Department for Environment and Heritage

Adelaide's Living Beaches
A Strategy for 2005 – 2025

Technical Report

Government
of South Australia

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Cover photo: Brighton

Foreword

Adelaide's coastline is a special asset and an inspiration to many local residents and visitors. The coastline is dynamic, always shifting in response to the wind and waves. However, human impacts have altered the dynamics of the coast to such an extent that natural processes can no longer sustain the beaches.

Most of the land behind the foreshore was developed from the early 1900s onwards. Roads, buildings, houses, recreational areas, and their sewerage and stormwater infrastructure were often built right over coastal dunes. Consequently, dune sand is unable to erode away during storms, and so substantial protection works have been put in place to retain the foreshore and beaches. Early on, this protection was in the form of seawalls. From the 1970s, however, protection was mainly achieved by replenishing beaches with sand.

Adelaide's coastline is now a highly managed one. The sand that forms the beaches is a scarce and moving asset. The strategy for the future management of the beaches cannot be static but needs to be responsive to changing conditions to ensure that future generations are not disadvantaged by our decisions now. Climate change is likely to gradually alter the forces that act on the coastline, so we must allow for additional supplies of sand to maintain beach width and provide for strengthened dune buffers.

Effective management of the coast depends on an alliance with an informed community involved in sound decision-making. The issues are often complex and inter-related, the solutions are costly, and some members of the public believe that a permanent structural solution to the moving sands is preferable to the ongoing recycling of sand from north to south. However, the strategy since 1972 of beach replenishment and rock revetment as the last line of defence has been a successful and cost-effective method for maintaining sandy beaches, rebuilding sand dunes and preventing storm damage to property.

In 2000, the Department for Environment and Heritage, on behalf of the Coast Protection Board, initiated a review of the management of Adelaide's metropolitan beaches. Based on examination of the benefits and costs of a range of strategies, along with the results of a series of modelling and feasibility studies and input from the community, the Department has developed an innovative strategy for managing Adelaide's beaches called *Adelaide's Living Beaches: A Strategy for 2005–2025*.

This technical report has been developed to accompany *Adelaide's Living Beaches: A Strategy for 2005–2025*.

Of necessity, the report adopts a scientific and engineering approach, and the level of detail makes it particularly appropriate for use by the State Government and seaside councils. The report provides a timely review of knowledge about Adelaide coastal processes, taking into account previous reports since 1972. It also provides an updated assessment of measures available to protect the coast.

GRAHAM FOREMAN

Chair, Coast Protection Board

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- Department of Treasury and Finance
- Marine and Coastal Managers Forum

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Consultant studies forming part of this review were:

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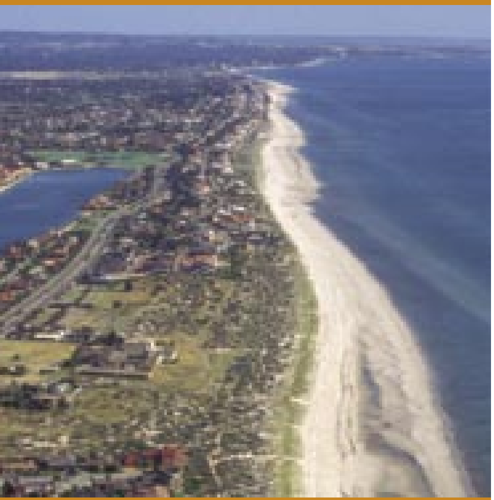
Except where otherwise indicated, all figures and photographs have been provided by the Department for Environment and Heritage.

All volumes of sand quoted in this report are compacted volumes, i.e. volumes in situ on the beach. When sand is loaded into trucks, the volume increases by approximately 30%.



The Adelaide coastline, 1992 (SA Tourism Commission)

Executive Summary

Background

Metropolitan Adelaide's coastline is eroding under natural conditions. Sand moves in a net northerly direction along the coast and mean sea level is rising gradually. Erosion of the coastline has been compounded by unwise coastal developments in earlier years. The Coast Protection Board is restoring and maintaining beaches on the metropolitan coastline as the most desirable means of coast protection. As a consequence, the Board also sustains a beach environment that is a valuable State amenity and tourist asset. Annual public visitation to Adelaide beaches far exceeds that of other recreational activities.

Since 1973, the necessary supply of sand to the southern beaches has been drawn from northern onshore sites by recycling or from offshore areas by dredging pockets of suitable sand. The replenishment method is effective and economical in that rates of replenishment can be adjusted to meet periods of greater or lesser sand movement or local damage from storms.

The program has been demonstrably successful. The protective sand dunes that have now built up at Brighton, Henley South and Grange are the result of over three decades of beach replenishment carried out by the Coast Protection Board. Seaside councils have contributed by stabilising dunes with sand drift fencing and revegetation programs, and by installing walkways over the dunes. Before the replenishment program, the beaches from Brighton to Henley Beach were narrow with no beach at high tide, and storm erosion regularly damaged foreshore roads, car parks and community facilities. Since the replenishment program, storm damage has been reduced to around 5% of the damage bill for the same period before 1973.

Reviews of the management of Adelaide's metropolitan beaches in 1984, 1992 and 1997 supported the replenishment strategy as the most cost-effective way of maintaining sandy beaches and protecting property on the foreshore. However, beach replenishment relies on sustainable and economical sources of sand being available. By the late 1990s, historical sources of sand had been exhausted and alternatives were likely to cost considerably more.

The reference group for the 1997 review recommended that alternative sources of sand be investigated as a matter of urgency to supplement the existing finite amount of sand within the metropolitan beach system. The reference group also recommended that maintaining beach quality for recreation and amenity should be given due regard in future coastal protection programs.

Of immediate concern to the 1997 reference group was the erosion at Semaphore Park and the associated loss of amenity and risk to property. Ten years of sand carting had not provided a long-term solution to the erosion problem in that area and alternative protection measures needed to be considered. A plan for protection of the area with a field of breakwaters was initiated, with construction of a trial breakwater at Point Malcolm starting in 2003 and being completed in February 2005. The trial is at an early stage but the breakwater is already holding sand in the area and performing as expected.

Since the 1997 review, the Coast Protection Board has carried out a range of offshore and land-based sand source investigations. A large reserve of suitable sand has been identified in the Mount Compass area, estimated to be sufficient to supply Adelaide's beaches for hundreds of years at current replenishment rates. However, the need for washing to remove clay and the supply costs for sand from Mount Compass are much higher than for sand from within Adelaide's beach system.

