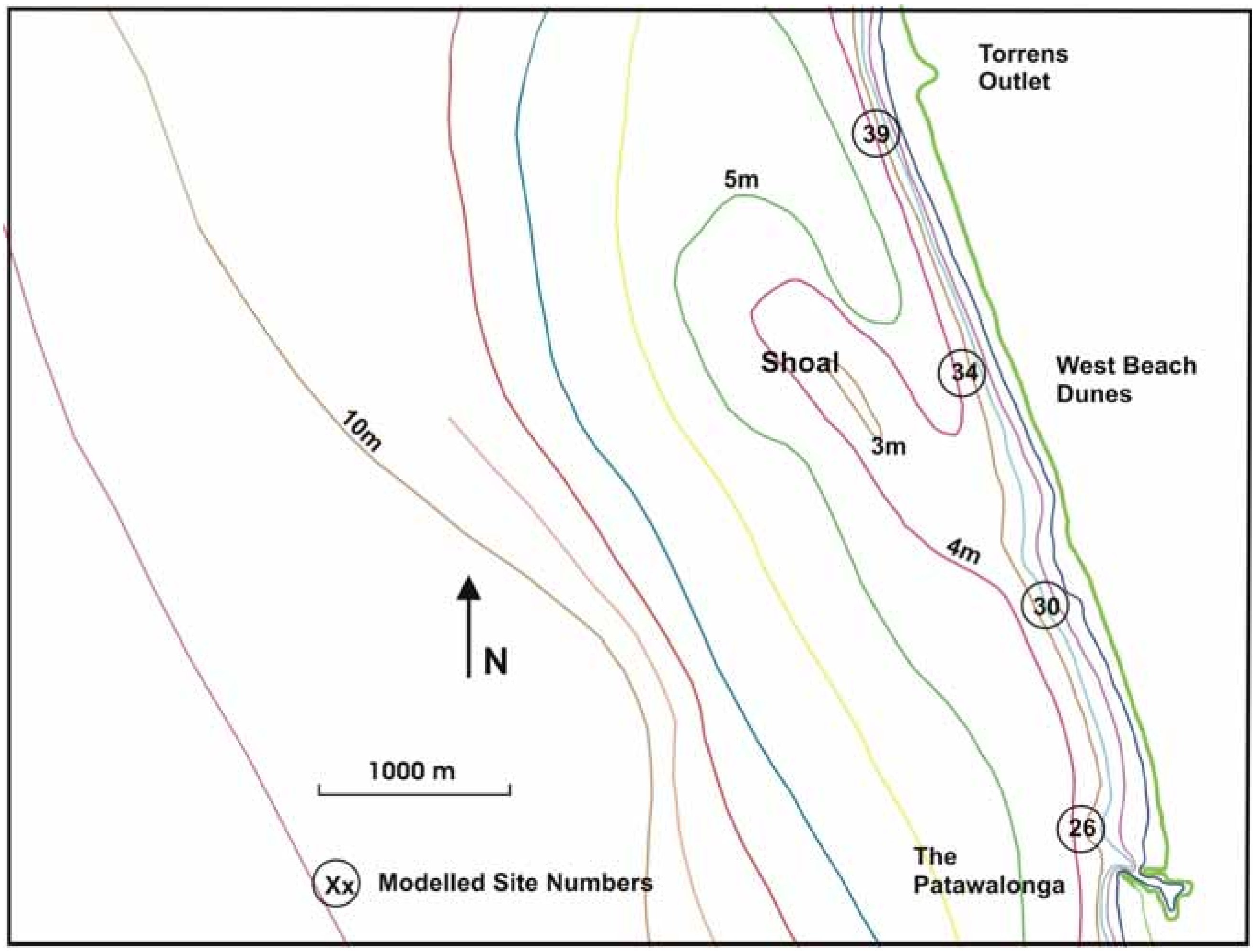


FIGURE 5.2: The shoal off West Beach Dunes

- o The component of swell wave energy may be under-estimated. Referring back to Figure 4.8, it can be seen that the 10 metre contour, derived from AUS 781 is strongly curved to the south-west of West Beach. Such a curvature would deflect energy away from West Beach. If this curvature were not real, the net effect would be an under-prediction of northward sand movement by swell waves. It would also impact on the northward sediment transport capacity of sea waves during storms, which may have peak energy periods of up to 9 seconds.
- o It is important to appreciate that whilst the sea wave refraction phenomenon reduces the longshore transport potential at West Beach, it has no such implication to the capacity of storm waves to erode sand off the beach and deposit it offshore. In fact quite the opposite is likely, with the offshore transport processes being enhanced at this location due to the focussing of wave energy onto the West Beach Dunes foreshore.

  - Surveys and local knowledge indicate that sand does not accumulate at West Beach Dunes. If the longshore transport modelling is correct (which implies the shape of the offshore seabed contours are real) the implication is that sand must be moved away from this section of the shoreline by means other than longshore transport by waves. The following process would contribute to additional movement of sand northward:
    - Since there is a focussing of sea waves in this area, there will tend to be greater offshore sand movement during storms than occurs on adjacent beaches.
    - There is a wide shallow area between West Beach shoreline and the shoal. Sand moved offshore during storms will be deposited into this relatively shallow area.
    - Wherever water depths are shallow, waves can readily initiate sediment motion on the seabed and lift sand up off the bed into suspension. Once in suspension, this sand can be transported northward by the wind-set currents that occur when the wind and waves are from the south-west (as described in Coastal Engineering Solutions, 2000).
    - Sand moved northward by this natural process will be brought back into the nearshore area by the background swell waves. This low persistent swell tends to move sand onshore rather than offshore along Adelaide's metropolitan coast. Consequently the sand transported to the West Beach Dune region moves back onto the beach north of the offshore shoal – that is, at Torrens Outlet (Sites 38 to 40) by way of the offshore shoal feature. Once in the vicinity of the Torrens Outfall, the availability of sand for longshore transport by waves is reinstated.

7. At Torrens Outlet From Torrens Outlet the longshore sediment transport potential has been computed at about 475,000 cubic metres over the 10 years, with equal portions being attributed to sea and swell waves. This longshore sediment transport potential remains constat as far as Tennyson (Site 58). It is known from the historical survey data that sand continues to accumulate at Torrens Outlet. This accumulation is due to the "groyne" effect of the water flow out of the Torrens. The modelling process does not account for this "groyne" effect.

8. There is then a slow reduction in the transport rate to around 400,000 cubic metres from Tennyson to West Lakes (Site 63). The implication is that sand tends to accumulate slowly along this reach, provided that offshore transport during storms is not greater than for the beaches to the north and south. Dune growth along this section of coast implies that this is the case.

9. The longshore sediment transport potential then increases to over 500,000 cubic metres at Semaphore Park (Sites 66 to 68). This correlates well with the persistent erosion that has been experienced at Semaphore Park in recent years. The beaches directly to the south of Semaphore Park have not eroded.
10. North of Semaphore Park, the sediment transport potential gradually decreases all the way up to North Haven (Site 91). Sites 92, 93 and 94 are between North Haven and Outer Harbor and are within a contained beach precinct. The decreasing sediment transport potential is consistent with the accreting regime of this stretch of coast.
11. The rapid decline in sediment transport potential north of Semaphore Park is consistent with the significant accretion that occurs at Semaphore.

5.2 Minus 100 Year Scenario

The Minus 100 Year Scenario represents the seabed and shoreline conditions that could have existed prior to there being any loss or degradation of seagrass areas in nearshore waters. It was also unlikely that at that time any significant seawalls (or other such marine structures) would have been constructed in the active beach/dune zone that might have influenced coastal processes.

5.2.1 Seabed Schematisation

When developing the mathematical model for this scenario, there were no accurate historical surveys of the nearshore area available. Consequently some assumptions had to be made when schematising the seabed form. The main differences from present day conditions were assumed to relate primarily to the extent of seagrass coverage on the seabed, the level of the seabed in those areas where seagrass has been lost and the position of the coastline and the seabed contours - particularly at North Haven, where they were several hundred metres further inland than they are now.

In particular these various assumptions included:

- The seabed bathymetry south of Glenelg Jetty was assumed to be as it is now. It was assumed that there were no seawalls along this foreshore. There would have been extensive sand dunes, but the position of the sand dunes would not have affected the location of the -2 to -3m (to LWD) seabed contours which were are now and were then in the seagrass meadow area. South of the jetty, there has been little apparent loss in the overall extent of the seagrass meadows. There seems to have been some localised blow-outs, however their scale are all too small to influence wave refraction effects and have therefore not been included in any seabed schematisation.

- The Patawalonga was not dammed and the entrance un-trained. The position of the ocean entrance would have simply meandered along the coast over timescales of several years, in a similar manner that the Torrens Outlet moves now. It is probable that there would have been extensive sand dunes on both sides of the entrance as occur now at the Torrens Outlet.
- Seagrass once extended into about the 3 metre depth contour (to LWD) for the entire coastline between The Patawalonga and Outer Harbor. The surveys and monitoring of the presently diminishing seagrass meadows suggest that when seagrasses are removed, the seabed level is scoured and drops by about 0.5 to 1 metre. Consequently when schematising the seabed for the Minus 100 Year Scenario, the seabed level was raised by 0.5 to 1 metre (relative to present day levels) in those areas where it is inferred that seagrass has since been lost.
- There is no information available re the existence or otherwise of West Beach shoal. It has therefore been assumed that the shoal existed.
- The Torrens Outlet did not exist 100 years ago. Therefore the present accumulation of sand at the Outlet would also not have existed. The coast was straighter and the seabed contours would have been approximately parallel to the coast.
- The shoreline between the Torrens Outlet and Semaphore Park would not have been significantly different to what it is now - except that water depths were slightly shallower due to the seagrass meadows extending closer to shore.
- The accretionary deposits currently evident on the foreshores and in the sand dunes north of Semaphore Park were not there 100 years ago. North Haven had not been built, but the Outer Harbor breakwater was in place.
- The shoreline position and contours north of Semaphore are shown in Figure 5.3 for the Minus 100 Year Scenario. The figure also shows the bathymetry for the present day and those inferred for the Plus 100 Year Scenario. In summary, this figure shows that the conditions inferred for modelling the one minus hundred year historical scenario are primarily:
    - North Haven did not exist;
    - The shoreline against the Outer Harbor breakwater was about 500 metres landward of its present day position;
    - All of the nearshore contours inshore of the 5m depth contour were located further east than at present.

It was further assumed that ocean water levels and swell / sea wave climates were virtually the same as those at the present time. That is, there have been no significant climate change effects as a consequence of greenhouse gas emissions during the last 100 years. However, there has been some change in relative sea level, particularly for the northern Metropolitan shore line due to land subsidence. The relative increase in water depth at North Haven is of the order of 200mm. That is 100 years ago, the water level relative to the land level would have been up to 200 mm lower.

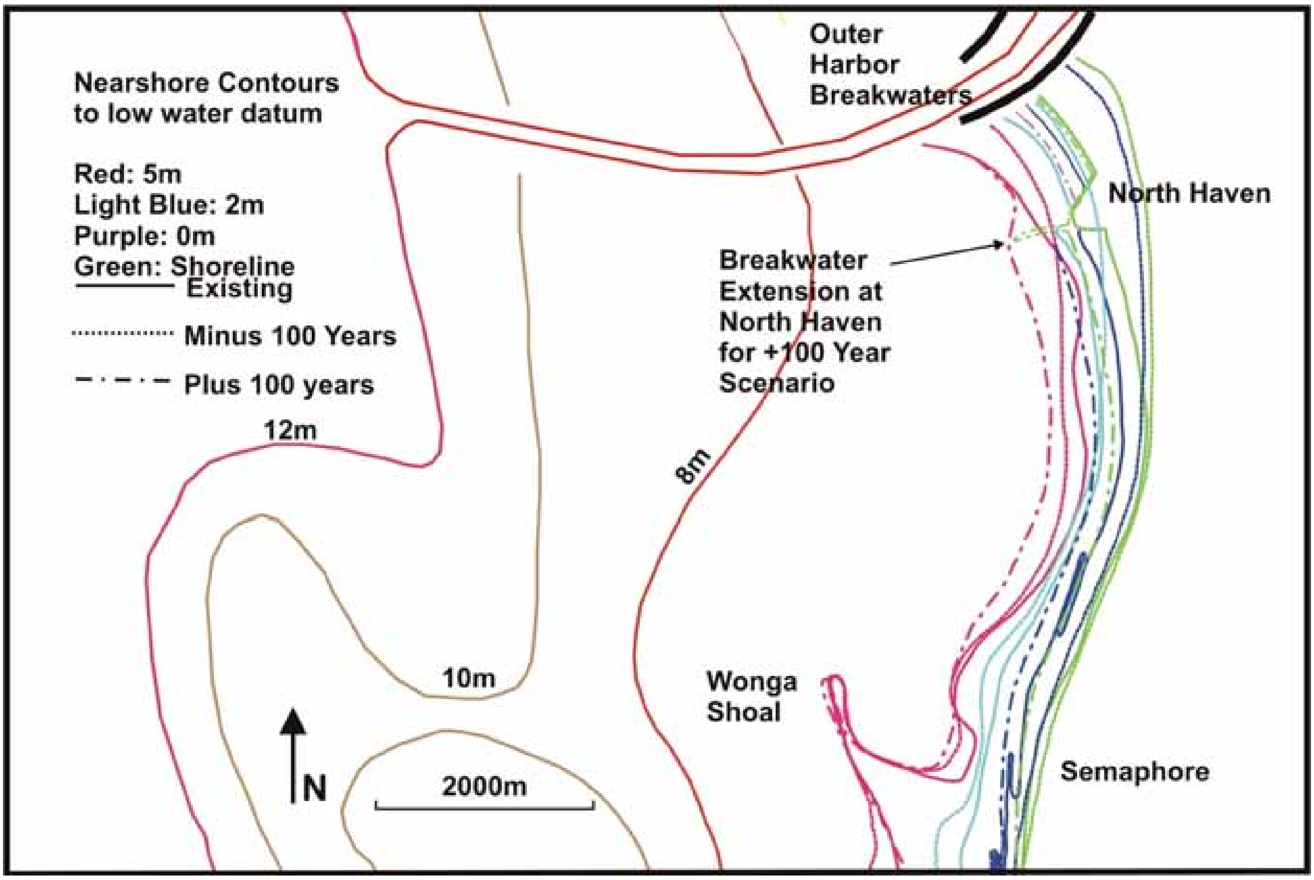


FIGURE 5.3: **Seabed contours north of Semaphore for present day, -100 Year and +100 Year scenarios**

5.2.2 Results of Modelling

Figure 5.4 shows a comparison of the resulting longshore sediment transport potential for the Minus 100 Year Scenario compared to present day conditions. The following observations and conclusions can be inferred from an examination of the modelling results summarised in Figure 5.4:

1. As might be expected, there is negligible change in sediment transport potential south of Broadway (Site 19) since there was no effective change in the bathymetry, other than the dunes, and the extent of seagrass coverage.
2. North of Broadway, the extent of seagrass coverage was significantly more than today and the sediment transport potential is generally 10% to 20% less than for present day conditions - as far north as Semaphore. North of Semaphore, there has been little change in the extent of seagrass meadows but the shoreline was assumed to be located further to the east. The additional expanse of shallow water results in more wave attenuation than for present day conditions; and so the sediment transport north of Semaphore is also less for the Minus 100 Year Scenario.
3. The Patawalonga was not trained for the Minus 100 Year Scenario. The precise bathymetry and shoreline shape at this particular location on the coastline are not certain. However, The Patawalonga would have acted much like a partial groyne and collected sand as the Torrens Entrance does now. Sand trapped by the groyne effect would be blown onshore and resulted in dune growth. That is, the calculated reduction in the longshore sediment transport potential at The Patawalonga for the Minus 100 Year Scenario reflects some sand trapping of the order of 10,000 m^3/year. However the shoreline probably did not accrete at this rate due to offshore sand transport during storms. Sand eroded from this area and deposited offshore by storms would likely to have been moved back onto the shoreline further north by the subsequent action of swell waves.
4. There is still a reduction evident in the sediment transport rate at West Beach - but it is significantly less than for present day conditions. The change may be attributed to the offshore shoal having been a less prominent feature 100 years ago - and therefore had a lesser effect on wave refraction processes. The higher seabed to the north and south of the shoal (as a consequence of greater seagrass coverage) would have meant the shoal was potentially a less prominent local feature. Some of the sand from (3) above may have contributed to the growth of the shoal.