The cost of managing Adelaide's beaches continues to grow because of dwindling local sand sources, seagrass loss, rising sea levels and the need to bypass sand around the harbours at Holdfast Shores and Adelaide Shores. In 2000, on behalf of the Coast Protection Board, the Department for Environment and Heritage initiated a review of the management of Adelaide's beaches to address these issues. Based on the effectiveness of existing strategies, input from the community and a series of modelling and feasibility studies, the Department for Environment and Heritage has developed *Adelaide's Living Beaches: A Strategy for 2005–2025*.

Somerton Park
(SA Tourism Commission)

Seacliff (Johnny Kamma)

Components of the future strategy

Adelaide's Living Beaches: A Strategy for 2005–2025 has five main components:

1. ***Continue beach replenishment*** – Continue the existing program of beach replenishment, placing 160,000 cubic metres of sand each year at strategic locations on southern and central beaches to maintain the sandy foreshore, build up dune buffers, and protect coastal infrastructure.
2. ***Recycle sand more effectively using sand slurry pumping and pipelines*** – Existing sand supplies will be recycled more effectively using sand slurry pumping and pipelines, which will minimise the need for trucks to cart sand along beaches and suburban roads.
3. ***Add coarse sand from external sources*** – Coarser, more stable sand will be added to the system from external sources such as Mount Compass to tackle the ongoing loss of dune volume and beach width caused by sea level rise and other factors.
4. ***Build coastal structures in critical locations*** – Structures such as groynes and offshore breakwaters may be used in a few critical locations to slow the northerly drift of sand.
5. ***Integrate sand bypassing at harbours with beach management*** – Integrating sand bypassing requirements at harbours with the beach replenishment program will result in more effective recycling of sand and reduced harbour management costs.

The following aims are also part of the strategy:

- Continue the Semaphore Park Protection Strategy, which may involve construction of five low-profile offshore breakwaters by 2010, after trial completion in 2006–07. Assess the benefit of using similar breakwaters at a few critical locations elsewhere.
- Trial sand slurry pumping methods such as the Sand Shifter and Slurrytrak, and investigate how pipelines can be installed unobtrusively behind dunes and at the top of seawalls.
- Maintain the necessary sand dune buffer along the metropolitan coast to provide protection for two 1-in-100-year average return interval storms, with an allowance over time for one metre of sea level rise as a consequence of climate change. This is in accordance with Coast Protection Board policy and provides for a dry sandy beach amenity above high tide. Sand dune volumes and beach widths are used as management performance indicators.
- Redistribute the existing sand dune supplies that have built up over the last half-century in order to protect development and maintain beach width from Kingston Park to North Haven.
- Educate the community on the value of recently created dunes as primarily a source of sand to provide protection and beach amenity rather than for conservation of biodiversity. The dunes need to be vegetated to prevent sand drift and this provides a secondary benefit as habitat for birds and animals. Even so, it must be recognised that the dunes could be eroded away in a storm event. In contrast, the Tennyson and Minda dunes are remnants of the original Adelaide coastal dune field and will be preserved and restored accordingly. Native vegetation at these and other locations will be managed according to current best practice and in line with management plans being prepared in conjunction with local councils.

- Finalise offshore sand investigations at North Haven, the Section Bank, Port Stanvac and Moana. Continue evaluation of onshore and inland sand reserves, particularly at Mount Compass, and determine methods of sand supply to the beach from the main arterial roads to avoid trucking through residential streets. Continue investigation of the benefits of using coarse versus fine sand for beach replenishment.
- Continue investigation of the use of the Section Bank as a sand source. Consider using fine sand from Taperoo and North Haven to maintain seabed levels at the Section Bank, which would minimise changes to wave energy and habitat.
- Continue seagrass rehabilitation investigations, because seagrass loss increases littoral drift. Rehabilitated seagrass meadows would improve the marine ecosystem and halt further increases to coastal erosion (they would not reduce coastal erosion to previous levels).
- Continue to assess sand losses from the metropolitan beach system and evaluate survey data on beach and seabed levels to indicate sand volume and beach condition changes.

West Beach (Johnny Kamma)

Implementation

The strategy for 2005–2025 will be implemented in a phased manner to:

- trial the Semaphore breakwater over three years to ensure an adequate assessment of design features
- trial sand pumping methods and equipment
- investigate how pipelines can be installed unobtrusively behind dunes and at the top of seawalls
- ensure that designs are prepared in a manner that takes into account existing development and land use
- allow time for public consultation in conjunction with development applications
- allow time for the necessary infrastructure to be put in place
- allow the dune reserves at the Torrens Outlet and Semaphore to erode gradually over time with the mechanical removal of sand.

The Adelaide metropolitan coast will effectively be divided into seven management cells, with some interconnectivity between them (see Figure A).

Brighton (Johnny Kamma)