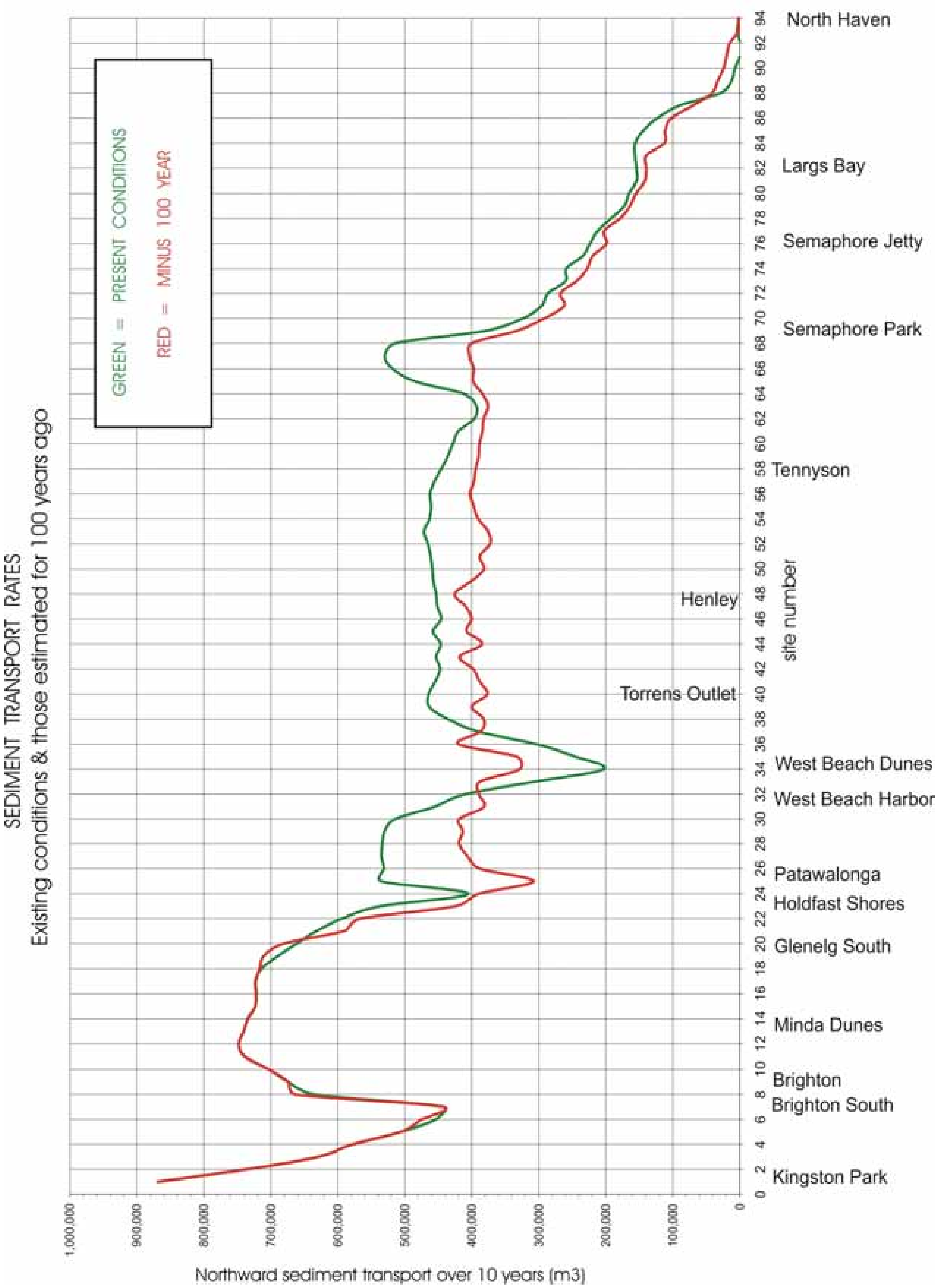


FIGURE 5.4: **Comparison of Minus 100 year and Present Day longshore sediment transport potential**

5. The changes in the longshore sediment transport rate between The Patawalonga and West Beach dunes are dramatic, particularly considering that the change in the shape of the modelled seabed between the -100 year scenario and the present day scenario are not large. This suggests that the net longshore sand transport is very sensitive to even small changes in seabed. It also raises the question of the influence of inaccuracies in the seabed schematisation due to sparse data seaward of the-8m contour (to low water datum).
6. For the Minus100 Year Scenario the sediment transport potential on the coastline between The Torrens Outlet and Semaphore Park is effectively constant at about 400,000 cubic metres for the 10 years. This implies that the shoreline from Torrens Outlet to Semaphore Park was stable with respect to longshore sediment transport. There would still have been some short-term erosion of the beach face during storms as a consequence of the offshore/onshore transport of sand.
7. North of Semaphore Park, the longshore sediment transport potential decreases because sand was being trapped by the Outer Harbor breakwater. Prior to the construction of the breakwaters, there would also have been a similar longshore sand transport potential. This would have resulted in the growth of Lefevre Peninsula, upon which Port Adelaide is now situated.

5.3 Plus 20, Plus 50 and Plus 100 Year Scenarios

The results of the sediment transport modelling of the Plus 20 Year, Plus 50 Year and the Plus 100 Year Scenarios are discussed together. The modelling approach adopted was to firstly model the Plus 100 Year Scenario, and to then model the Plus 20 Year and the Plus 50 Year Scenarios.

5.3.1 Seabed Schematisation

The seabed for the Plus 100 Year Scenario was schematised first; and then the nearshore seabed contours for the Plus 20 and Plus 50 Year Scenarios were interpolated. The positions of the shoreline and the form of the nearshore seabed contours for the Plus 100 Year Scenario were based on the following assumptions:

- That sand management of Adelaide's beaches would include beach nourishment at Brighton to the extent required to supply the northern beaches and that sand by-passing of The Patawalonga and West Beach Harbor would continue. These assumptions may change in the future. Also when this study was initiated the Semaphore Park offshore breakwater construction had not started and its influence is not included.

- The net northward sediment transport along the southern metropolitan beaches would continue to feed sand to the beaches between Semaphore and North Haven. The rate of sand supply is assumed to be the same as for present day conditions. This implies a longshore supply of about 50,000 cubic metres per year to Semaphore which is accompanied by additional sediment moved in suspension (approximately 25,000 cubic metres per year) and seagrass wrack that contributes approximately 50,000 cubic metres each year to the volume of material forming the beach.
- The accumulating sand causes the shoreline to prograde seaward; however it is assumed that the beach maintains the same slope as it does at present. Figure 5.3 shows the assumed position of the shoreline, as well as the assumed nearshore seabed contours (out to the 5 metre depth contour) north of Semaphore Park. Contours further seaward than the 5 metre depth contour do not change significantly.
- It has been assumed that the southern breakwater at North Haven would be extended seaward to prevent the accreting beach from spilling sand directly into the navigation channel.
- The small beach compartment between North Haven and the Outer Harbor breakwater would not receive any additional sand and therefore is assumed to remain in its present day position.
- The extent of seagrass loss has stabilised and would not increase in the future. However, areas of the seabed that have lost seagrass in recent years would continue to lose sand and deepen. The extent of deepening was set at 1 metre adjacent to the remaining seagrass meadow and tapered to zero at the existing 0 m contour.

5.3.2 Climate Change

Of all the potential impacts of future greenhouse effects, only sea level has been quantified to the extent that some policy statements quote actual values. Nevertheless, there are still significant uncertainties regarding predictions of the impact of the greenhouse gas emissions on sea level rise.

At the present time, the best assessment of the potential climate changes affecting the Adelaide beaches is presented in a study completed by the Climate Impact Group, CSIRO Atmospheric Research (CSIRO, 2003). The sea level increases shown in Table 5.1 have been derived from considerations of the CSIRO's report.

Scenario	**Sea Level Rise**

Plus 20 years	0.1 m
Plus 50 years	0.2 m
Plus 100 years	0.5 m

TABLE 5.1: Allowances for sea level rise

Storm surges occur regularly along the entire South Australian coast, with the greatest frequency of events occurring during the winter and spring months. These events are caused by the westerly or south-westerly winds that follow the passage of cold fronts and their associated mid-latitude low pressure systems further to the south. It is also these winds which generate the sea and swell waves that have a significant influence on the sand transport regime of Adelaide's beaches. Consequently it is important to appreciate the possible implications of any greenhouse induced changes to these occurrences.

The CSIRO study investigated the effects of enhanced greenhouse conditions on extreme weather conditions along the South Australian coastline. The following conclusions have been drawn from the findings of that study with respect to future changes to the weather systems which most affect the wave climate on Adelaide's metropolitan beaches:

- The frequency of winter-time low pressure systems was found to increase over the open waters of the Southern Ocean to the south of the Australian continent. This suggests that significant swell events could become more frequent.
- Whilst the frequency of these winter-time lows is expected to increase to the south of the continent, over the Great Australian Bight and the mainland of South Australia they are expected to decrease. However the central pressures of these lows are expected to reduce on average by around 2 hPa, indicating slightly more intense systems. The inference is that whilst the winter weather systems over local coastal regions may not occur as frequently as at present, they will be more intense whenever they do occur. Consequently the larger sea waves generated within Gulf St Vincent could become less frequent, but greater in height.

A detailed analysis of the likely implications to the wave climate on Adelaide's beaches as a consequence of these expected climate change predictions is beyond the scope of this study. Consequently the following approach has been adopted as a result of a broad appraisal of likely future changes to weather systems:

- the same wave conditions that are currently being experienced on Adelaide's beaches have been adopted for each of the modelled scenarios,
- some sensitivity testing has nevertheless been undertaken. For the Plus 100 Year Scenario, an increase of 10% was applied to the significant wave heights for those instances when heights exceeded 1.5 metres. An increase of 5% was applied to the same instances for the Plus 50 Year Scenario and a 3% increase for the Plus 20 Year Scenario.

5.3.3 Other Parameters

Land subsidence

Land subsidence affects the northern segments of Adelaide's beaches, primarily the foreshore north of Semaphore. It has been speculated that the rate of subsidence is up to 2mm per year in this region, which implies a lowering of some 200mm over the next 100 years. This foreshore area accumulates significant quantities of sand and the prospect of very minor shoreline recession due to such a lowering does not present a concern. Provided the sand supply from the south continues, then land subsidence should not become an adverse issue.

Even if (as part of future foreshore management strategies) the sand supply discontinues, there is sufficient sand deposited within these northern foreshores to enable the beach and the dunes to be naturally re-contoured. This would then compensate for any subsidence without the risk of any notable foreshore erosion. Consequently an allowance for subsidence has not been specifically made in the mathematical modelling process.

Composition of the Seabed

Apart from the issue of seagrass coverage, the composition of the seabed in future scenarios is not expected to change from what it is currently. The size of sand on the beaches is also not expected to change. Nevertheless some modelling has been undertaken to check the sensitivity to different sand grain size should future beach replenishment campaigns be undertaken using a coarser sand than occurs naturally on the beach.

5.3.4 Results of Modelling

Figure 5.5 shows the results of the modelling undertaken to determine the longshore sediment transport potential for the Plus 20, Plus 50 and Plus 100 Year Scenarios.

Figure 5.6 shows the plan alignment of the beach (ie. the “*beach angle*”) adopted for each site under each scenario. The present day conditions are shown for comparison on both plots. The beach angle adopted for the coastline from Kingston Park up to Semaphore is the same for all of the future scenarios and corresponds to the beach angle used for the present day scenario. North of Semaphore, the beach angles change to accommodate the change in beach position and the realignment of the coastline caused by the on-going accretion in this area.

The results of the modelling are now discussed in relation to separate coastal precincts.

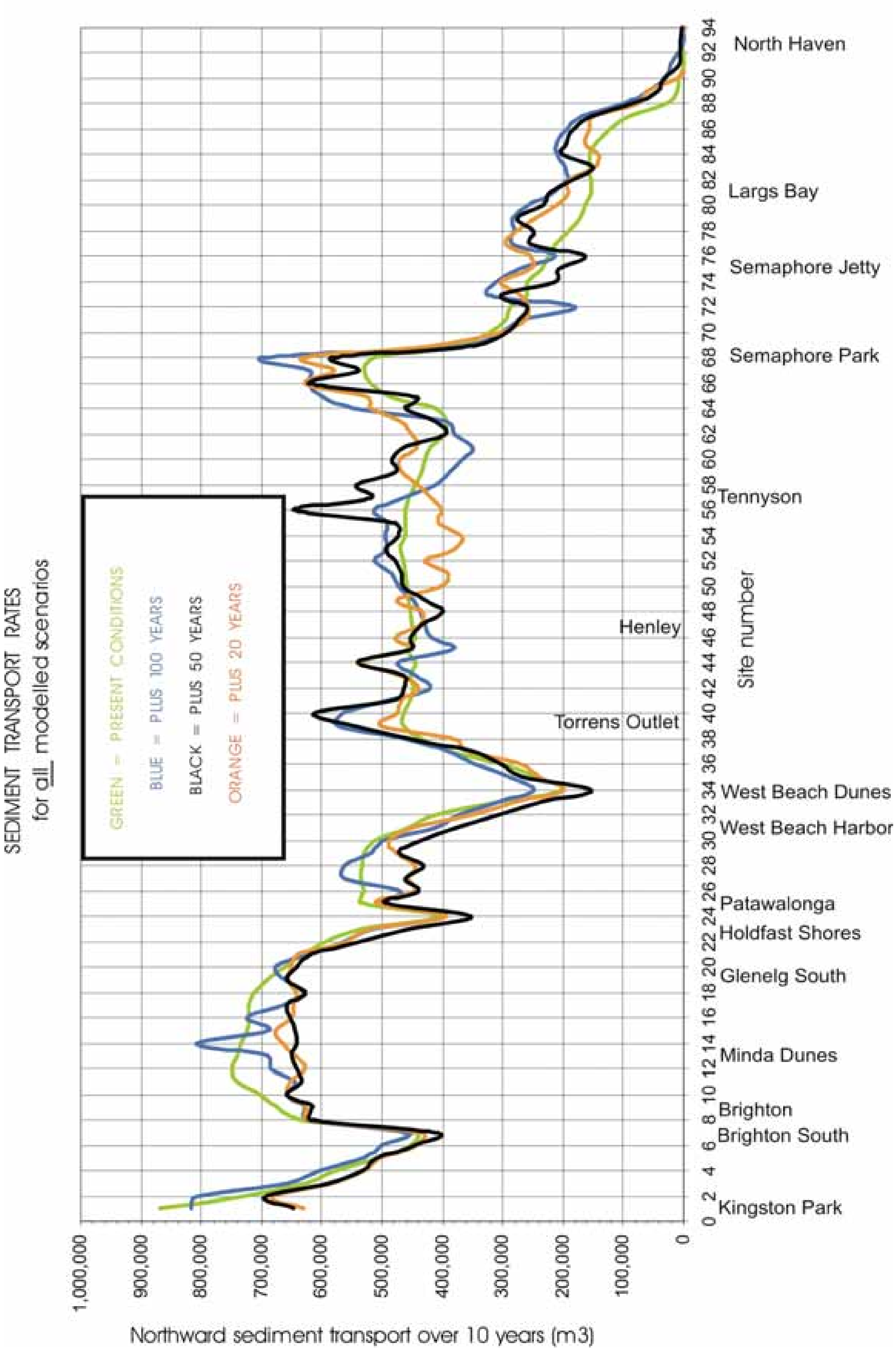


FIGURE 5.5: Longshore transport potentials for future scenarios

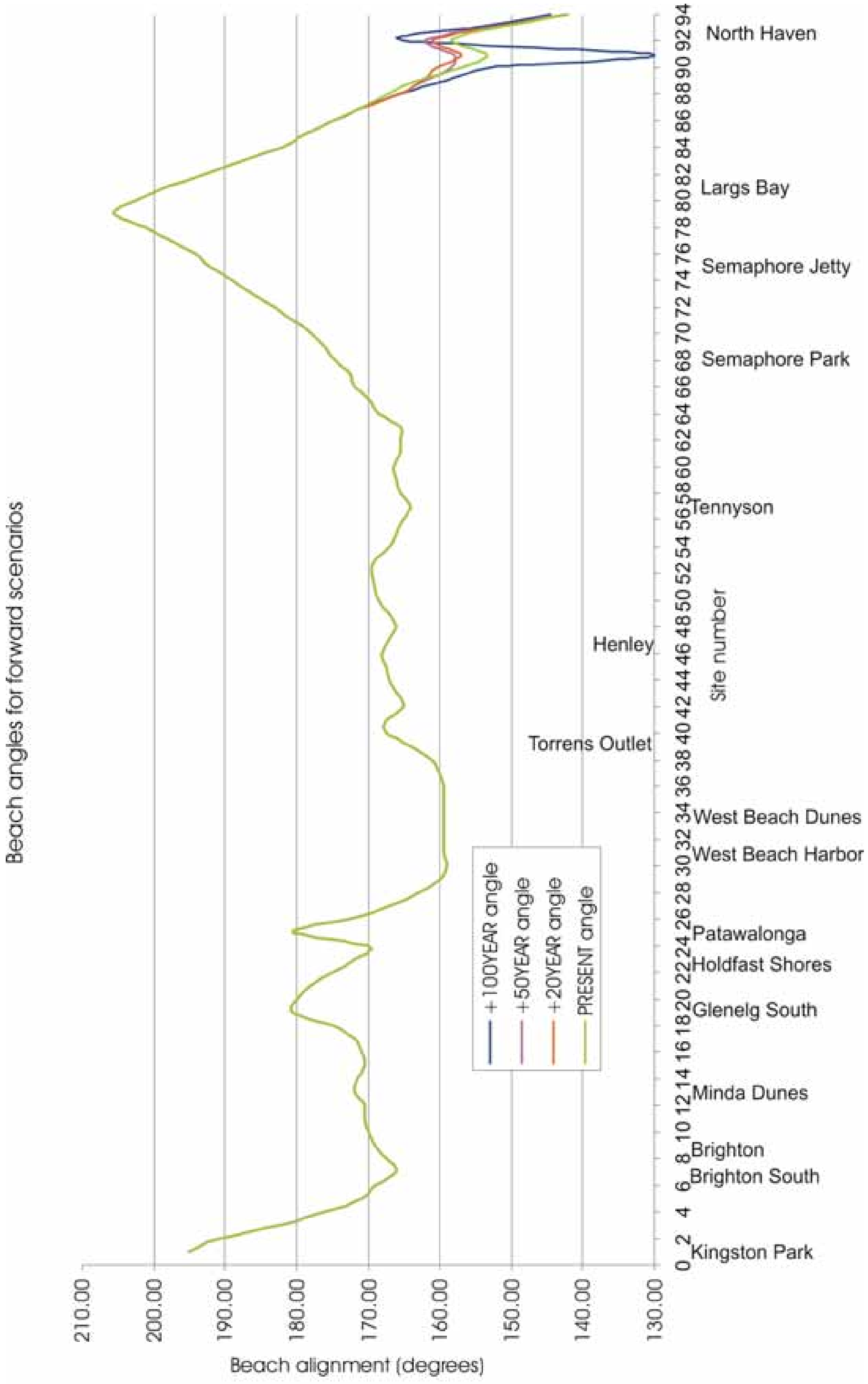


FIGURE 5.6: Beach angles adopted for modelling of future scenarios

Kingston Park to Brighton Jetty (Sites 1 to 8) – Figure 5.7

The slight increases in water level associated with the Plus 20 Year and the Plus 50 Year Scenarios appear to result in slightly reduced wave energy and therefore small reductions in longshore transport potentials to the north. Other than at Sites 1 and 2 (which may be affected by the assumptions that had to be made regarding local nearshore bathymetry), the reductions are less than 5%. There is no significant difference between the Plus 20 and Plus 50 Year Scenarios.

For the Plus 100 Year Scenario, the trend reverses and the sediment transport increases by up to 5%. For this scenario the increase in sea level is 0.5 metres (compared to present day levels). The inference is that the small increases in water level of 0.1 to 0.2 metres (for the Plus 20 and Plus 50 Year Scenarios respectively) result in a greater attenuation of wave energy as a consequence of refraction effects. However, the larger increase in water level for the Plus 100 Year Scenario reduces the attenuation - due to there being less effects of seabed friction in the deeper water.

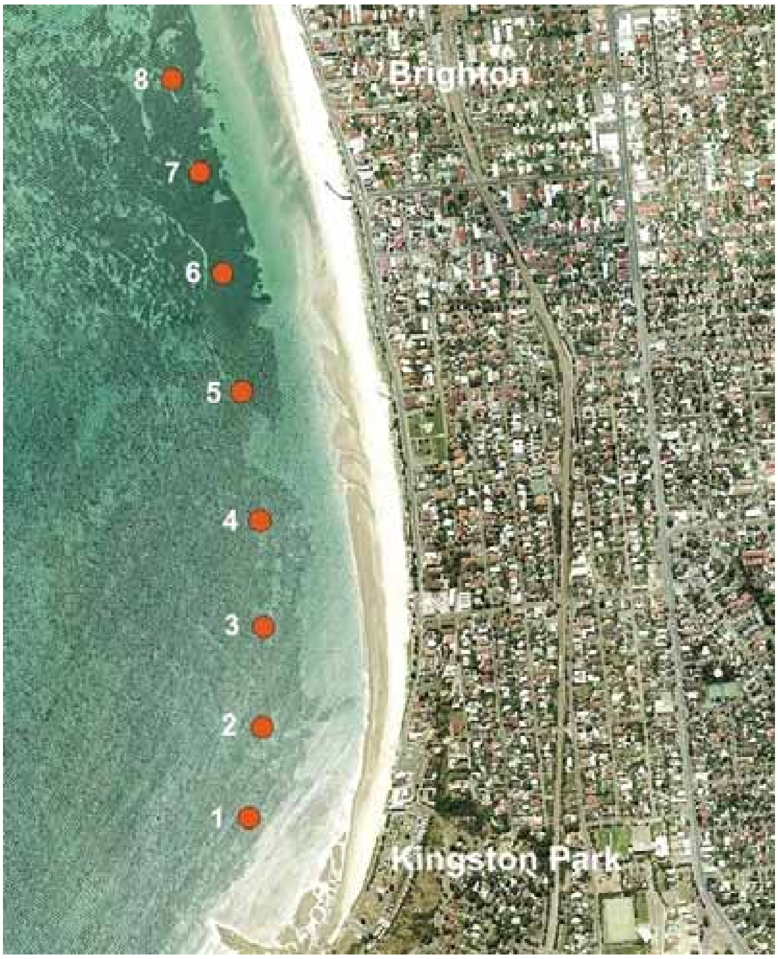


FIGURE 5.7: Kingston Park to Brighton Jetty modelling sites

Brighton Jetty to Broadway / Glenelg (Sites 9 to 20) – Figure 5.8

There are again reductions in sediment transport potential for the Plus 20 Year and the Plus 50 Year Scenarios. The reductions are some 10% to 15% when compared to present day conditions.

Nevertheless, the sediment transport potentials are still quite high at about 65,000 cubic metres per year. Therefore the longshore transport rate is still more than sufficient to supply the northern beaches, provided the strategy of beach replenishment at Brighton is continued. Note that the only difference between the conditions affecting these two scenarios is the 0.1 and 0.2 metre increase in the respective sea levels. The reduction in sediment transport rate appears to result from slightly changed wave refraction due to the greater water depth over the seabed approaches. The changed net transport rate is also due to the amount of swell wave energy propagating to this coastal reach through Backstairs Passage. It is significantly greater for present day conditions than for the Plus 20 and Plus 50 Year Scenarios.

For the Plus 100 Year Scenario, the sediment transport capacity along this segment of coast appears to fluctuate, but the average rate is still slightly less than for present day conditions. The variability in the sediment transport potential is primarily due to the changes in how swell waves refract as they propagate to the beach with the increased sea level. These changes occur because the seabed contours near the shoreline (ie. in 3 to 6 metre depths) tend not to be parallel to the coast, but rather have a gentle sinusoidal plan-form. This can be seen by reference to the 3 and 5 metre depth contours presented on Figure 4.8. The long period swell waves are affected quite markedly by the 0.5 metre water level increase over this type of seabed feature.

Despite the apparent fluctuation in sediment transport along this particular coastal reach, the sediment transport processes would be “smoothed out” along the beach - much as they are now. In other words, there is not expected to be a corresponding sinusoidal plan-form resulting on the beach. Nevertheless, it is apparent that the sediment transport potential will peak around site 14 (just north of Minda Dune). The beach to the north of Minda dune is narrow. Re-alignment of the beach to smooth out the sediment transport potential is not possible because of the presence of the seawall. Re-alignment would only be possible if there was a general beach replenishment which widened the beach and provided space for the beach to rotate.

In conclusion, the future year scenarios are not expected to significantly increase the sediment transport potential along this coastal precinct. In the short term, it is expected that there would be a reduction in the rate by about 10% and this reduction would ease to about 5% in 100 years time. This all assumes that the seagrass meadows maintain their current form.

FIGURE 5.8: Brighton Jetty to Glenelg South modelling sites

Broadway to The Patawalonga (Sites 21 to 25) - Figure 5.9

The longshore sediment transport potential decreases slightly for all future scenarios compared to the present day situation. Along this coastal reach, the nearshore bathymetry is relatively smooth and it appears that the future increased sea levels will result in increased wave attenuation due to the slightly increased water depth.

Sand continues to be delivered to this area from the south at a rate of about 65,000 m^3/year, but because of the beach angle, which is controlled by The Patawalonga Training wall and the Holdfast Shores offshore breakwater, the sand is not moved northward by longshore transport. The scenario is therefore a continuation of the present day requirement for sand by –passing to North Glenelg and back-passing to Brighton.

FIGURE 5.9: Broadway to The Patawalonga modelling sites

Patawalonga to West Beach Harbor (Sites 26 to 30) - Figure 5.10

The trend in future sediment transport potential is very similar to that predicted for the Brighton to Broadway coastal reach, that is a 10% to 15% decrease in sediment transport rate in the short-term future, but increasing again for the Plus 100 Year Scenario. However this subsequent increase is not expected to exceed present day transport rates. Therefore the present sand management arrangements for by-passing The Patawalonga and West Beach Harbor would still be applicable in a 100 years time.

FIGURE 5.10: The Patawalonga to West Beach Harbor modelling sites

West Beach Boat Ramp North to Torrens Outlet South (Sites 31 to 38) - Figure 5.11

The reduction in sediment transport rate at West Beach Dunes (Site 34) which is attributable to the offshore shoal is still evident for all future scenarios. This is because it has been assumed that the relative height between the crest of the shoal and the surrounding seabed does not change significantly for future scenarios. There may in fact be some infilling of the troughs adjacent to the shoal and this would impact on the sediment transport rates.

The dip in longshore sediment transport at West Beach is evident for all scenarios and the explanatory comments of Section 5.1 apply.

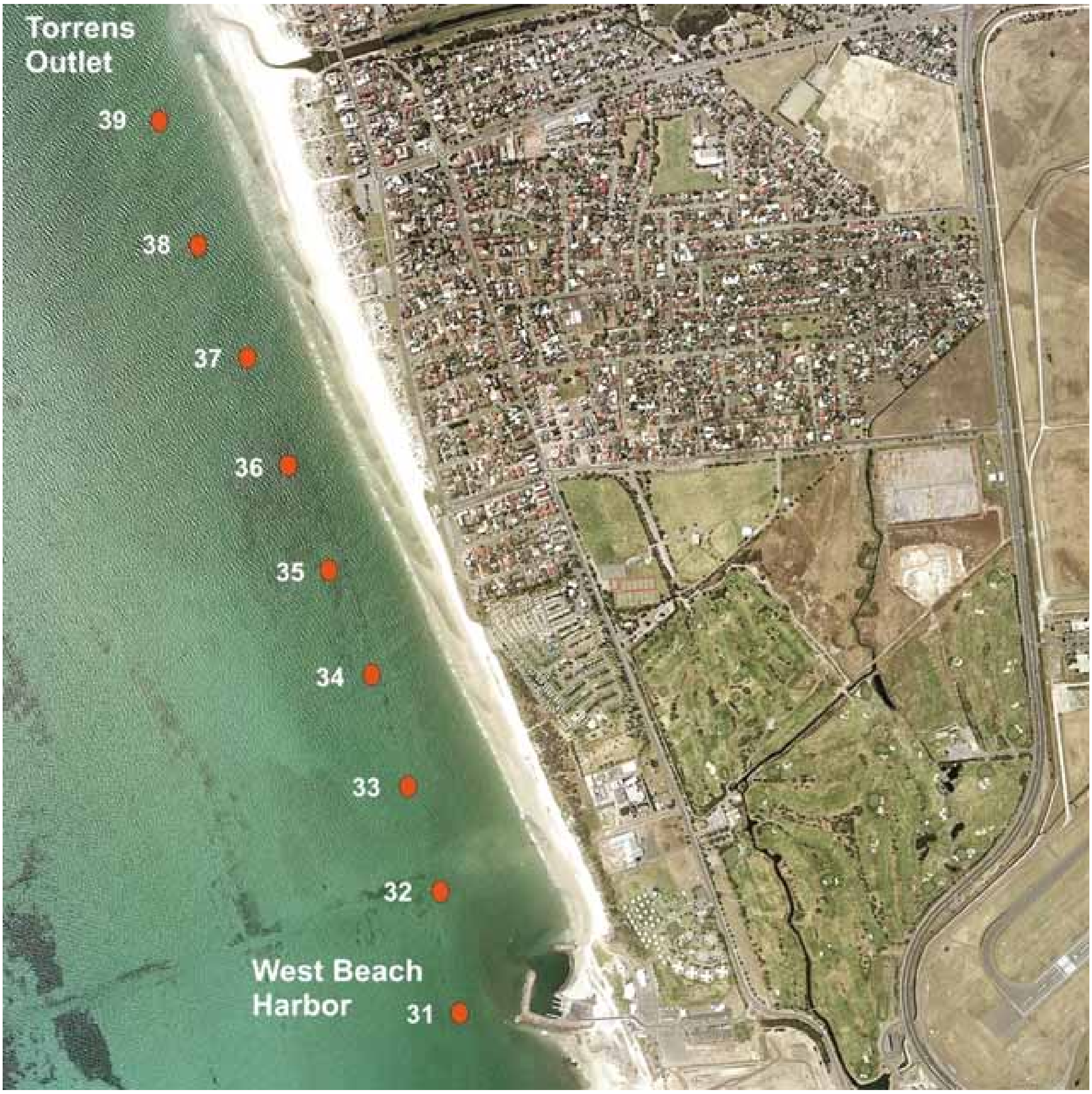


FIGURE 5.11: West Beach Harbor to the Torrens Outlet modelling sites

Torrens Outlet to Grange (Sites 39 to 50) - Figure 5.12

The sediment transport potential increases immediately to the north of the Torrens Outlet (Site 40) for all scenarios. The only changes in the modelling parameters relate to increased water levels and the results again highlight the potential sensitivity of longshore transport rates to small water level changes. This localised longshore sediment transport increase is likely to manifest itself as a realignment of the beach plan-form adjacent to the northern side of Torrens Outlet. The local dune width would reduce and the slight change in beach alignment would bring the longshore sediment transport back to the present day scenario. It is unlikely to produce erosion of beach width to cause concern, because the dune is presently quite wide.

FIGURE 5.12: Torrens Outlet to Grange modelling sites

The sediment transport potential develops small fluctuations northwards along this coastal reach. This would manifest itself in the form of small realignments in the plan-form of the beach, mainly around Site 44. It appears that there is sufficient sand in the beach system at this time to accommodate such a realignment in the future.

Grange to West Lakes (Sites 51 to 68) - Figures 5.13 and 5.14

Of the entire study area, it is this coastal reach which is expected to undergo the biggest changes to longshore sediment transport potential in the future. The predicted changes are quite variable, with no smooth trend into the future being evident.

FIGURE 5.13: Grange to Tennyson modelling sites

FIGURE 5.14: West Lakes to Semaphore Park modelling sites

The most significant changes are expected to occur between Grange and Tennyson (in the vicinity of Sites 54 to 56) and at West Lakes (at Sites 62 and 63). All of these changes can be attributed to the considerable sensitivity of swell waves to wave refraction in the nearshore zone - which in turn results from the strong sinusoidal shape of the nearshore contours offshore of an almost straight shoreline. A small difference in water level, as occurs for future scenarios, over such a varying bathymetry results in substantial changes to both the wave refraction coefficients and the angles at which the incoming waves arrive at their breaking point.

Considering the Plus 20 Year Scenario, and allowing for a small localised beach realignment to compensate for the sinusoidal sediment transport potential along the coast, the trend is for decreasing sediment transport potential from Site 50 to Site 54; and then increasing potential from Site 54 to Site 68. This implies that sediment will accumulate slowly on the foreshore between Sites 51 and 54, but erosion will start at Site 55 and continue all the way north to Semaphore Park (Site 68). By comparison, at present the erosion process is not initiated until around Site 65 (ie. at Semaphore Park).

Note that the offshore breakwater at Semaphore Park was not constructed when this study was undertaken so that the modelling did not include this feature.

For the Plus 50 Year Scenario, the area subjected to erosion and accretion differs somewhat - even once again allowing for a smoothing out of the small fluctuations in the sediment transport potential by beach realignment. There is a peak in the sediment transport potential at Sites 56 and 66; and a minimum at Site 62. This implies that:

- The shoreline between Sites 50 and 56 will erode in response to the increasing sediment transport along this segment of shoreline.
- The shoreline will accrete between sites 57 and 62.
- The erosion trend would continue to increase at Semaphore Park in the absence of the offshore breakwater. However, the offshore breakwater will result in accretion until a new stable alignment is reached.

For the Plus 100 Year Scenario, the sections of foreshore variously affected by erosion and accretion revert to much as they are at present. However the maximums and minimums in the sediment transport potential along this coastal reach are more pronounced (ie. the various peaks and troughs evident in the graphical presentation on Figure 5.5 are more prominent). This implies that the erosion (particularly at Semaphore Park) would be more severe than at present.

The modelling indicates that some 50,000 to 55,000 cubic metres of sand is currently being transported northward from Semaphore Park each year. For the Plus 100 Year Scenario, this is expected to increase to around 60,000 to 70,000 cubic metres. These changes are primarily due to rising sea level and the further lowering / scouring of the seabed in those areas of recent seagrass loss. The areas of existing seagrass meadows themselves have not been changed when considering future scenarios.

Semaphore Park to Semaphore South (Sites 69 to 70) - Figure 5.15

There is little apparent change in sediment transport potential for all future scenarios between the Semaphore Park erosion precinct to the accretionary shoreline at Semaphore, excluding the influence of the offshore breakwater which is being constructed off Semaphore Park near site 70. The influence of the breakwater will result in a reduction in the wide dune width at occurs north of Bower Road.

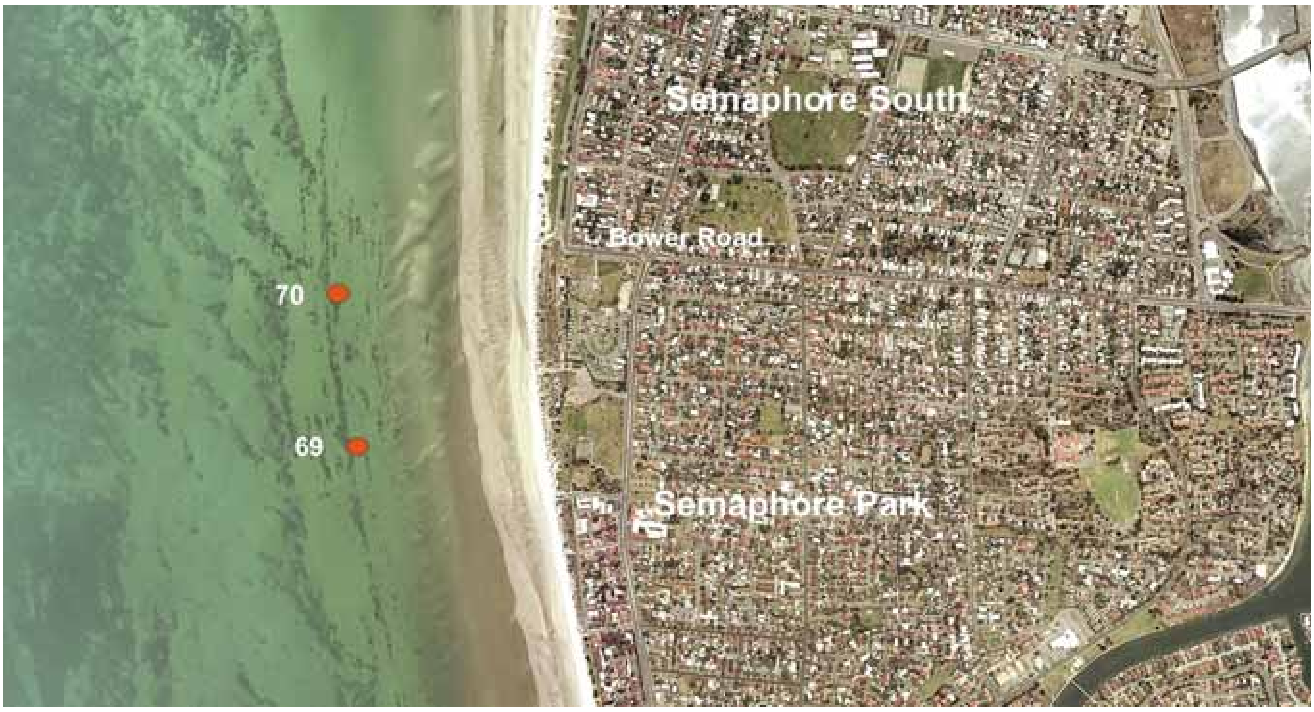


FIGURE 5.15: Semaphore Park to Semaphore South modelling sites

Semaphore South to North Haven (Sites 71 to 91) - Figure 5.16

The fluctuations in the sediment transport potential that are predicted along this coastal reach are expected to result in localised and minor beach alignment changes. The modelling indicates that there is expected to be an increase in sediment transport potential for all future scenarios. However since this is an accretionary foreshore, the scale of the increase should not cause concerns about excessive erosion. Provided sand supply continues past Semaphore Park, once the beach created by the offshore breakwater has filled, the shoreline between Semaphore and North Haven would continue to accrete at a rate of up to 0.5 metres per year.