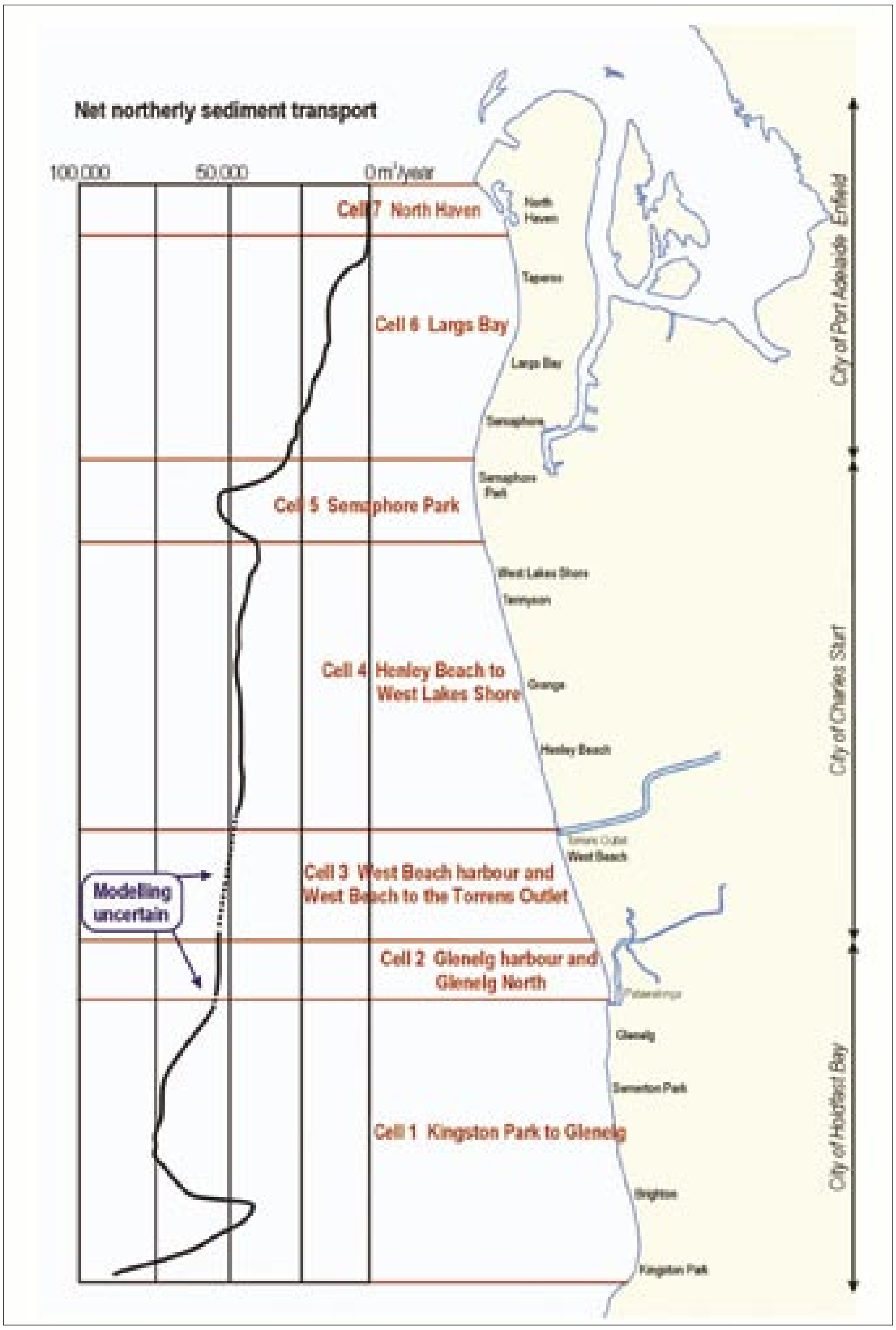


Figure A *Coastal management cells in the strategy for 2005–2025*

The actions proposed for each coastal management cell are outlined in Table A.

Table A *Management actions based on sediment transport rates within each coastal cell*

Coastal management cell	Proposed actions
1: Kingston Park to Glenelg Average annual net northward drift of sand is 70,000 m^3	Add 25,000 m^3 of sand each year to the dunes at Brighton/Seacliff to counter the ongoing loss of dune volume and beach width along the metropolitan coast caused by sea level rise and other factors. From 2005–06 to 2008–09 this sand will be backpassed from the Torrens Outlet, with coarse sand added from trials of onshore sources. In 2006–07 backpass 40,000 m^3 of sand from Glenelg to Brighton/Seacliff by truck and commence construction of the pipeline between Glenelg and Kingston Park. In 2007–08 start pumping 50,000 m^3 of sand each year from Glenelg to Kingston Park.
2: Glenelg harbour and Glenelg North Expected annual net northward drift of sand is 50,000 m^3 at Glenelg North	Dredging of the Glenelg harbour will be managed by the Department for Environment and Heritage from 2005–06 onwards (it was previously managed by Transport SA). In 2005–06 bypass approximately 100,000 m^3 of sand from channel and tombolo maintenance around the Glenelg harbour to Glenelg North. Thereafter, bypass only 20,000 to 30,000 m^3 of sand each year. Continue using a dredge to bypass seagrass from the channel and tombolo to offshore Glenelg North. In 2006–07 undertake a sand pumping trial to backpass 30,000 m^3 of sand from the West Beach harbour to Glenelg North and commence construction of the pipeline between the West Beach harbour and Glenelg North. In 2007–08 start pumping 30,000 m^3 of sand each year from the West Beach harbour to Glenelg North. Consider construction of two breakwaters between Glenelg North and the West Beach harbour as an alternative to backpassing.
3: West Beach harbour and West Beach to the Torrens Outlet Expected annual net northward drift of sand is 50,000 m^3 from West Beach to Torrens Outlet	Dredging of the West Beach harbour will be managed by the Department for Environment and Heritage from 2005–06 onwards (it was previously managed by Transport SA). From 2005–06 bypass approximately 30,000 m^3 of sand and seagrass around the West Beach harbour each year. From 2005–06 to 2008–09 draw down the sand reserves at the Torrens Outlet by 50,000 m^3 each year, with 25,000 m^3 of sand backpassed to Brighton and 25,000 m^3 bypassed to Henley Beach South. In 2005–06 undertake a sand pumping trial to backpass 40,000 m^3 of sand from south of the Torrens Outlet to the West Beach dunes. In 2006–07 backpass 40,000 m^3 by truck/scraper and commence construction of the pipeline from the Torrens Outlet to the West Beach dunes. In 2007–08 start pumping 40,000 m^3 of sand each year from the Torrens Outlet to the West Beach dunes. This assumes that, of the dredged bypass sand, at least 10,000 m^3 each year can be fed onto West Beach and that, under current conditions, an average of around 16,000 m^3 of sand accumulates each year at the Torrens Outlet despite annual mechanical bypassing of 25,000 m^3. Construct a breakwater north of the West Beach Surf Life Saving Club if erosion there cannot be contained. Consider a breakwater south of the West Beach Surf Life Saving Club to further stabilise dunes if necessary.
4: Henley Beach to West Lakes Shore Expected annual net northward drift of sand is 50,000 m^3	Until the Semaphore Park breakwater field is completed, this area will depend on mechanical bypassing of 25,000 m^3 of sand each year from the Torrens Outlet plus natural northerly drift. From 2009–10 onwards, backpassing of 50,000 m^3 of sand by pipeline from south of the breakwater field will be necessary.
5: Semaphore Park Expected annual net northward drift of sand to breakwater is 60,000 m^3	In 2005–06 backpass 40,000 m^3 of sand from the trial breakwater at Semaphore South to Semaphore Park. The trial breakwater is currently operating until 2006–07. In 2007–08, subject to successful completion of the trial, armour the trial breakwater and construct a new rock breakwater. In 2008–09 construct two further breakwaters (subject to the results of the trial) and commence construction of the pipeline from south of the breakwater field to the Torrens Outlet. In 2009–10 construct a final breakwater (subject to the results of the trial) and start pumping 50,000 m^3 of sand each year from south of the breakwater field to the Torrens Outlet.
6: Largs Bay Expected annual net northward drift of sand is 30,000 m^3	During the breakwater trial, backpass up to 10,000 m^3 of sand each year from Semaphore to the north of the trial breakwater using trucks or scrapers. This assumes around 33,000 m^3 of sand drifts north past the breakwater each year. Subject to successful completion of the breakwater trial, draw down the Semaphore dunes to fill the salients of the breakwater field, using a temporary pipeline to pump the sand to Semaphore South.
7: North Haven No expected annual net northward drift of sand except for accumulation south of, and in the channel of, North Haven	Dredge the channel at North Haven (conducted by the Department for Transport, Energy and Infrastructure). Consider using the reserve of fine sand at North Haven, and further south towards Largs Bay, to backfill the Section Bank if dredging of beach replenishment sand from the Section Bank is found to be economically and environmentally sound in the future.