FIGURE 5.16: **Semaphore South to North Haven modelling sites**

North Haven to Outer Harbor Breakwater (Sites 92 to 94) - Figure 5.17

The beach between North Haven and the Outer Harbor breakwater has been considered as a pocket beach which receives no sand from outside sources. Negligible changes are expected along this beach for future scenarios.

FIGURE 5.17: North Haven to Outer Harbor modelling sites

5.4 Replenishment at Hallett Cove

As a result of the prevailing sea and swell wave conditions, there is a net northward movement of sand along Adelaide's beaches. Very little sand enters this beach system from the south. This deficiency in supply from the south, combined with the net northward drift, has contributed considerably to the recession of the downdrift Adelaide beaches. This foreshore has been experiencing steady ongoing erosion since ocean levels stabilised some 4,000 years ago.

Over the years, the strategy of placing a "reservoir" of sand in the vicinity of Hallett Cove (south of Adelaide's metropolitan beaches) has been proposed. The objective being that sand from this reservoir would be transported northward by the prevailing littoral drift onto the beaches of Adelaide, thereby mitigating the erosion caused by a deficiency in sand supply from the south. Some comments regarding this concept of a "feeder beach" at Hallett Cove can be offered as a result of the mathematical modelling undertaken for this study.

Hallett Cove is about 5 kilometres south of Site 1 at Kingston Park. As can be seen in Figure 5.18, the foreshore is composed primarily of a shingle/cobble beach.

FIGURE 5.18: Hallett Cove Foreshore

The longshore sediment transport potential for a sandy beach at this location has been modelled and determined to be in excess of 100,000 cubic metres per year. This suggests that:

- Should a reservoir of sand be placed at Hallett Cove, longshore sediment transport processes would indeed feed the sand towards Adelaide's beaches.
- However, the placed sand would be quickly moved off the Hallett Cove feeder beach (at a rate of at least 100,000 cubic metres per year), and transported alongshore towards the southern metropolitan beaches.
- A significant quantity of sand would need to be placed in the Hallett Cove feeder beach so as to offer several years of sand reserves prior to having to re-charge the replenishment area. Alternatively an annual campaign of placing at least 100,000 cubic metres of sand into the Hallett Cove feeder beach would be necessary.

- Either way of beach nourishment at Hallett Cove would result in a transient beach at Hallett Cove and the end product before a new beach renourishment campaign would be a shingle beach for much of the foreshore. Beach nourishment at Hallett Cove should be considered if it is considerably cheaper to place sand there than at Brighton. However, if costs are similar for renourishment at both locations it is suggested that the sand should be placed at Brighton. Creating a temporary beach at Hallett Cove may raise the public expectation that there should be a beach there all of the time.
- The 100,000 cubic metres yearly rate of sand supply to the southern reaches of the Adelaide beach system is greater than the rate at which sand moves along those beaches. Consequently there would be a transient accumulation of sand at Kingston Park and Brighton South, at least until such time as the sand supply from Hallett Cove ceased. This accumulation would spill over on to the seagrass meadows and may suffocate them. In addition sand would be “lost” from the beach system because the seagrass would catch the sand.
- There is a risk that sand maybe lost from the supply due to the steep nearshore seabed which exists between Hallett Cove and Kingston Park. Offshore sand movement during storms may take sand from this sediment pathway into deeper water, where it might no longer be re-mobilised and subsequently moved back onshore by ambient waves. There is no detailed bathymetry off Hallett Cove or for the foreshore between Hallett Cove and Kingston Park. The model SBEACH has been used with the limited bathymetric data which is available to model offshore sand movement during storms. The results imply that there would not be significant offshore sand losses – but this is a tentative conclusion because of the sparsity of the bathymetric data.

5.5 Offshore Sediment Transport

Figures 5.19 to 5.28 show the results of the SBEACH modelling undertaken for ten locations between Brighton and Semaphore Jetty. Each plot shows how the local beach would have responded to each of the eight severe storms that occurred between 1948 and 2002. For the purposes of modelling beach response, the profile surveyed at each site in 1999 was selected as that occurring prior to the onset of each storm.

The term “storm bite” is used to describe the sand cut out of the beach dune system during a storm. That is, the difference in the volume of sand on the beach before and after the storm. Two definitions of the storm bite appear to be appropriate at Adelaide:

1 The cross-sectional area of the eroded portion of the beach

2 The cross-sectional area above a nominated level. The Coastal Protection Branch use the volume of sand above the +1m AHD level that is available for erosion – that is, the allowable storm bite.

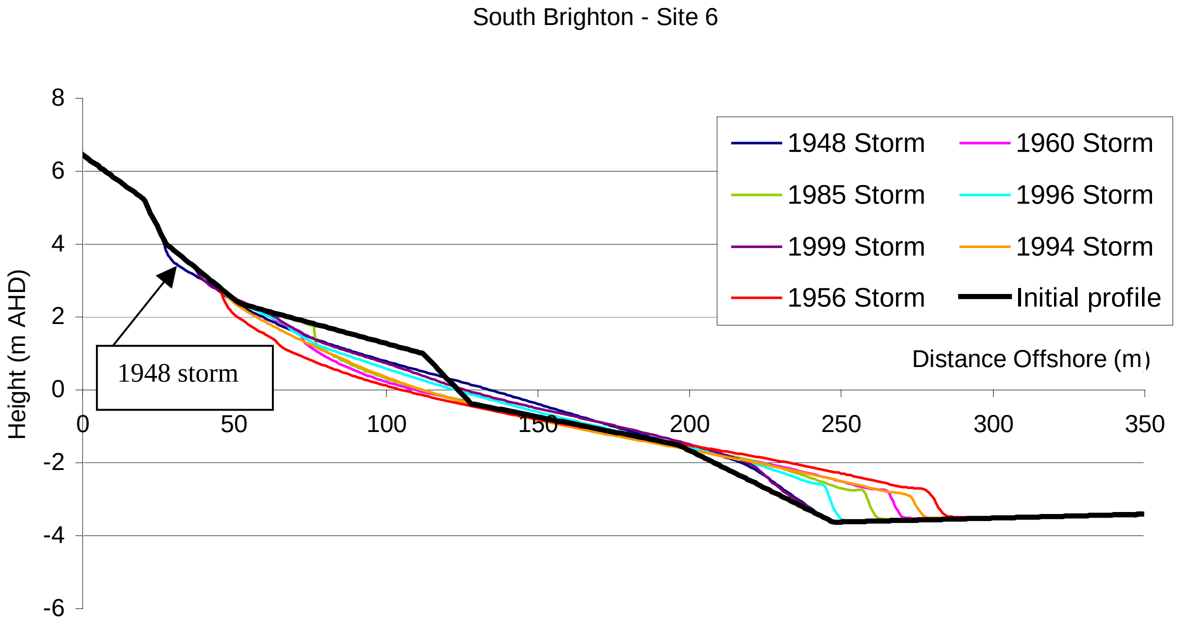


FIGURE 5.19: Brighton South offshore sand movement during storms

The following features can be noted in Figure 5.19:

- The initial profile at South Brighton represents a replenished beach with a berm of sand between 50 and 130 metres offshore. The seabed then slopes at about 1:60 to 200 metres offshore and then steepens to 1:25 to 240 metres offshore. The seabed is then relatively flat for the next 100 metres.
- The 1948 storm does not produce a large erosion "bite", but because of high water levels associated with the storm, it produced the highest cut into the dune of all of the storms. The storm was of short duration.

- The largest volumetric cut of the dune/berm was caused by the 1956 storm, followed in severity by the 1994 storm. These were both long duration storms. The volume of material eroded from the dune/berm during the 1956 storm is about 55m^3 per metre length of beach. The volume of sand eroded from above the +1m AHD level is about 50% of the total eroded volume. This applies for all beaches for the severe storm scenario.
- Most of the sand eroded from the dune/berm is transported offshore to where the water depth is 2 metres or greater.

The profile at South Brighton is typical of a replenished beach where sand has been placed on the beach at or above low water level. The sand that is moved offshore during a storm would then be slowly moved back onshore ad northward by the persistent background swell. Note that the initial (1999) profile is an ambient profile rather than a storm profile. The 1999 storm was one of the milder storms and it would have caused very little offshore movement.

At Brighton (Figure 5.20) the profile features are:

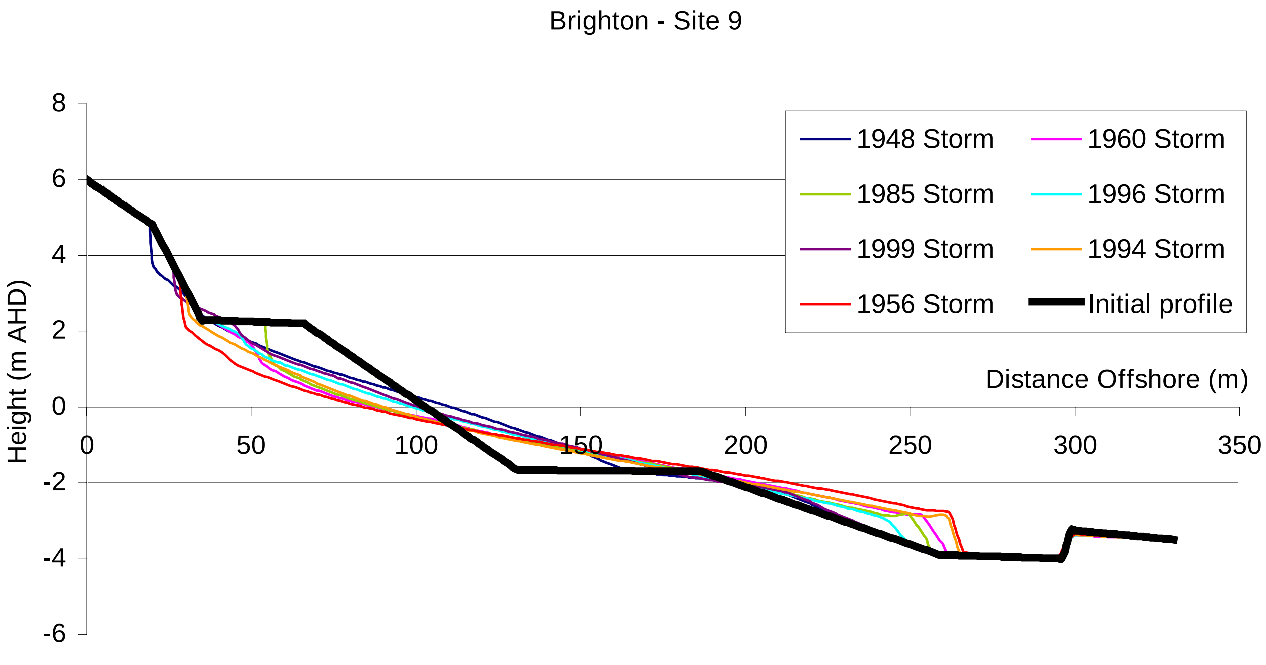


FIGURE 5.20: Brighton offshore sand movement during storms

- A replenished beach with a berm width of about 30 metres was captured in the 1999 survey. The beach sloped offshore from the berm to the level of low water datum at 1:17. This is a relatively steep slope for Adelaide beaches, since the natural sand tends to have a grain size of about 0.22mm. However it is apparent from records that when the replenishment took place, the sand exhibited a bi-model size distribution. The larger D_{50} sand size being about 0.45mm. This coarser sand fraction would stand at slopes of 1:10 to 1:20. The inference is that sand placed on the beach face during beach replenishment has been subsequently sorted by waves - leaving generally coarser sand.

- Further offshore the initial beach profile is similar to that at South Brighton, except that there is a depression between 260 and 290 metres offshore. This corresponds with the bare seabed area at the end of Brighton Jetty. The higher level at about 300 metres offshore represents intact seagrass coverage.
- The 1948 storm does not produce a large erosion “bite”, but because of the high water levels associated with the storm, of all the storms it was the one that produced the highest level of cut into the dune.
- The largest volumetric cut of the dune/berm was caused by the 1956 storm, followed by the 1994 storm. These were both long duration storms. The volume of material eroded from the dune/berm during the 1956 storm is about $80m^3$ per metre length of beach assuming that the median sand size is 0.22 mm. However, the steeper beach slope from the 1999 survey suggests that the sand may be coarser. For a sand with D_{50} = 0.45mm the expected eroded volume reduces to about $60m^3$. Since the sand in the berm is most likely to be bi-modal if it has not been reworked by waves, the most likely erosion volume would be about 70 m^3 per metre length of beach.
- About 50% of the eroded sand moves offshore by a distance of about 50 metres, thereby filling the depression between the beach and the offshore sloped seabed. The balance of the sand eroded from the dune/berm is transported offshore to a water depth of around 2 metres or greater.

At Minda Dune (Figure 5.21) the profile features are:

- A high dune exists and there is not a well defined beach berm in front of the dune. The beach slope above mean sea level is 1:60 which then steepens to 1:20 further offshore to the level of the lowest tide. Further seaward there is a small bar before the seabed again slopes at about 1:20 to the –3.0m AHD level (about 1.5 m below lowest water level). A shallow trough occurs seaward of the beach slope before the seabed level rises again slightly. The rise corresponds to the start of the seagrass meadow.
- For a narrow beach backed by a dune, the 1948 storm does produce a large erosion “bite” from the dune, but because of the short duration of the storm, the eroded sand from the dune does not move very far seaward. The width of dune eroded is some 4 metres more than for the 1956 storm. The volume of sand eroded is about 45 m^3 per metre length of beach.
- However, the 1956 and 1994 storms still erode the largest volume of sand from the dune/beach system; namely $65m^3$ per metre length of beach. The sand in the dune system is fine grained and so there is unlikely to be any reduction in eroded volume due to the presence of a coarser sand fraction.
- The 1994 storm moves the sand further seaward than the 1956 storm. In the relatively shallow water where the sand is deposited it is expected that the underlying swell would slowly return the sand to the beach.

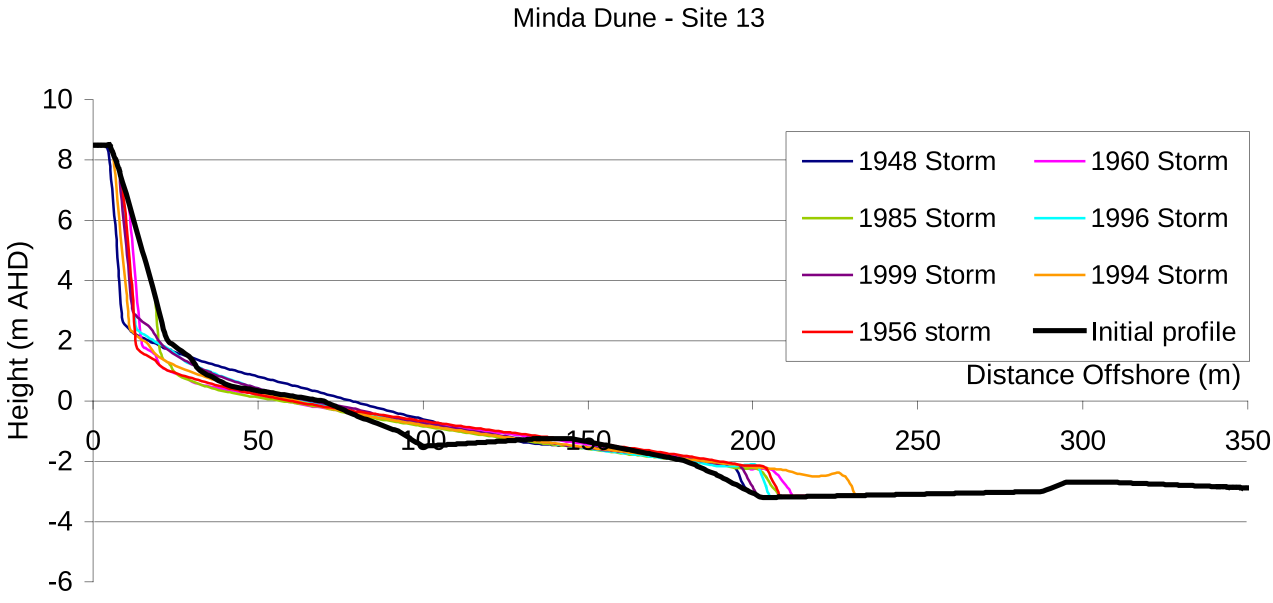


FIGURE 5.21: **Minda Dune offshore sand movement during storms**

At Glenelg Jetty (Figure 5.22) the profile features are:

- A nearly vertical seawall, in front of which there is a beach berm about 25 metres wide. The beach slopes away from the berm at 1:30 down to low water mark. There is a steep drop off (1:15) from low water to the –3.5m AHD level from where the seabed slopes gently seaward.
- None of the modeled storms erode the beach back to the seawall; and as is the case for all other locations, the 1948 storm cuts the beach berm back the furthest.
- The largest volumetric cut of the beach berm and beach was caused by the 1956 storm, followed by the 1960 and 1994 storms. These were all long duration storms. The volume of material eroded from the dune/berm for the 1956 storm is about 65m^3 per metre length of beach - assuming that the median sand size is 0.22 mm.
- All of the eroded sand moves offshore into deeper water. It is expected that the underlying swell would slowly return the sand to the beach.