Glenelg (Johnny Kamma)

Economic assessment

All practical alternatives for managing Adelaide's beaches are costed in this report, including three different ways of recycling sand within coastal management cells – using trucks and excavators, using a Slurrytrak and pipelines, and using Sand Shifters and pipelines.

Completion of the Semaphore Park Coast Protection Strategy, involving the possible construction of a field of breakwaters at Semaphore Park, is assumed in each scenario. An increased supply of externally sourced sand is also assumed in each scenario, with the cost based on supply from Mount Compass. The net present values provided in Table B do not take into account the expected planning, policy, research and monitoring costs over the next 20 years. These costs are similar for each scenario.

The net present value of the progressive construction of a groyne field has been included to demonstrate its prohibitive cost.

Table B *Net present value of the costs of each scenario over a 20-year period*

Scenario	NPV ($million) at different discount rates		
	4%	7%	10%
Progressive construction of a groyne field	–113	–89	–73
Existing management activities	–89	–70	–57
Future strategy using excavators and trucks	–76	–60	–49
Future strategy using a Slurrytrak and pipelines	–75	–61	–51
Future strategy using Sand Shifters and pipelines	–67	–56	–47

The cost of the Sand Shifters and pipelines scenario in today's dollars using a discount rate of 7% is approximately $56 million over 20 years, whereas the cost of continuing the existing management activities in today's dollars is approximately $70 million over the same period. This equates to a saving of 20%.

Table C shows the budget impact of the strategy to 2008–09 based on forward estimates and the estimated costs of the future strategy using Sand Shifters and pipelines. The forward estimates include the base allocation for Adelaide beach management and the anticipated funding for managing the harbours at Glenelg and West Beach. The estimated costs shown in Table C do include policy, planning, research and monitoring costs. All costs have been calculated based on an annual inflation rate of 2.5%.

Table C *Budget impact of the strategy to 2008–09**

Financial period	Forward estimates ($ million)	Estimated costs ($ million)	Budget impact Improvement/ (deterioration) ($ million)
2005–06	8.533	8.533	0.000
2006–07	9.168	9.168	0.000
2007–08	10.075	10.075	0.000
2008–09	14.535	14.535	0.000
Total	**42.311**	**42.311**	**0.000**

*The budget required in 2009–10 is estimated at $11.95 million. The budget required from 2010–11 onwards (once no more capital works are required) is estimated at $4.75 million/year.

Social impacts

Beach replenishment activities to date have usually required the presence of trucks and earthmoving equipment on the beach. Earthmoving equipment is loud, especially when reverse warning alarms are in use, and nearby beach users and residents must endure their repeated and unpleasant noise. Although these activities are mostly carried out during those months when there are fewer people on the beach, the work still poses a risk of injury, disturbs beachside residents and deters visitors from using the beaches.

Another concern about beach replenishment activities to date has been the amount of disturbance and traffic congestion created when trucks cart sand along suburban roads. Much of this disturbance has been experienced in Brighton and Seacliff. Rail crossings and roundabouts are common in these suburbs, and trucks need to slow or stop regularly, thus generating noise from braking and acceleration and air pollution from exhaust fumes.

A major benefit of the strategy for 2005–2025 is that the use of pipeline transfer systems will minimise the need for earthmoving machinery and trucks on beaches and suburban roads. Nevertheless, some negative impacts on the community will be associated with the strategy. For example, a significant but short-term matter will be the effect on beach amenity and public safety during construction of pipelines and booster stations. It is likely that some beach areas will need to be fenced off. In the event that this is necessary, all efforts will be made to maintain a safe route along the coast for pedestrians, as has been past practice for coastal works.

There will be ongoing but relatively minor impacts associated with the sand acquisition and pipeline transfer systems. It is anticipated that the Sand Shifter system would be fully automated and would operate at night under off-peak electrical power, which would reduce the likelihood of noise levels and machinery affecting local residents and beach users. The Slurrytrak system, on the other hand, would operate during the day and, being mobile, could not as easily be electrically powered. Therefore, it would cause some inconvenience due to noise levels and reduced amenity. However, the system is able to transfer sand at a much higher rate than the historical method of excavating and trucking, so the impact on any given area of the coast would be minimal.

The concept of each system has particular merits for use at different locations along the coast, depending on sand depth, beach slope and the wave energy that provides the supply of sand. The proximity to development will also be an important consideration because of noise and machinery impacts. Both concepts will be evaluated on the basis of performance and site impact.

It is expected that the Sand Shifter and Slurrytrak systems would pump sand only intermittently, thus minimising the time of discharge from pipeline outlets. Because seagrass and other material is separated through a screening process before entering the pipelines, discharged sand can be placed directly onto the beach, and the likelihood of nuisance odours and deleterious matter being present is reduced.

The use of structures to slow sand will be limited to a few critical locations because of their visually intrusive nature and potential interference to beach users and coastal residents. To be effective they have to be high enough to be exposed during most tidal conditions. Careful design can, however, minimise this impact by ensuring that the height is carefully chosen for the structure's purpose. Breakwaters are generally preferred over groynes because they do not have such a hard effect on the coast and maintain easy alongshore pedestrian access.

Sand carting at Glenelg, 2004

West Beach dunes, June 2005

Environmental impacts

The environmental impacts caused by beach replenishment activities are many and varied although once identified they can be minimised through best-practice management.

The Coast Protection Board has many years of experience in undertaking beach replenishment using sand from both within and external to the Adelaide beaches. As part of its beach replenishment program, the Board has undertaken and commissioned environmental impact investigations, put in place measures to minimise and manage environmental impacts, and commissioned studies to evaluate impacts that have occurred. Therefore, the Board is well placed to identify potential environmental impacts and prepare plans to manage these.

Environmental impacts of each component of the strategy for 2005–2025 are discussed in detail in section 7.3. Overall, options such as recycling sand within coastal cells and adding sand from external sources are preferable to structures in terms of environmental considerations.

Risk assessment

The current management strategy is to replenish beaches by trucking sand, which maintains beach amenity and provides protection to development, with seawalls constructed as the last line of defence against storms. This strategy is flexible because management activities can be adapted early to adjust beach levels without costly changes to capital infrastructure. Harbour management, currently carried out by contract dredging, is adaptable to the volume of sand that needs to be bypassed and is not constrained by a commitment to capital investment in infrastructure. However, current beach replenishment and harbour management methods disrupt public enjoyment of the beach and coastal residents, and move sand inefficiently.

The main risks associated with the future strategy are that the sand slurry pumping equipment may not have sufficient capacity, may not be able to access sand accumulations effectively, and may require additional screening devices to handle dead seagrass. These risks can be accounted for in a trial period sufficiently long to evaluate the available equipment before committing to a plan of action. The pipeline component of the strategy has been well tested in practice, poses minimal risks apart from storm damage, and is most suited to being provided through public infrastructure investment.

The alternative management options of extensive structural solutions such as groynes and breakwaters present much higher risks, needing a high level of capital investment in fixed infrastructure that is not readily adaptable to unforeseen or changing management requirements.

Community education and consultation

The community has the right to not only be informed about issues facing the beaches and their possible solutions, but also to be involved in decisions about how the beach is managed. Community members often bring valuable experience, knowledge and skills to coastal management activities.

A number of public meetings have taken place since the 1997 review to discuss beach management activities with local residents and community groups. Participation in the Metropolitan Seaside Councils Committee and the City of Charles Sturt Community Coastal Reference Group has facilitated communication between the Department for Environment and Heritage, community groups and councils concerning coastal issues and potential management strategies.

In early 2003, a focus group was formed to update the Coast Protection Board's understanding of community views on beach management and provide assistance in identifying stakeholders. The focus group included representatives from Coastcare, the Conservation Council of SA, the Port Adelaide Residents Environment Protection Group, the Henley and Grange Residents Association, the Friends of Patawalonga Creek and the Marine Discovery Centre.

In 2003, the Department for Environment and Heritage commissioned a study to determine how the community uses the beach, the value of particular beach attributes, and attitudes towards different beach management strategies. A clean beach, a clean ocean and having sandy beaches were considered valuable by a large proportion of respondents. Beach replenishment received the most support in terms of different management strategies, because it was generally perceived to be the most effective and least intrusive method. Pipelines were suggested by some participants as an effective way of maintaining sand on the beaches while minimising social impacts.

The community clearly agrees that sand must be maintained on the Adelaide beaches, not only for protecting coastal properties and infrastructure but also for the social, recreational and economic benefits a sandy beach provides. However, there is a need to reduce the impact of beach replenishment and sand slowing activities on beach users and coastal residents.

The views of the community have been considered carefully during the development of the strategy for 2005–2025. For example, the strategy will use pipeline transfer systems to recycle sand more effectively and minimise the need for trucks and earthmoving equipment on beaches and suburban roads. Structures such as groynes and breakwaters will only be used in critical locations because of their visually intrusive nature and potential interference to beach users and coastal residents.

It is important to note that affected individuals and groups will be consulted on the strategy over the coming years as part of the development application process, which is required before the necessary infrastructure can be put in place.

Glenelg (SA Tourism Commission)

Conclusion

On behalf of the Coast Protection Board, the Department for Environment and Heritage has developed a strategy for managing Adelaide's beaches from 2005 to 2025. The strategy has resulted from a review of Adelaide beach management initiated in 2000 in response to the increasing cost of coastal management and the need to reduce the number of trucks carting sand along beaches and roads.

The strategy for 2005–2025 is an innovative plan to ensure the long-term future of Adelaide's sandy beaches. It is based on the examination of the benefits and costs of a range of strategies along with the results of a series of modelling and feasibility studies and input from the community. By using pipeline transfer systems to recycle sand, and integrating sand bypassing at harbours with beach management, the strategy will reduce not only the cost of managing the Adelaide coastline but also the impact of coastal management on beach users and seaside residents. The pipeline transfer system also allows for the placing of sand where it is most needed, rather than being constrained as at present by the availability of only a few truck access locations along the coast. Structures such as groynes and breakwaters will only be used in a few critical locations because of the impact they have on coastal amenity. Coarse sand will be added to the system from external sources to counter the ongoing loss of dune volume and beach width caused by sea level rise and other factors.

Children playing at Kingston Park (Johnny Kamma)

1. The Adelaide Coast

1.1 The metropolitan beach

The metropolitan beach extends for over 30 kilometres (km) from Marino Rocks in the south to Outer Harbor in the north. For the purpose of managing sand, it is defined as the zone of beach deposition onshore to the seaward limit of seagrass meadows, which is at a water depth of approximately 18 metres (m) (Figures 1.1 and 1.2).

Figure 1.1 *Composite aerial photograph of the Adelaide metropolitan coastline, 2002*