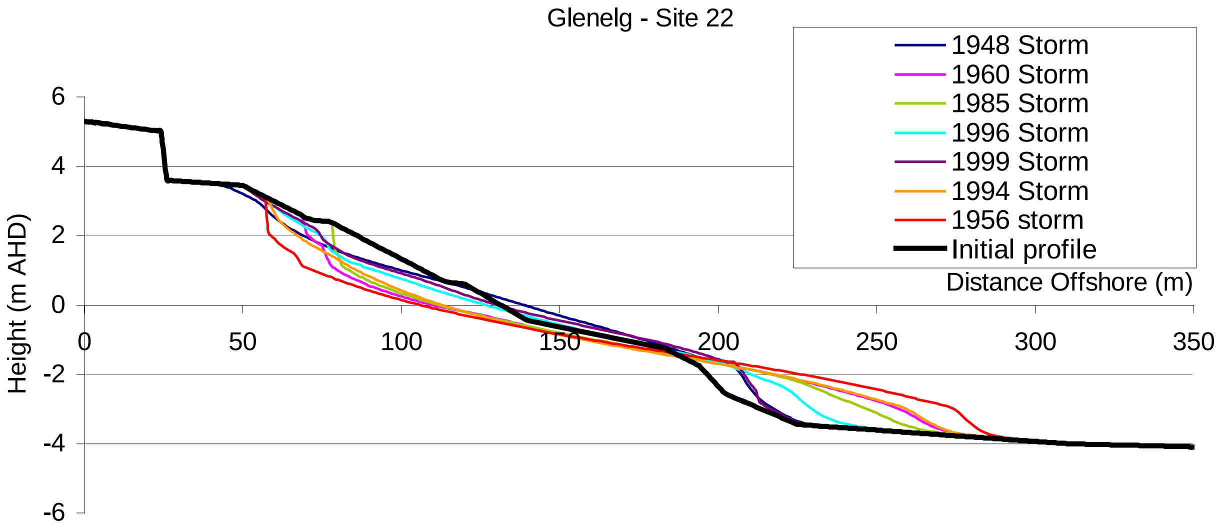


FIGURE 5.22: Glenelg offshore sand movement during storms

At West Beach dune (Figure 5.23) the profile features are:

- The dune is very high in comparison to other locations along the Adelaide foreshore. The dune has a crest elevation of about +12m AHD.
- The beach slope from the toe of the dune to below low water mark is fairly constant at 1:30. The seabed slope then flattens out for about 70 metres before resuming a gentler slope.
- Again the 1948 storm induces the highest storm cut along the dune, but the largest volume of sand eroded from the dune and beach would have occurred during the 1956 storm, some 70m^3 per metre length of shoreline.

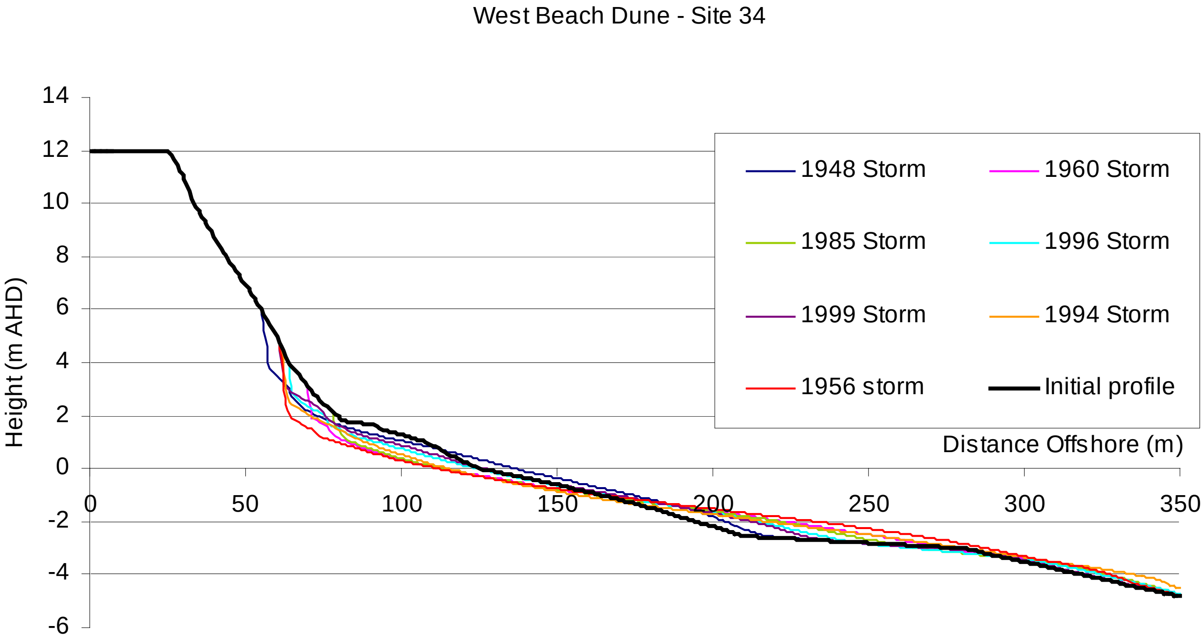


FIGURE 5.23: West Beach dune offshore sand movement during storms

South of Torrens Outlet there is a 6 metre high dune which has built up since the outlet was opened. In Figure 5.24 the profile features are:

- The dune is about 50 metres wide at the level of 6 metres AHD. There is then a berm about 20 metres wide from which the beach slopes quite steeply at 1:15 to just above low water mark. The reason for the steep beach slope must relate to the blocking effect that the Torrens Outlet has on northward longshore transport. Then there is another nearly horizontal segment about 60 metres wide followed by a seabed slope of about 1:20 down to a level of –4m AHD. The seabed slope then flattens out to about 1:50.
- The 1948 storm provides the highest storm cut into the dune. All of the storms effectively wipe out the stepped beach berm profile. This occurs because the offshore sediment transport model does not include **any cross-shore** component. In a real storm situation, particularly if the storm is from the south-west, it is expected that the stepped berm would be only partially smoothed out because longshore transport from the south would replace some of the sand removed to offshore bars.
- The volume of sand eroded for the 1956 storm would have been about 90m^3 per metre length of beach. The probable reason why the erosion volume for this beach is higher than all the beaches to the south is the presence of deeper water closer to shore and the steeper beach slope which allows approaching waves to shoal, resulting in larger waves reaching the dune.

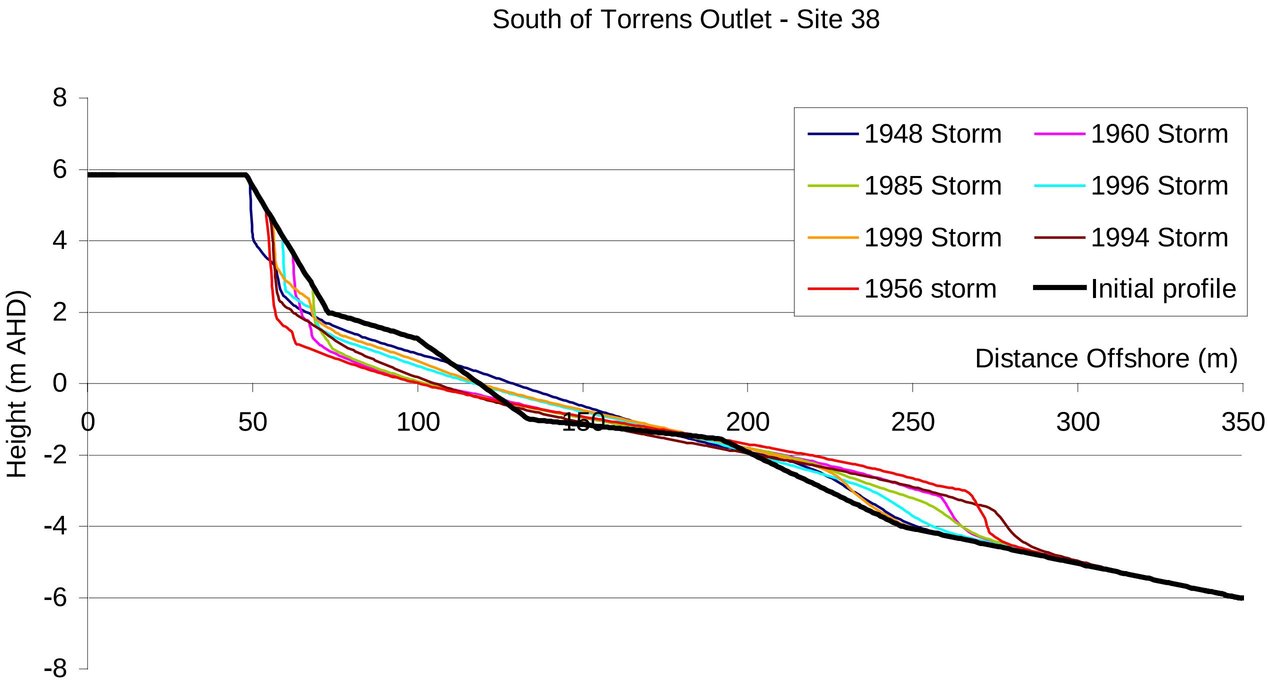


FIGURE 5.24: South of Torrens Outlet offshore sand movement during storms

Figure 5.25 shows the beach profile performance at Tennyson:

- The beach profile contains two bar features at about 120 metres and 220 metres offshore. The nearshore beach profile, within the tidal range, has a slope of about 1:20. The beach slope seaward of the first bar is 1:40. Further offshore the beach slopes are flatter.
- The 1948 storm, would have eroded the full width of the high berm on the front face of the dune.
- The significant difference at Tennyson (in comparison to more southerly sites) is that sand moved offshore during the storm tends to fill in the swales between the bars rather than all moving offshore. This probably occurs because of the gentle slope of the offshore profile, which results in more wave energy losses than for a steep foreshore slope.
- The volume of sand eroded for the 1956 storm would have been about 45m^3 per metre length of beach. This volume is less than for beaches further to the south and can be attributed to the more gentle offshore seabed slope.

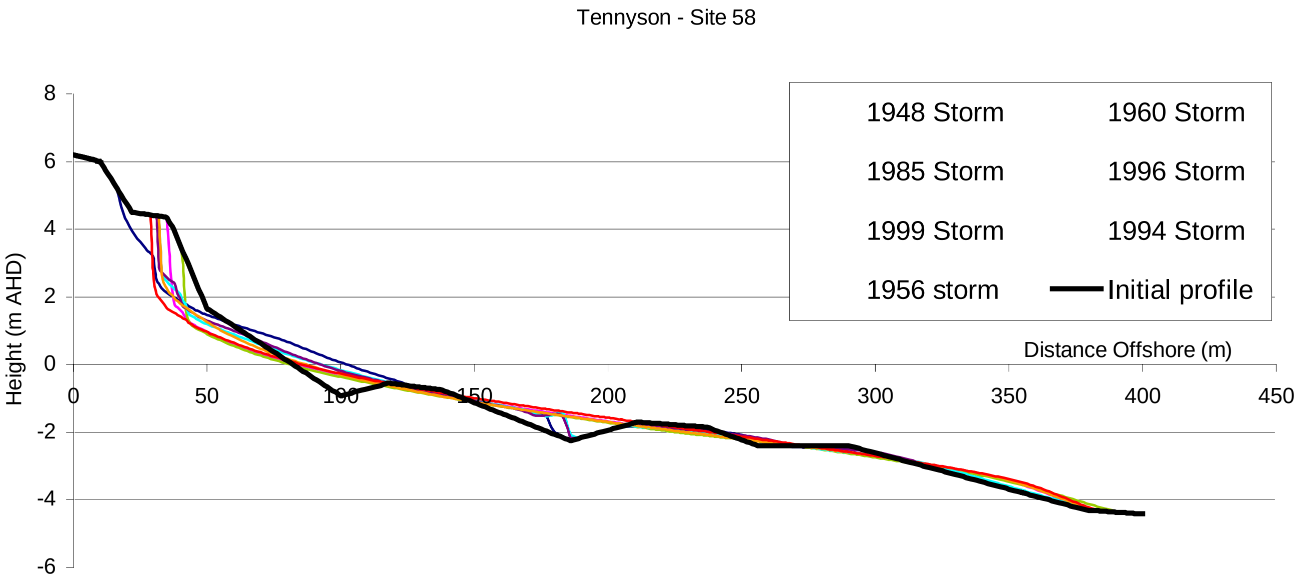


FIGURE 5.25: Tennyson offshore sand movement during storms

Figure 5.26 shows the beach profile features at Tennyson dunes:

- The dune is not as high as the dunes at Minda, West Beach and the Torrens Outlet.
- The beach profile again contains two bar features. The nearshore beach profile, within the tidal range, has a slope of about 1:20. The beach flattens below low water to about 1:55 out to the first nearshore sand bar. Seaward of the first bar the slope is 1:30. Further offshore the beach slopes are flatter.
- The 1948 storm totally removed the foredune and started to erode the primary dune because of the high water levels that occurred during the storm.
- The sand eroded from the dune system performs in a similar manner as at Tennyson and does not move offshore into deep water.
- The volume of sand eroded during the 1956 storm is 40m^3 per metre length of beach, again a smaller quantity than for the southern beaches, due to the gentle offshore beach slope.

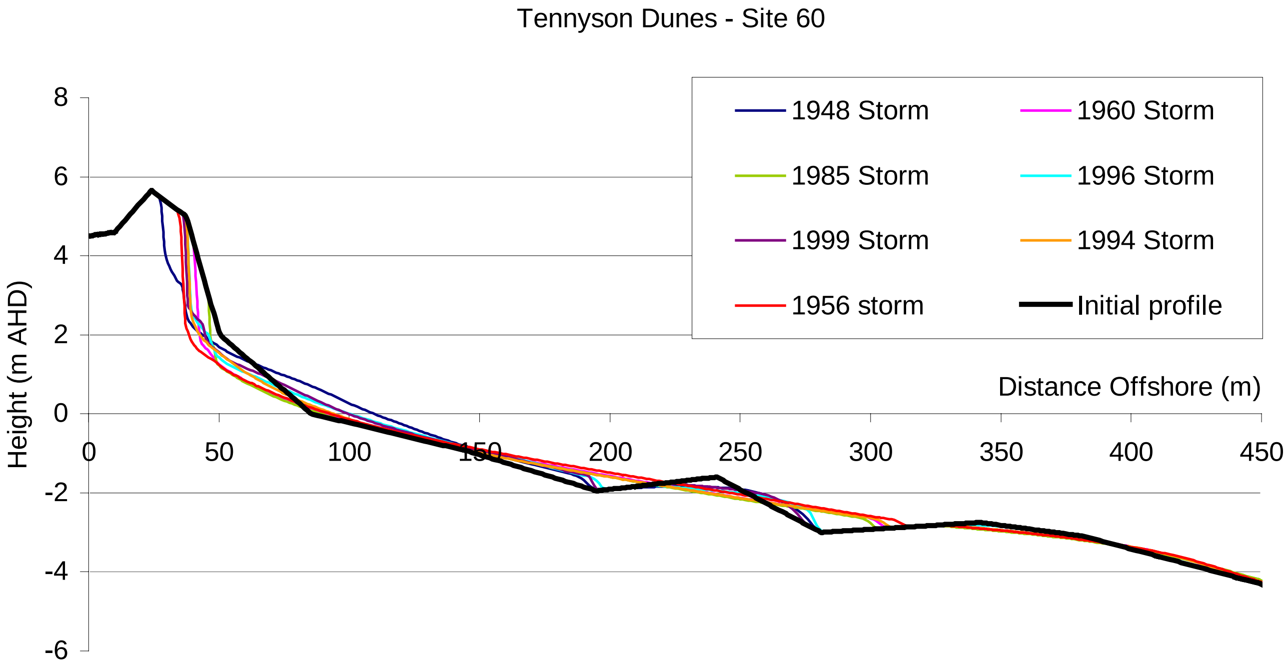


FIGURE 5.26: Tennyson Dunes offshore sand movement during storms

Figure 5.27 shows the beach profile features at Tingira Place, Semaphore Park:

- The dune is about 6 metres high and the beach profile has a similar form to Tennyson - except that there are more bars and the overall beach slope is flatter.
- The 1948 storm has the highest cut in the dune, but the volume of sand eroded from the dune and beach and moved offshore is only about 35m^3 per metre of beach for both the 1956 and 1994 storms.
- The sand eroded from the dune does not move offshore to any great extent, but rather fills the swales between the nearshore bars.
- The recent erosion history at Semaphore Park is due to the imbalance in longshore sediment transport past Semaphore Park rather than offshore movement of sand during storms.