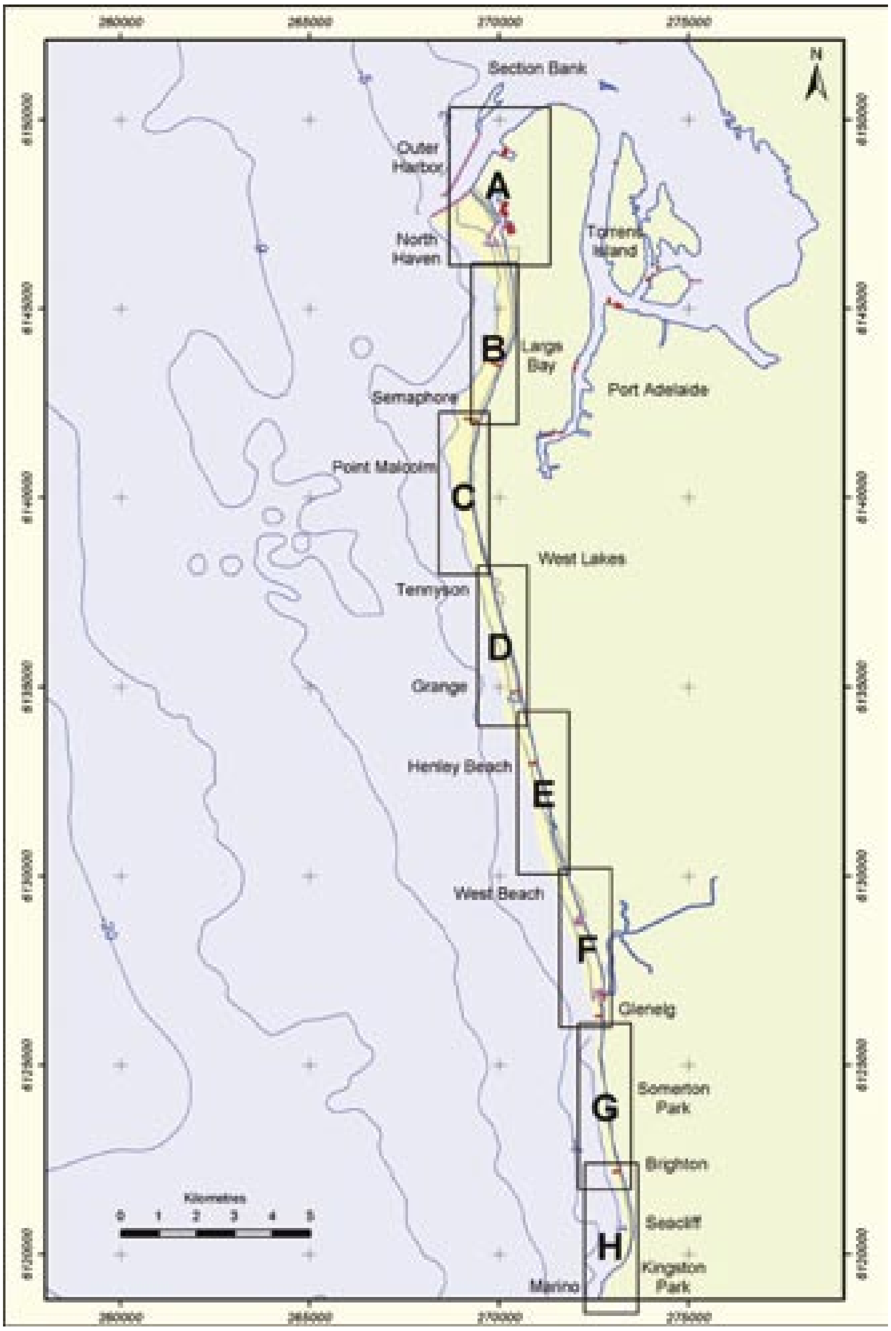


Figure 1.2 *Extent of the Adelaide metropolitan coastline – comparative aerial photographs from 1949 and 2002 of areas A–H (see pages 15 to 22)*

The narrow beach at Somerton Park, 2000

The region consists of a largely independent littoral cell in which sand is moved in a net northward direction by waves and currents. Adelaide's beaches are mostly continuous, although the Outer Harbor breakwaters, North Haven marina, Torrens Outlet, Adelaide Shores boat haven and Holdfast Shores marina each cause disruption to sand movement along the coast.

Most of the land behind the foreshore was developed from the early 1900s onward. Roads, buildings, houses, recreational areas, and sewerage and stormwater infrastructure were often built right over coastal dunes. Consequently, less of the dune sand is available to act as a buffer to coastal erosion during storms, and so the foreshore and beaches are now protected by substantial works – early on in the form of seawalls and from the 1970s mainly by replenishing beaches with sand.

Many of the changes on the metropolitan coast over the past 50 years can be seen in Figure 1.2 (a–h), which shows comparative aerial photographs taken in 1949 and in 2002. The extensive urban development at North Haven, West Lakes Shore through to Tennyson (including West Lakes itself), West Beach and Glenelg North has been mostly over sand dunes. Several structures have been built out onto the coast including the North Haven marina, the Adelaide Shores boat haven and the Holdfast Shores marina. The 'blue line' (i.e. the line showing the inner seagrass meadow boundary) has moved far offshore north of Glenelg. For example, compare aerial photo D from 1949, in which the inner seagrass meadow boundary is quite distinct offshore from Grange, with the 2002 photo, in which very little seagrass is visible. Changes in beach width are less obvious, although some beaches such as those north of Point Malcolm have widened while others further south have narrowed. Current areas of interest for managing Adelaide's coast are the sand dunes, beaches, sandbars, seabed and seagrass meadows. Many of the issues that affect our coast lie away from it, in water catchments, urban areas and drainage outlets. The metropolitan coast needs to be considered not only as a system in its own right but also as part of the greater Adelaide region.

1.2 Geological setting

Adelaide beach sand was deposited as a result of a natural rise in sea level from approximately 18,000 to 6500 years ago. Sea level rose by about 130 m submerging land surfaces including those in Gulf St Vincent. The beach sand is derived from sediments deposited by rivers and streams into the gulf during low sea level periods. These sediments were eroded by waves as the sea level rose, with the main influx of sand to the coast occurring 7000–5000 years ago. Sediments were deposited onshore until waves had eroded the seabed to a depth at which they could no longer transport sand; and dunes were formed by wind action on the beach deposits. (Beach sand is generally more coarsely grained than the windblown sand of the dunes.)

1.2.1 St Kilda formation

The sand along most of the Adelaide coast is known geologically as 'Semaphore sand', named after its type locality. It forms part of the Holocene (c. 10,000 years ago to present) St Kilda formation (Figure 1.3). The sand consists mainly of siliceous grains reworked from sediments that are most likely of Permian origin, i.e. 300 to 350 million years old.