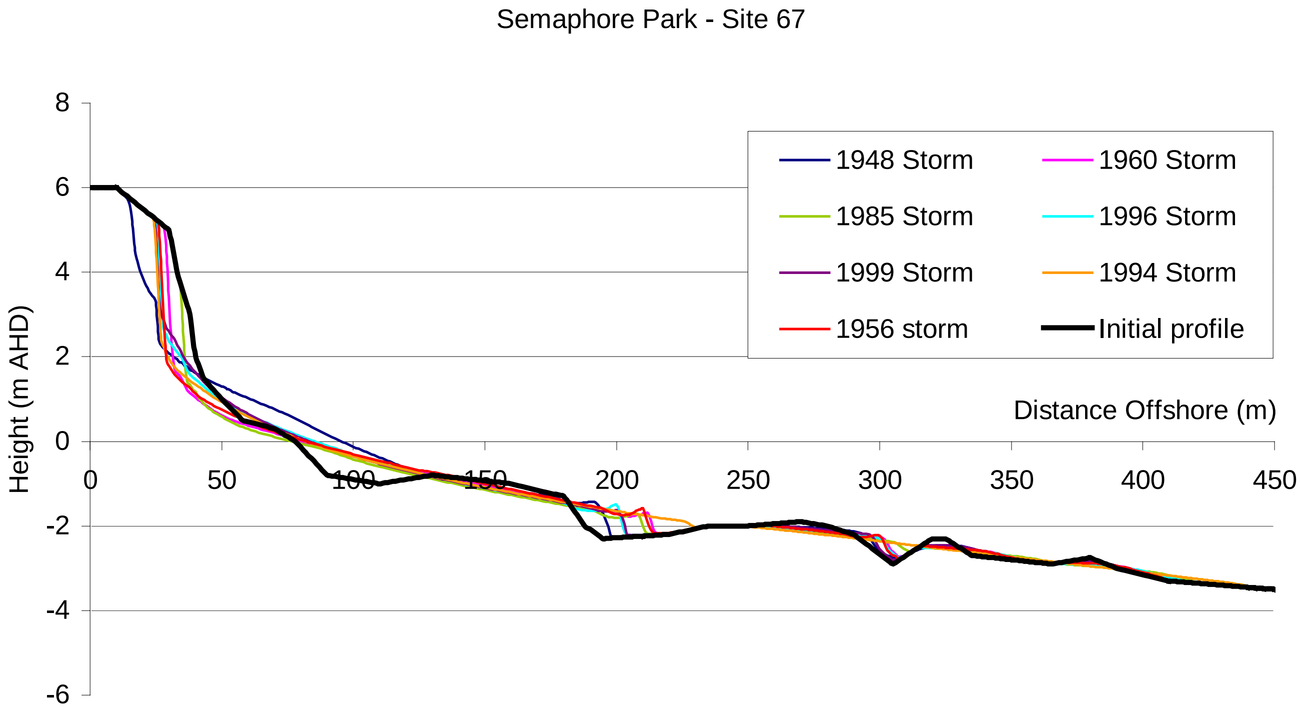


FIGURE 5.27: Semaphore Park offshore sand movement during storms

Finally, Figure 5.28 shows the beach profile features at Semaphore Jetty, where sand accretion is active due to longshore sediment transport supply:

- There is a wide, but low dune system that has accreted 100 to 150 metres in width over the last 80 years.
- The 1948 storm has the highest cut in the dune, but the height of the cut is at less than +3m AHD.
- The volume of sand eroded from the dune and beach and moved offshore is only about 25m^3 per metre of beach for the 1956 storm, which was the most severe event.
- The reason for the relatively low rate of erosion is the wide, shallow offshore sand bank system which significantly attenuates waves before they reach the dunes.
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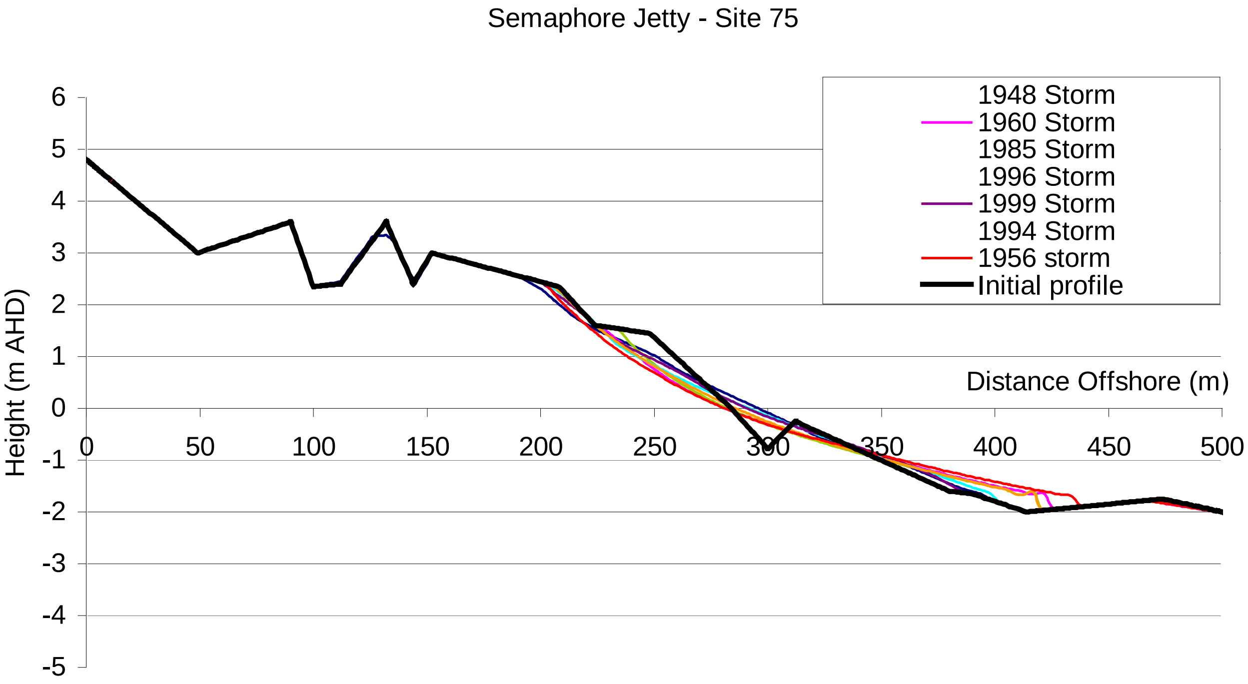

FIGURE 5.28: Semaphore Jetty offshore sand movement during storms

5.6 Effect of Steady Currents

As part of the Coastal Engineering Solutions (2000) study for Semaphore Park, some current measurements were also made between Kingston Park and Semaphore Park. The following current trends can be deduced from those measurements:

- Off Semaphore Park, the strength of the flood tide current peaks at 0.24m/s and the ebb tide peaks at 0.28m/s. This implies that the influence of tide alone results in a slight net southward passage past Semaphore Park.
- The same structure of tidal currents was apparent between Semaphore Park and Kingston Park.
- Winds from the south-west sector with a speed of 15 to 25 knots generated currents with a speed of 0.1 to 0.15 m/s. This current was superimposed on the tidal current.
- The depth-averaged current (parallel to the shoreline) generated by the wind was about 1.5% of the wind speed.

Neither the wind-generated current nor the tidal-generated current will initiate sediment movement on the seabed offshore from Adelaide's beaches. The combined current initiated by a 20 knot wind in conjunction with the tide could initiate sediment transport provided the currents were both in the same direction. Moderate sea wave conditions will lead to the suspension of sediments and their subsequent transport by tidal or wind set currents.

The ratio of southward to northward sediment transport caused by seas generated in Gulf St Vincent varies in the range of 10% to 25%. This implies that winds from the south-west sector, which can produce a northerly wind set current, will dominate and provide a capacity to create a net northerly movement of sand in suspension. Wave action is required to bring the sand into suspension.

Using Soulsby (1997), a wave with a period of 4 seconds and height 0.8 metres will bring fine sand into suspension near the seabed in water depths less than 6 metres. A 5 second wave with a height of 1.2 metres will bring sand into suspension in water depths of up to 9 metres.

Only moderate winds are required to produce these wave conditions. For example, a sustained wind speed of greater than 10 knots from the south-west will produce 4 second waves capable of bringing sand into suspension. Winds equalling or exceeding a speed of 10 knots occur from the south west sector for about 30% of the time.

These calculations reinforce the conclusion reached in Coastal Engineering Solutions (2000) that currents can contribute significantly to northward sediment transport of suspended sediment, particularly where there is little seagrass cover binding the sand on the seabed. The quantity of suspended sand that can be moved by the current will depend on the water depth in those areas where the seabed is not protected by seagrass.

The width of bare sand in water depths of less than 5 metres (relative to LWD), tends to be greatest off Semaphore Park.   It was suggested previously (CES, 2000) that some 25,000 cubic metres of sand may be moved northward in suspension each year by the current.

In Section 5.1 it was noted that the wide shallow sandy seabed off West Beach dunes may result in enhanced northward sediment transport due to currents.   This may be due to the 5 metre contour being closer to shore at this location than it is to the north or to the south. However, it is not possible to verify this sediment transport mechanism in any quantitative manner within the scope of this study.

The most likely scenario is that suspended sediment transport by currents has been enhanced considerably since the loss of the nearshore seagrass meadows and probably contributes to the movement of about 25,000 cubic metes of fine sand each year from south to north between Glenelg and Semaphore Park where the loss of seagrass meadows has been very significant. The rate of production and movement of the suspended sediment is dependent on the water depth and width of the sandy seabed areas.

5.7 Equilibrium Beach Angles

The alignment of the beaches at Adelaide is such that there is a movement from south to north along the total beach system. If the beaches could be rotated in an anti-clockwise direction, alignments could be reached where there is zero net longshore transport by waves in the long term. These beach angles are termed the “equilibrium beach angles”. This angle is particularly relevant to any scenario where beaches are stabilised with the aid of groynes or offshore breakwaters. A beach located to the south of a groyne will attain the equilibrium beach angle if the groyne is long enough to prevent any sand by-passing it. This would also require zero net supply from the south. Usually it is more practical to utilise a shorter groyne that only allows sand by-passing during extreme storms, particularly if there is still a sand supply from downstream.

The QUEENSED model has been run for each of the sites from Kingston Park to North Haven, using the beach angle as a variable, to determine the beach angles for which there would be no longshore transport. The model was run for the 10 year hindcast wave data set. The results of the modelling are presented in Figures 5.29 and 5.30.

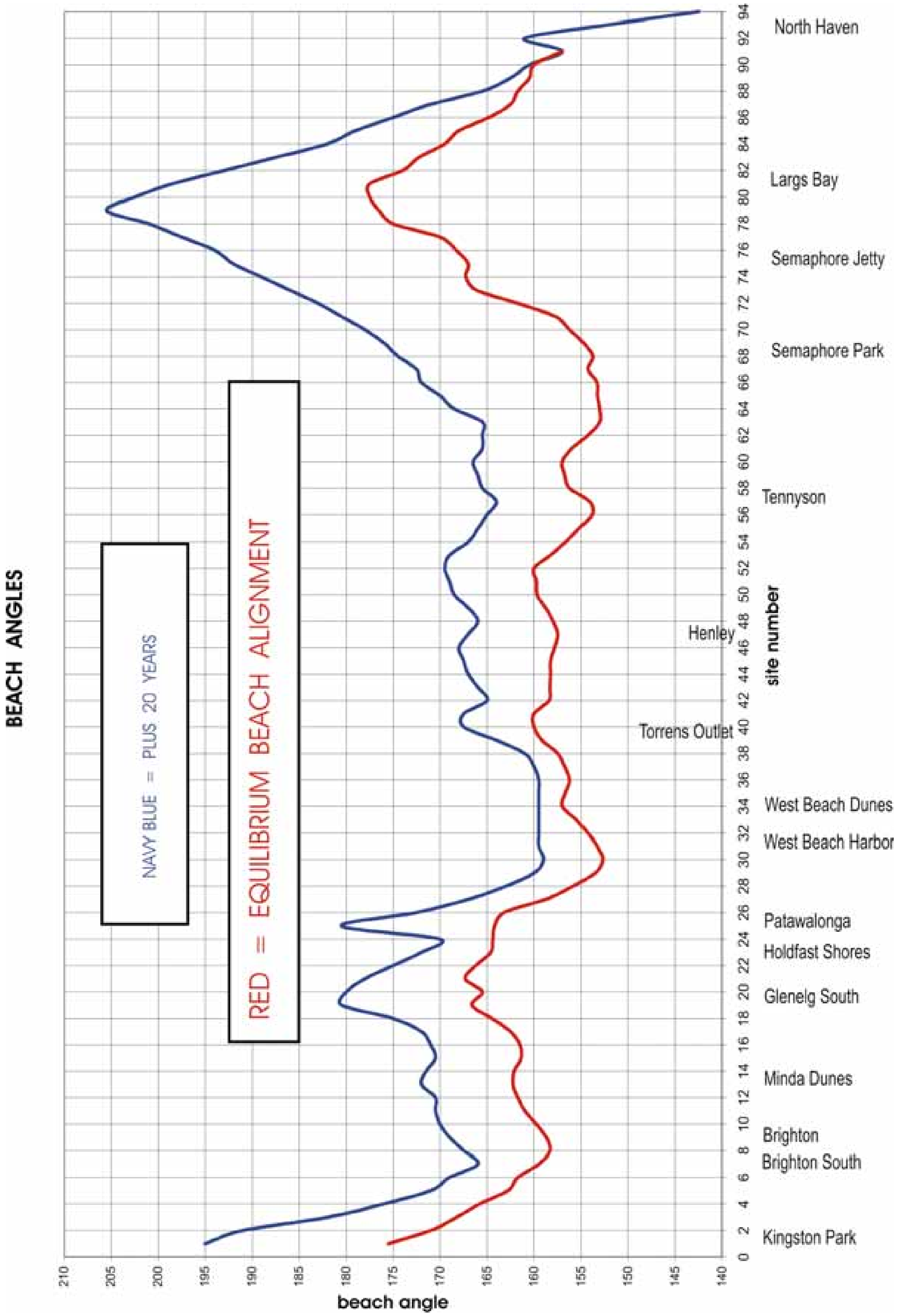

FIGURE 5.29: **Equilibrium beach angles**

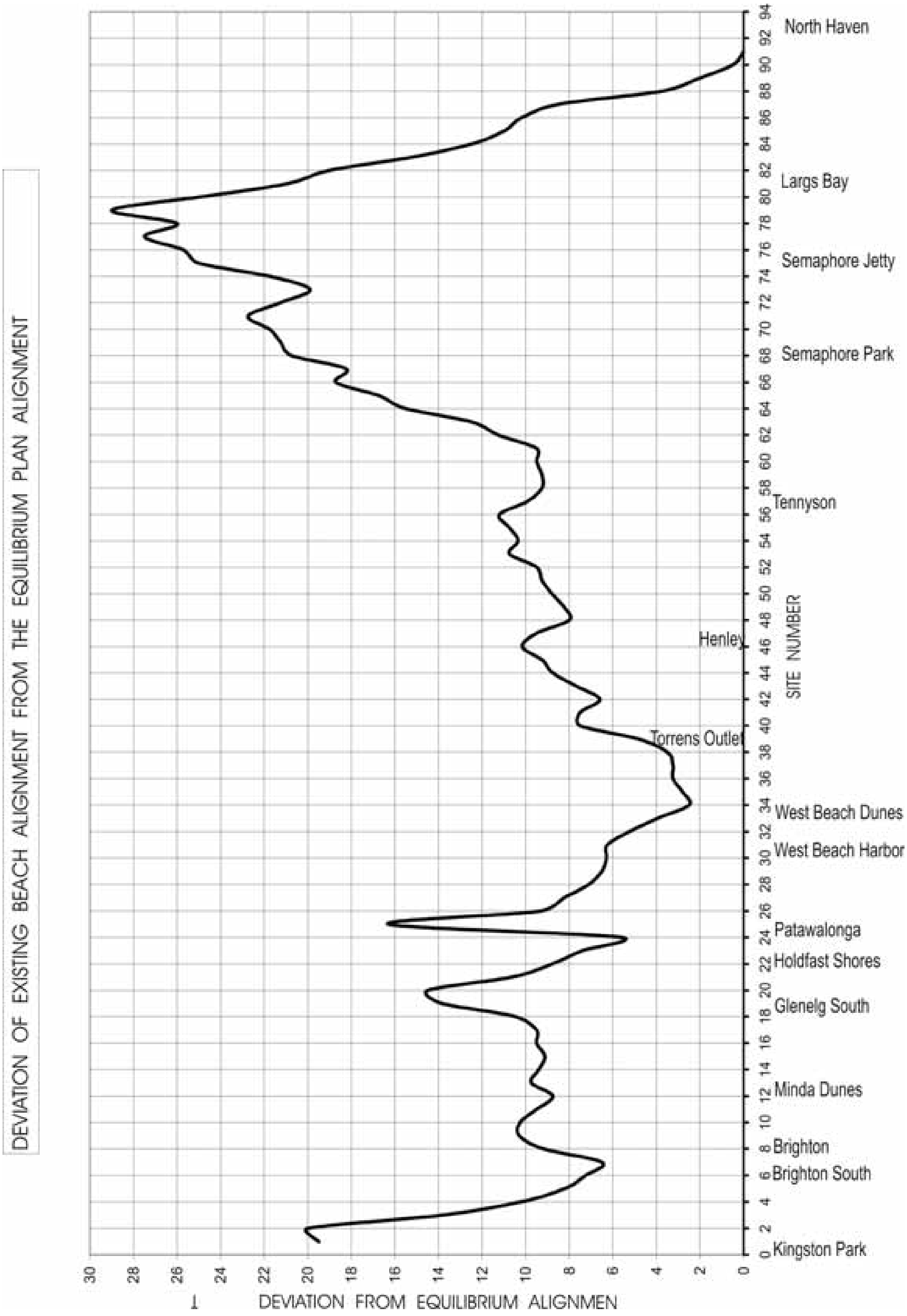

FIGURE 5.30: Deviation of beach alignments from the equilibrium alignment

Figure 5.29 shows the beach angles used for the Plus 20 year scenario and the equilibrium beach angles. The Plus 20 year scenario is shown rather than the existing beach angles, because any changes to the beaches to create equilibrium beach angles would occur some time in the future. Figure 5.30 shows the deviation of the existing beach angle from the equilibrium alignment.

There is a large variation in the difference between beach angles and the equilibrium angle along the coast. A large proportion of the deviation is due to the swell waves which all arrive at the shoreline at an angle which pushes sand to the north. The following provides an explanation of this large variation moving from south to north along the beach system:

- At Kingston Park, where the Adelaide beaches start, the large deviation of 12 to 20 degrees is due to the shoreline angle which is partly controlled by the cliffed headland to the south.
- From Brighton to South Glenelg the deviation is about 10 degrees.
- At The Broadway, the coast changes angle in a clockwise direction, which results in the deviation becoming larger – the incident wave climate is changed little between sites 10 and 24.
- The dip in the deviation from The Broadway (Site 20) to the Patawalonga training wall is due to the trapping effect of the training wall and the ongoing sand by-passing from the lee of the offshore breakwater. If sand by-passing did not occur there would be the potential for the beach to rotate a further 5 to 6 degrees at Holdfast Shores.
- Immediately to the north of The Patawalonga (Site 25) the deviation jumps to 16 degrees, which is a direct influence of the training walls. From The Patawalonga the deviation decreases to a minimum of about 3 degrees at West Beach dunes.
- The minimisation of the deviation in the vicinity of West Beach dunes (Sites 34 and 35) appears to be due to the shoal shown previously in Figure 5.2. This shoal effectively rotates the wave crests in a clockwise direction.
- North of The Torrens Outlet, as far as Tennyson, the deviation angle averages at about 10 degrees as it does from Brighton to Glenelg.
- From Tennyson Dunes to Largs Bay there is a steady increase in the deviation angle, resulting in a maximum deviation of 29 degrees at Site 79, about midway between Semaphore Jetty and Largs Bay. This increase in the deviation between existing beach angles and the equilibrium beach angles may be attributed to the increased angle of attack that swell waves make with the shoreline when moving further northward along the beaches.
- From Site 79 to North Haven the deviation rapidly decreases to zero. North Haven is a total sediment transport barrier and the beach immediately to the south of it, Site 91, would be expected to have attained an equilibrium alignment.