Figure 1.2a 1949

Figure 1.2a 2002

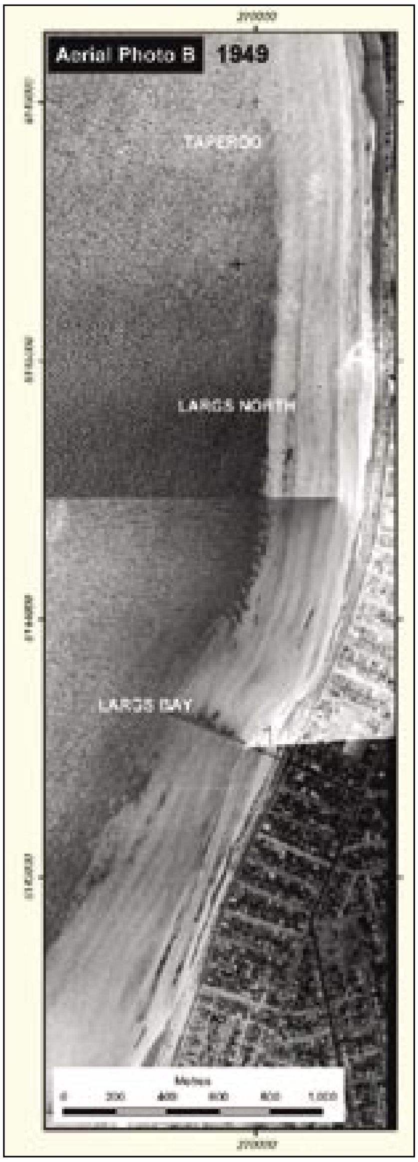


Figure 1.2b 1949

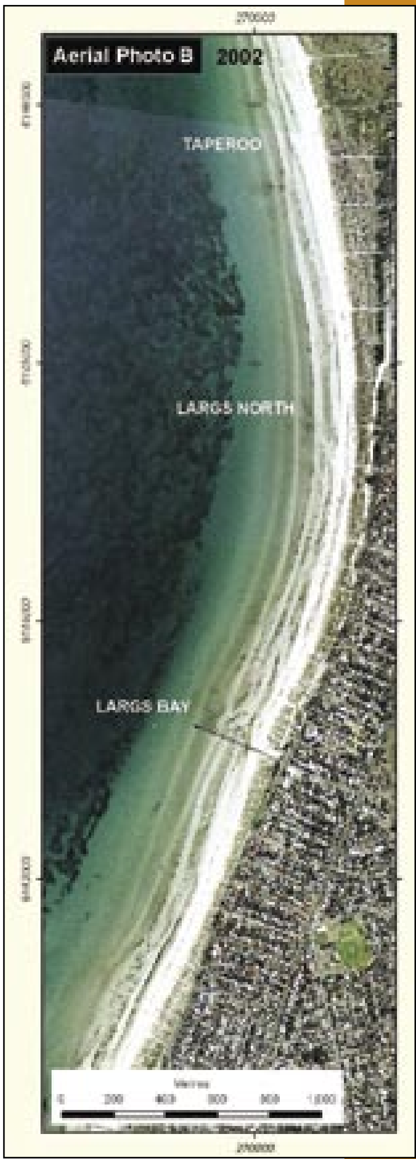


Figure 1.2b 2002

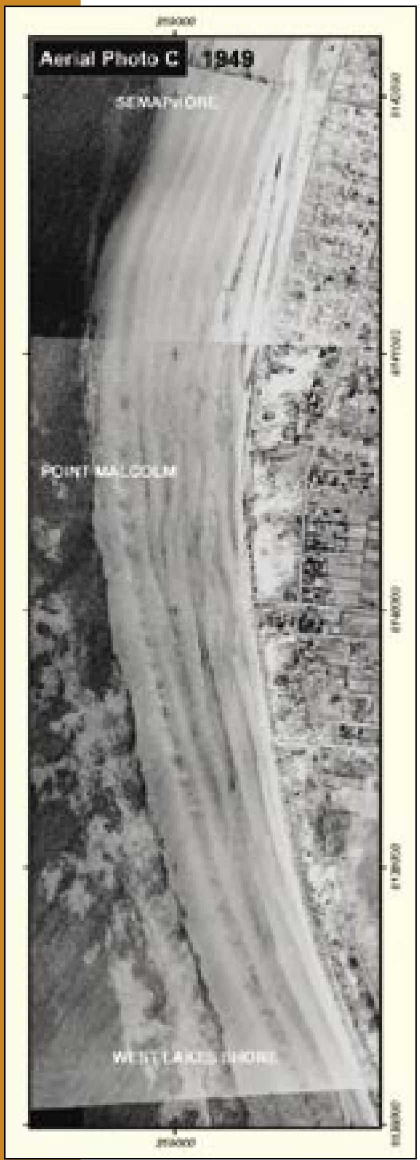


Figure 1.2c *1949*

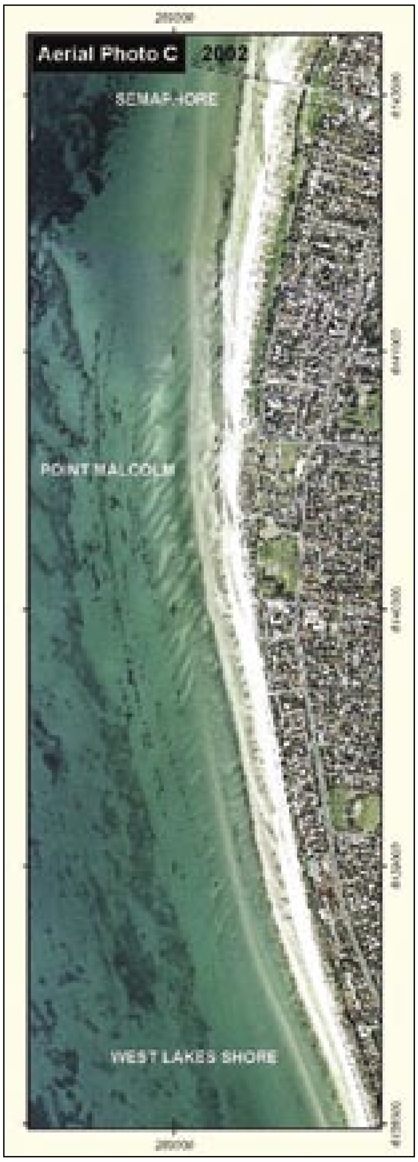


Figure 1.2c *2002*

Figure 1.2d 1949