The wide variation between existing beach angles and equilibrium beach angles suggests that different beach management techniques may be applicable to different coastal segments.

5.8 Sand Size Sensitivity

The naturally occurring sand on Adelaide's beaches is fine grained, typically with D_{50} = 0.22mm. The size of the sand becomes slightly smaller on the northern beaches. In recent years beach replenishment has taken place using a bi-modal sand size distribution with the coarser fraction having D_{50} = 0.45mm. At this time there is no defined sand source for future beach replenishment. Figure 5.31 shows the different rates of longshore transport that are likely to occur with sand sizes of 0.5mm and 0.8mm, compared with the native 0.22mm sand. The data presented in this figure has been derived by running the QUEENSED model for the different grain sizes. Note, however, that only the grain size was changed for the model runs. In reality the beach slope is likely to be steeper in the swash zone for larger sand sizes. This would increase the rate of sand movement.

On the basis of a constant beach slope for all sand sizes, the 0.5mm sand moves along the beach about 20% slower than the 0.22mm sand, and the 0.8mm sand moves about 30% slower. If the beach slope steepens, as would be expected for coarser sized sand the sediment transport rate would increase so that the apparent benefit of using a coarser sand diminishes. If the beach slope steepened from 1:30 to 1:15 there would be an approximate 60% increase in longshore sediment transport. That is, coarse sand for beach replenishment does not necessarily diminish the rate of longshore sediment transport.

The main benefit of a coarser sand relates to offshore movement of sand during storms. Offshore sand movement is very sensitive to sand size. This is illustrated in Figure 5.32 for the Brighton area, which shows a comparison of how the coarse and the fine sand fractions from replenishment would have responded to the 1956 storm. The rate of offshore movement for the 0.45mm sand is only about 20% of that for the 0.22mm sand. The SBEACH model is not really applicable for sand sizes greater than 0.5 mm. This is because the model used beach profile data for sand in the size range of 0.2 mm to 0.42 mm for the model verification.

The same trends for offshore sand movement as a function of sand size, during storms, would apply for all of Adelaide's beaches.

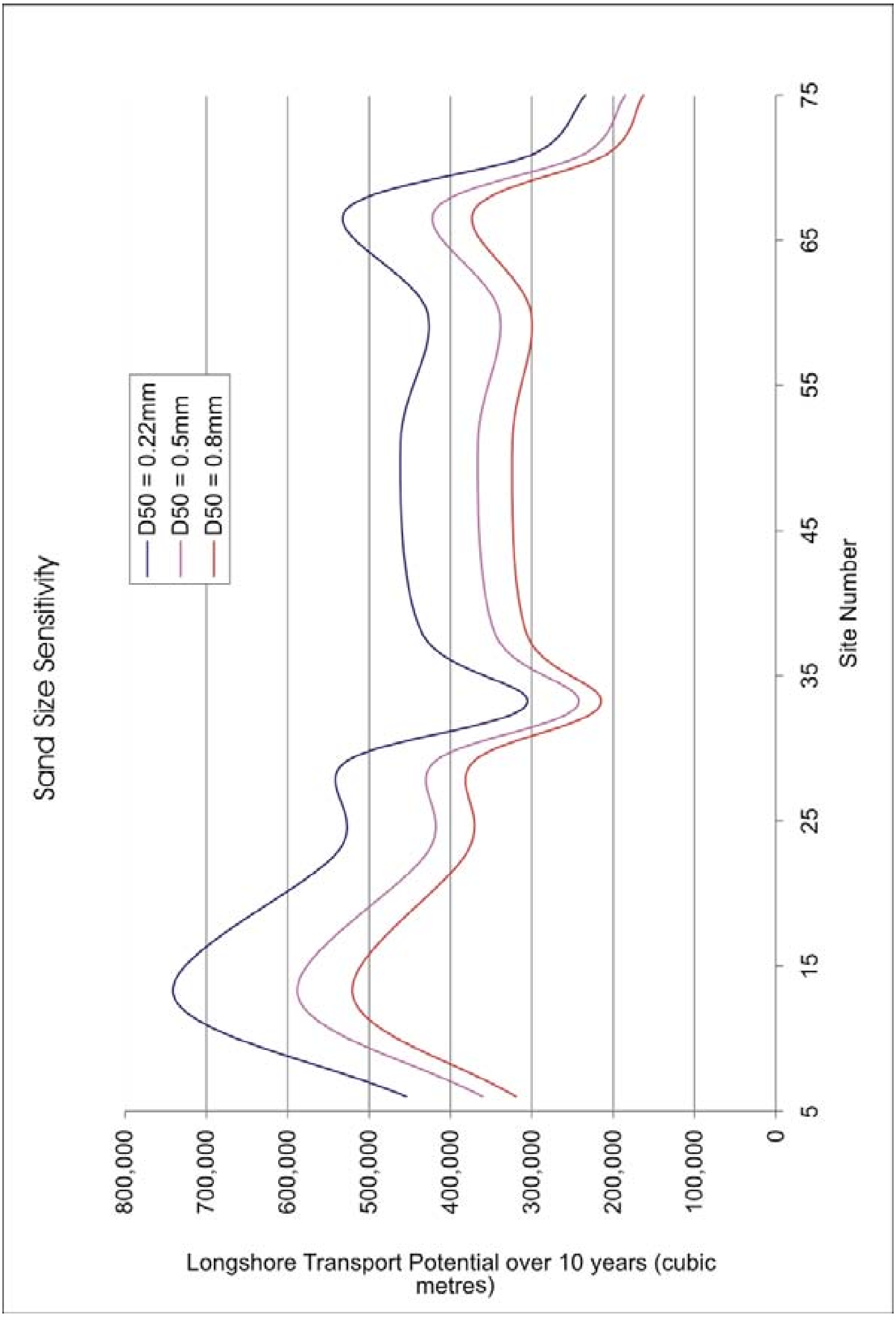

FIGURE 5.31: Longshore sediment transport vs sand size

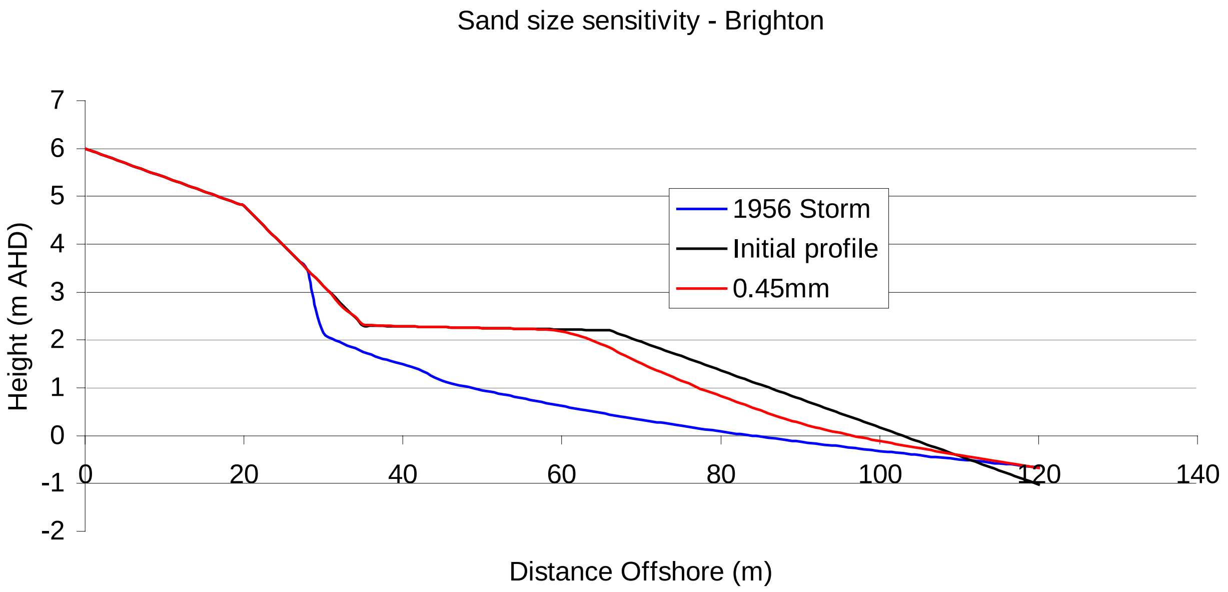

Figure 5.32: Offshore sand movement vs sand size

5.9 Increased Storminess

The sensitivity of the computed longshore sediment transport potentials to possible future changes in wave climate (as a consequence of greenhouse effects) has been investigated for the Plus 20 Year, Plus 50 Year and the Plus 100 Year Scenarios.

As discussed in Section 5.3.2, for the Plus 100 Year Scenario an increase of 10% was applied to the significant wave heights for those instances when the height exceeded 1.5 metres. An increase of 5% was applied to the same instances for the Plus 50 Year Scenario and a 3% increase for the Plus 20 Year Scenario. The implications to the longshore sediment transport potential are shown in Figure 5.33.

The modelling indicates that there is a uniform increase in longshore sediment transport potential that appears to be proportional to the increase in wave height. For the 50 Year Scenario, the increase in sediment transport potential is about 5%. For the 100 Year Scenario it increases to over 10%.

Increased storminess and sea level rise will also impact on offshore sand movement. Figure 5.34 illustrates the increase in storm erosion for the 1994 storm at Brighton.

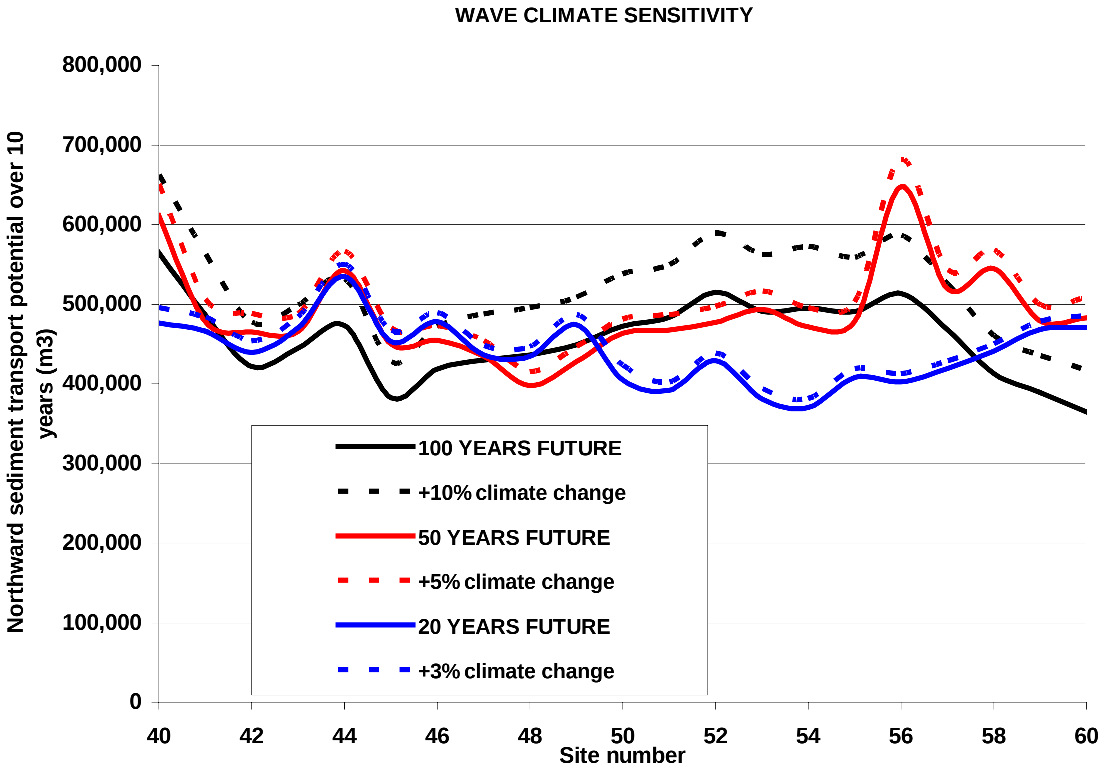

FIGURE 5.33: Sensitivity of sediment transport capacity to increased storminess

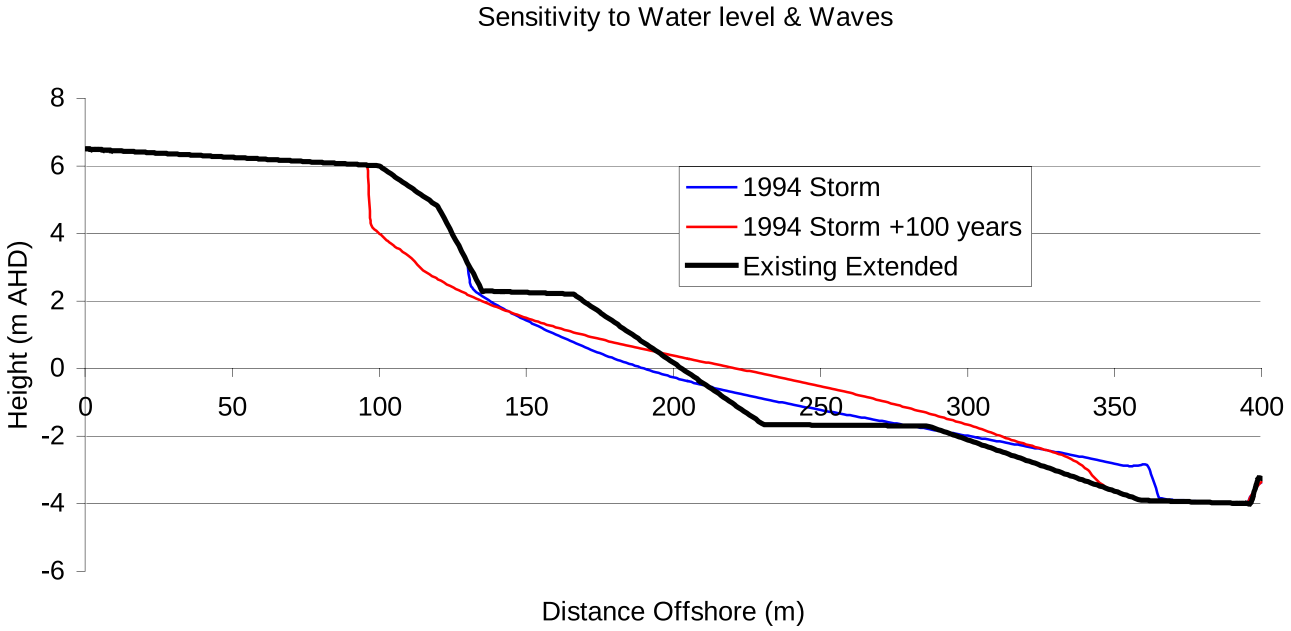

FIGURE 5.34: Sensitivity of offshore sediment transport due to water level increase and increased storminess

The increase in erosion with a 0.5 metre increase in sea level and a 10% increase in the generated wave height is very large. The volume of eroded sand nearly doubles and the height of the erosion scarp has increased from +3m to +6m AHD.

If the predicted sea level rise occurs for the Plus 100 year scenario, the erosion during storms will increase along the whole metropolitan shoreline by a factor of about 2.

Section 6

SUMMARY AND CONCLUSIONS

Previous Studies

1. The first detailed investigation of coastal processes affecting Adelaide beaches was undertaken in the late 1960's following a series of damaging storms. The conclusions of the ensuing report, *The Culver Report*, were implemented through the formation of the Coast Protection Board. Since its inception, the Board has been responsible for the determination and implementation of appropriate coastal protection strategies.
2. *The Adelaide Coast Protection Alternatives Study* of 1983 quantified longshore sediment transport rates along Adelaide's metropolitan beaches by applying an approach based on sediment budget principles. An average northerly longshore sediment transport rate of 30,000 m^3 / year was reasoned, but only 5,000 m^3 / year was estimated as being supplied into the metropolitan beach system from the south (past Kingston Park). The study examined a range of options for future management of the beaches. All sustainable options required major beach replenishment. Long term beach replenishment could reduce if structures such as groynes and offshore breakwaters were utilised. A concept using 11 major groynes or offshore breakwaters was suggested.
3. The beach works that have been undertaken since 1983 have not followed the suggestions of that report – with the exception of major beach replenishment from offshore sources because beach replenishment was assessed as the most cost effective solution to provide protection and beach amenity (The Adelaide Coast Protection Strategy Review 1984).
4. The *North Haven Siltation Study* and the *Jubilee Point Coastal Processes Study* were the first studies undertaken utilising mathematical modelling techniques for determining both wave transformation and longshore sediment transport processes. The sediment transport formula used – *The CERC Formula* – was a simple algorithm that assumed sediment transport was only dependent on wave height and the breaking wave angle. Calibration factors were applied by these studies to produce a modelled northerly longshore sediment transport rate of 40,000 m^3 / year.

5. From 1995 to 1997 coastal process modelling was undertaken for *West Beach, Glenelg* (Holdfast Shores) and *Brighton*. Modelling of wave transformation and coastal processes had been improved to the stage where a calibration factor no longer had to be applied to the computed longshore transport rates. However, the CERC formula was still being used. Longshore sediment transport rates were now believed to average 60,000 m^3 / year along the southern metropolitan beaches, with about 20% of the transport being caused by distant swell (which diffracted and refracted onto Adelaide's beaches) and 80% due to locally generated sea waves.
6. In 2000 the *Semaphore Park Protection Strategy Review - 2000* was undertaken. Extensive new mathematical modelling techniques were applied - including a fundamental change to the representation of the sediment transport processes. The *QUEENS* formula was introduced, which enabled the influence of important parameters such as wave period, beach slope and sand grain size to be included. The main consequence of utilising an improved representation of sediment transport processes was the recognition of a greater contribution to longshore sand transport by swell waves. Approximately 50% of the overall net sediment transport was found to be caused by distant swell waves, the remaining 50% was caused by locally generated sea waves. However the overall net rate of northerly longshore sediment transport was unchanged from that of the earlier studies.

Mathematical Modelling for 2003-2004 Study

7. For this current study, a completely new model regime was established - covering all of the metropolitan beaches, all of Gulf St Vincent, as well as Backstairs Passage and Investigator Strait, extending out into deep offshore waters. The area modelled was represented by over 800,000 depth grid points.
8. The swell waves generated by distant weather systems in the oceans south of the Australian continent and the sea waves generated by local winds blowing across the open water fetches of Gulf St Vincent were considered by the modelling.
9. Wave hindcasting was undertaken for swell waves and for sea waves. The period covered by the hindcasts was 1993 to 2002 (inclusive) thereby creating a 10 year wave data base for consideration by the modelling. Severe storm events, dating back to 1948, were also identified and modelled. The hindcast wave data was combined with measured ocean levels so that real water levels were included in the various data sets used for all subsequent modelling.

10. The largest offshore swell waves to occur in the 10 years of the hindcast period occurred in May 1994 and were estimated to have a H_s greater than 11 metres. The highest locally generated sea waves occurred in 1948 during a short duration storm which had very strong winds blowing across the open water fetches of Gulf St Vincent. The deep water significant wave height was about 4.5 metres in the deep waters of the Gulf.
11. As these deepwater swell waves and sea waves propagate shoreward they are modified by the processes of wave refraction, diffraction, shoaling wave breaking and attenuation by seabed friction. A *Wave Transformation Module* (consisting of a suite of mathematical models) was applied to replicate these processes
12. Seabed friction is an important phenomenon in the wave transformation process. The results of the transformation modelling are quite sensitive to how seabed friction is formulated. A good description of the nature of the seabed (in terms of sandy areas, the sand size, seagrass meadows, reef/rock substrata) is essential for accurate modelling. This is because a sandy seabed may either be rippled, or the sand may form a flat bed. The roughness of a rippled seabed is considerably greater than it is for a flat seabed. Consequently the algorithm adopted for representation of the attenuating effects of seabed friction simulates the formation of a rippled seabed whenever conditions cause its occurrence.
13. The foreshore between Kingston Park in the south and the Outer Harbor Breakwater in the north was investigated by selecting some 94 nearshore locations at approximately 300 metre intervals along the shoreline. Each site was selected so as to be in approximately 3.0m to 3.5m depth of water at mid-tide.
14. Application of the *Wave Transformation Module* resulted in the determination of the swell and sea wave characteristics at three-hourly time intervals over the 10 year long wave database - for each of these 94 inshore sites. This represents a comprehensive temporal and spatial representation of the inshore wave climate affecting the metropolitan beaches.
15. These 10 year wave data sets at each location were then used as input to a *Sediment Transport Module* to determine the rates of longshore sediment movement at each of the 94 inshore sites. Longshore sediment transport rates were determined for each site at three-hourly intervals over the 10 years.

16. The *Wave Transformation Module* and the *Sediment Transport Module* were applied for each of the 94 inshore locations and for each of five nominated scenarios:
    a. present day conditions;
    b. those which may have occurred 100 years ago;
    c. those possibly occurring in 20 years time;
    d. those possibly occurring in 50 years time; and
    e. those possibly occurring in 100 years time.

17. Sediment is moved offshore during severe storms by those waves generated within Gulf St Vincent. Swell waves do not contribute to offshore sediment transport. The most severe storms in recent times were identified by considering wave hindcast data. These were determined to have occurred in:
    a. April 1948
    b. April 1956
    c. May 1960
    d. April 1985
    e. November 1994
    f. September 1996
    g. June 1999

Present Day Scenario

18. The seabed was schematised using all of the latest available survey data, supplemented with recent aerial photos to define the extent of seagrass coverage.

19. The contribution of sea waves and swell to net northerly longshore transport potential varies along the coast:
    a. South of West Beach, the contribution by swell is generally 10% to 20% greater than the contribution by sea waves.
    b. From West Beach to Semaphore Park, the contribution by sea waves is about 10% greater than by swell
    c. From Semaphore Park to Largs Bay, the contribution by each is about equal; and
    d. Between Largs Bay and North Haven, the contribution by swell waves dominates.

20. The longshore sediment transport potential is largest off Brighton, mainly due to its exposure to swell waves. The longshore sediment transport potential is about 70,000 m^3 / year. This predicted rate of sediment movement out of the Brighton area is confirmed by measured changes of the beach and consideration of sand replenishment volumes.

21. Recycling of sand presently occurs within the Brighton area by trucking, which allows the larger sediment transport potential to be satisfied without initiating erosion processes.

22. The lowest longshore sediment transport potential occurs off West Beach. This may be due to a local offshore shoal which transforms the incoming waves in a way that minimises the northward movement of sand. It is suggested that the shortfall in sand supplied by waves to the beaches immediately to the north is compensated for by an increased contribution of sand movement over the shallow shoal (by suspended sediment moved northwards by wind-induced currents). This sediment transport mechanism will be maximised in shallow areas and on nearshore shoals where waves can more readily bring sand into suspension.

23. Alternatively, the apparent anomaly in longshore transport at West Beach may be due to the quality of the bathymetric data seaward of about the 8 metre (LWD) contour. The available survey data seaward of the 8 metre contour is at least 30 years old and rather sparse. This comment applies to all of the metropolitan coast and could have resulted in inaccuracies in the modelling process elsewhere.

24. The longshore sediment transport potential was about 60,000 m^3 / year at Semaphore Park prior to the construction of the offshore breakwater, whereas the potential to supply sand from Tennyson is only about 40,000 m^3 / year. This is consistent with the erosion that was being experienced at Semaphore Park prior to the construction of the offshore breakwater.

25. Longshore sediment transport potential between the Torrens Outlet and Tennyson is fairly constant at 40,000 – 50,000 m^3 / year.

26. The sediment transport potential decreases north of Semaphore Park which is consistent with the accretion that occurs between Semaphore and North Haven.

Minus 100 Year Scenario

27. The distinguishing feature of the Minus 100 year schematisation was the extent of seagrass coverage assumed. Given the lack of any precise records, the seagrass meadows were assumed to extend inshore as far as the RL-3 metre (to CD) depth contour. It was also assumed that the seabed level was some 0.5 to 1 metre higher in those areas where seagrass then occurred but does not occur at present.

28. The extent of seagrass south of Glenelg Jetty was assumed to have not changed over the past 100 years.

29. Other physical features that were different and included in the schematisation were:
    a. The Patawalonga was not trained;
    b. The Torrens Outlet did not exist;
    c. North Haven did not exist and the shoreline in this area was about 500 metres further to the east, and
    d. The Semaphore shoreline did not have a wide low dune as occurs today.
30. For those foreshores that had seagrass into the RL-3 metre (LWD) contour (that is between North Glenelg and Semaphore Park) the estimated sediment transport potential was 10% to 20% lower than for present day conditions.
31. The presence of the seagrass over the shoal and adjacent areas off West Beach resulted in a "smoothing" of the local decrease in longshore sediment transport potential that is currently occurring in this area.
32. Sediment transport past West Beach was therefore mainly by longshore transport by waves, with a negligible contribution from currents sweeping suspended sediments northwards. The presence of the seagrass would have minimised the occurrence of suspended sediments.
33. The average sediment transport potential was 40,000 m^3 / year for most of the coast from The Patawalonga to Semaphore Park.
34. The sediment transport potential south of Glenelg would have been much the same as it is today. It is likely that the full "potential" sediment transport was not occurring due to a diminishing supply from the south. The volume of sand that actually arrived at the Patawalonga, in excess of the potential to move sand north may have been stored in a substantial dune system that is likely to have been in place at The Patawalonga.

Future Scenarios

35. The schematisation of the seabed and shoreline for all future scenarios was based on the assumption that sand would continue to be supplied to replenish Brighton and by-passed at Holdfast Shores and West Beach at present day rates. The shoreline position and seabed contours were schematised to accommodate the expected accretion north of Semaphore Park. It was assumed that there would be no further seagrass losses, but the recently depleted seabed areas inshore of the seagrass meadows would drop in level by up to 0.5 metres over the next 100 years.

36. Increases in the ocean water level increases (due to the Greenhouse Effect) were selected at 0.1m (Plus 20 years), 0.2m (Plus 50 years) and 0.5m (Plus 100 years). Sensitivity modelling was carried out in relation to increased "storminess" that might accompany climate change. The potential longshore sediment transport is computed, implying that there was sand available at all tide levels for movement by waves.

37. The increase in water level and the decrease in seabed level (in those areas where seagrass meadows used to exist) will have a significant effect on wave refraction for the longer period swell waves. The nearshore seabed contours are generally not parallel to the beach and so the angles at which swell waves arrive on the beach varies between scenarios. The variation is not steady over the time scales of future scenarios.

38. For the Plus 20 year scenario the modelling predicts:
    a. Longshore sediment transport potential will decrease from Brighton to West Beach and from Grange to Tennyson;
    b. From West Beach to Henley the longshore sediment transport potential is unchanged;
    c. Longshore sediment transport potential will increase from Tennyson to Semaphore Park and from Semaphore Jetty to North Haven.

39. For the Plus 50 year scenario the modelling predicts:
    a. Similar longshore transport potentials as the Plus 20 year scenario for Brighton to West Beach;
    b. However, north of West Beach the sediment transport potential becomes more erratic with localised increases. The inference is that the changed refraction results in localised increased wave heights or angle of wave attack, which increases the sediment transport potential. This would result in a localised change of beach plan alignment and could cause a localised "hot spot" for erosion.

40. For the Plus 100 year scenario the modelling predicts the sediment transport potential becomes more erratic for the southern metropolitan beaches as well as for the northern beaches.

41. These predicted changes in sediment transport potential are due to the importance of swell waves in moving sand northward, and the sensitivity of the nearshore wave height and direction to water level and the seabed features that lie immediately off the beach.

42. The overall average longshore sediment transport potentials do not increase for future scenarios when compared to existing conditions - provided the extent of seagrass meadows does not change significantly.

Replenishment at Hallett Cove

43. The longshore sediment transport potential at Hallett Cove is well in excess of 100,000 m^3 / year.

44. Assuming that the prime purpose of replenishing at Hallett Cove is to provide a sediment feed to the Metropolitan beaches, whilst at the same time providing the added benefit of a sandy beach at Hallett Cove, the average annual replenishment rate would be 60,000 m^3. Since the sand would be transported northward at a rate in excess of 100,000 m^3 / year at Hallett Cove, the beach at Hallett Cove would be sandy immediately after replenishment, but the underlying shingle/cobble beach would become partly exposed before the next replenishment program took place.

45. There is a risk of sand losses into deep water between Hallett Cove and Kingston Park because of the steep nearshore seabed slopes and the deep water close to the shoreline. However, accurate bathymetry does not exist and using the available bathymetry modelling indicated that losses would be small.

46. Since sand movement to Brighton would be at a greater rate than sand movement from Brighton Beach due to longshore sediment transport, it is possible that the excess sand arriving at Brighton will:
    a. Smother seagrass meadows off Brighton; or
    b. Be trapped by the seagrass meadows and be lost from the active beach system.

Offshore Sand Movement During Storms

47. The SBEACH model was used to determine the extent of offshore sediment transport during seven severe storms that have occurred since 1948. The model was run for 10 locations along the shoreline between Brighton and Semaphore Jetty. The most severe storms were found to have occurred in April 1948, April 1956 and November 1994.

48. The 1948 storm was of short duration, lasting only about 12 hours, but was accompanied by the strongest winds on record and very high ocean levels. It produced the highest cut in the dune at each location, but the eroded sand stayed in the active beach zone because of the short duration of the storm.

49. The 1956 storm generally eroded slightly more sand than the 1994 storm. Both storms were of long duration but the maximum waves and water levels did not reach those of April 1948.

50. The volume of sand eroded from the beach and dune system was generally greater for the southern beaches than for the northern beaches. At Brighton the maximum predicted erosion was up to $80m^3$ / metre length of beach.

51. At Semaphore Park the erosion volume reduced to 35m^3 / metre length of beach - whereas at Semaphore Jetty the predicted erosion during these severe storms was only 25m^3 / metre length of beach.
52. The volumes in conclusions 51 and 52 relate to the total volume of sand eroded. About 50% of this volume is eroded from above the 1.0m AHD level.
53. For the southern beaches, much of the eroded sand is moved offshore to the toe of the sloping beach. Since offshore seabed slopes are gentle and the water depth relatively shallow, the eroded sand will be slowly returned to the active beach system by the subsequent action of background swell.
54. For the northern beaches, the seabed approach slopes are even flatter and consist of a series of nearshore bars and troughs. Sand eroded from the beach/dune system tends to move onto these bars and fill the troughs. This sand will also be subsequently moved shoreward by the background swell.

Effect of Currents

55. There is a predominant northerly current induced by winds blowing from the south-west sector. The wind set current alone cannot initiate sediment movement, but will move sand that may have been lifted into suspension by waves.
56. Waves having a period of 4 secs to 5 secs and a wave height of 1 metre will cause seabed sediments to lift into suspension. A 10 knot wind can generate such waves from the south-west.
57. The net quantity of sand moving northward due to tide and wind-generated currents is estimated to be of the order of 25,000 cubic metres per year (over nearshore areas where there is no seagrass cover). The rate of sediment movement is dependent on the width of bare seabed in water depths less than 6 metres.

Equilibrium Beach Angles

58. The *equilibrium beach alignment* is defined as the plan alignment of the beach for which the net longshore transport potential is zero.
59. The existing beaches are not at an equilibrium alignment with the prevailing wave conditions. The difference between the existing beach alignment and the equilibrium beach alignment varies from 3 degrees to 29 degrees over length of the Metropolitan beaches.
60. Except for the influence of localised topographical features such as training walls, headlands and the nearshore shoal off West Beach, the average angle difference from equilibrium is 10 degrees between Brighton and Tennyson.

61. North of Tennyson, the difference increases steadily to 29 degrees at Largs Bay. This change is attributable to the more acute angle at which breaking swell waves arrive on the foreshore.

62. From Largs Bay to North Haven the difference between the existing beach angle and the equilibrium angle quickly decreases to zero, reflecting the accreting state of these beaches.

Sensitivity to Sand Size

63. The sensitivity of longshore transport potential to varying sand size was investigated by the *Sediment Transport Module*. It appears that there is no benefit in using a coarse sand to reduce longshore sediment transport. A coarse sand will not move as quickly as a fine sand if both sand sizes are on the same beach slope. However, a coarse sand will create a steeper beach than a fine sand. A steeper beach increases the longshore transport rate for a given wave and water level. The net result is that coarse sand will move along a beach at the same rate as fine sand.

64. However offshore sand movement during storms is very dependent on sand size. Given the same severe storm wave conditions, the volume of sand eroded from a beach comprised of 0.5mm sand is only 20% of that removed from a beach comprised of 0.22mm sand.

65. Coarse sand also has the benefit of not being as susceptible to being transported by wind and will tend to remain in the active beach zone.

Sensitivity to Climate Change

66. Increased storminess as a consequence of climate change will have a relatively small impact on longshore sediment transport potential. The modelling suggests that an increase of 10% to15% for the Plus 100 year scenario will occur - based on the assumption that storm waves increase in height by 10%.

67. Increased storminess accompanied by sea level rise will have a significant effect on offshore sand motion during storms. Increasing the still water level by 0.5m and the storm wave heights by 10% will approximately double the quantity of sand moved offshore during a storm. Ambient waves will move the sand back onshore, but this is expected to occur at the same rate as it does for present conditions. Consequently the eroded beach will not recover as quickly as it does now.

Section 7

REFERENCES

CERC (1977). *"Shore Protection Manual"*, Coastal Engineering Research Center (CERC), U.S. Army Corps of Engineers Washington DC, U.S. Government Printing Office.

Coastal Engineering Solutions (1997a). "*Holdfast Shores Beach Management - Phase 2". * Report prepared for Holdfast Shores Pty Ltd.

Coastal Engineering Solutions (1997b). "*Shoreline Evolution Studies West Beach Facilities ".* Report prepared for Holdfast Shores Pty Ltd.

Coastal Engineering Solutions (1997c). "*Brighton Coastal Processes Modelling".* Prepared for Coast & Marine Branch, Dept of Environment & Heritage.

Coastal Engineering Solutions (2000). "*Semaphore Park: Protection Strategy Review 1999 - 2000".* Report No. 99v21-hprp-000320, prepared for Coast and Marine Section, Environment Protection Agency South Australia. March 2000

CSIRO (2003). "*Climate change in South Australia : Assessment of climate change, impacts and possible adaptation strategies relevant to South Australia".* Undertaken for the South Australian Government by the Climate Impact Group, CSIRO Atmospheric Research. Authors: K.L. McInnes, R. Suppiah, P.H. Whetton, K.J. Hennessy and R.N. Jones. February 2003.

Culver, R. (1970). "*Final Summary Report on Beach Erosion Studies".* Report prepared by Civil Engineering Department, University of Adelaide. (Also known as the Culver Report)

Hsiao, S.V. & Shemdin, O.H. (1978). "*Bottom Dissipation in Finite-Depth Water Waves".* Proc. 16th International Coastal Engineering Conference, Hamburg.

Kinhill Stearns / Riedel & Byrne (1983). *"Adelaide Coast Protection Alternatives Study".* Report prepared for Coast Protection Board.

Nielson, P. (1977). "*A Note on Wav Ripple Geometry".* ISVA Technical University of Denmark. Prog. Report 43 pp 17-22

Reference Group (1997). *"Report of the Review of the Management of Adelaide Metropolitan Beaches".* Report prepared by Reference group appointed by the Minister for the Environment and Natural Resources.

Riedel H.P. (1972) *"Direct Measurement of Bed Shear Stress Under Waves".* PhD dissertation. Dept of Civil Engineering, Queen's University at Kingston, Ontario.

Riedel & Byrne Consulting Engineers Pty Ltd (1985). *"North Haven Siltation & Dredging Study".* Report prepared for North Haven Trust.

Riedel & Byrne Consulting Engineers Pty Ltd (1985). *"Jubilee Point Coastal Processes Investigation".* Report prepared for Kinhill Stearns, Engineers.

Shepherd, S.A. and Sprigg, R.C. (1976). "*Substrate, Sediments and Subtidal Ecology of Gulf St Vincent and Investigator Strait".* Published in: "Natural History of the Adelaide Region"; edited by S.R. Tindale, M.J. Tyler and B.P. Webb - Royal Society of South Australia, Adelaide. pp161 - 174.

Soulsby, R. (1997). *"Dynamics of Marine Sands – A manual for practical applications".* Thomas Telford Publications.