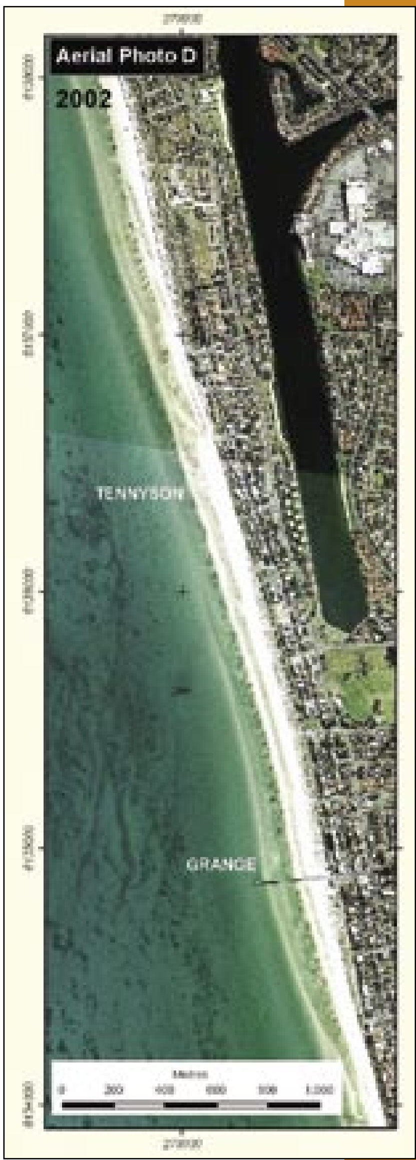


Figure 1.2d 2002

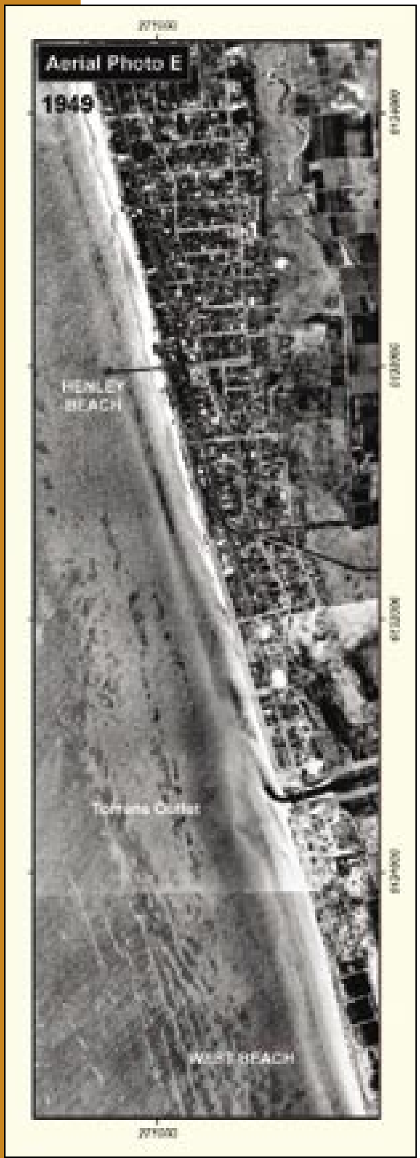


***Figure 1.2e** 1949*

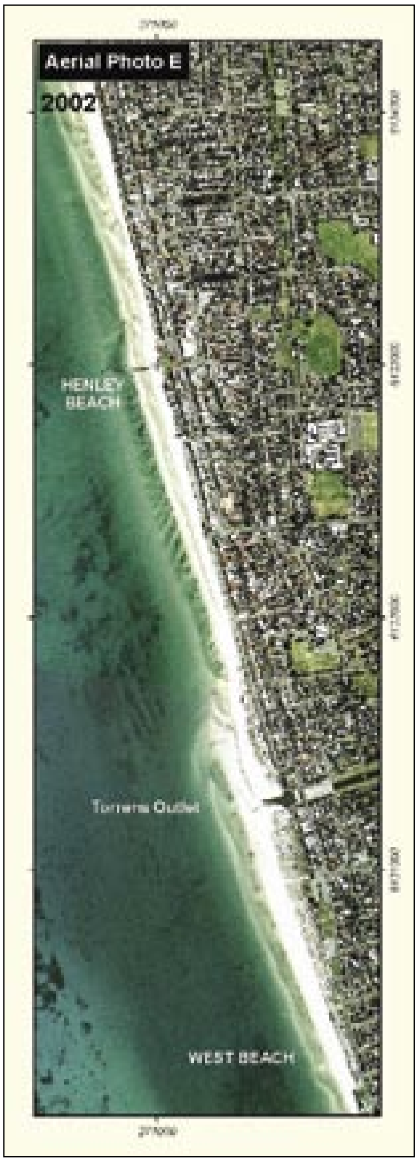


***Figure 1.2e** 2002*

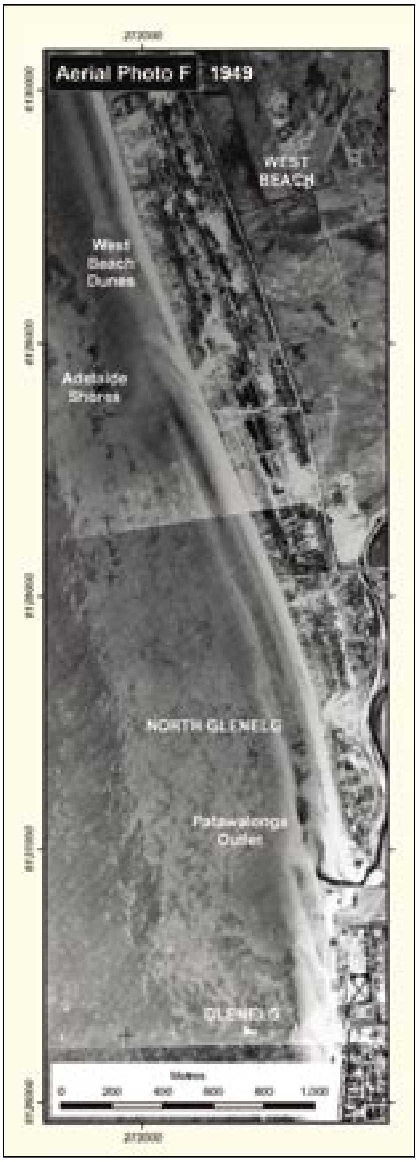


Figure 1.2f 1949

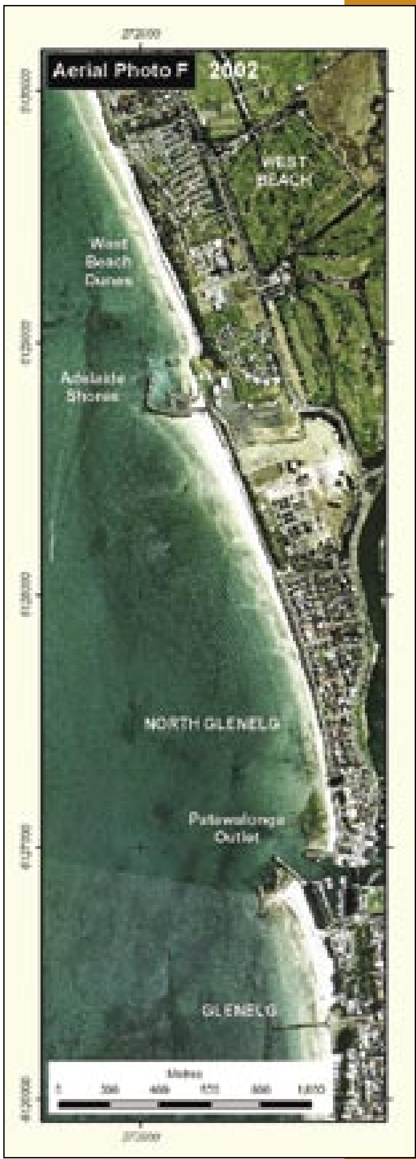


Figure 1.2f 2002

Figure 1.2g 1949

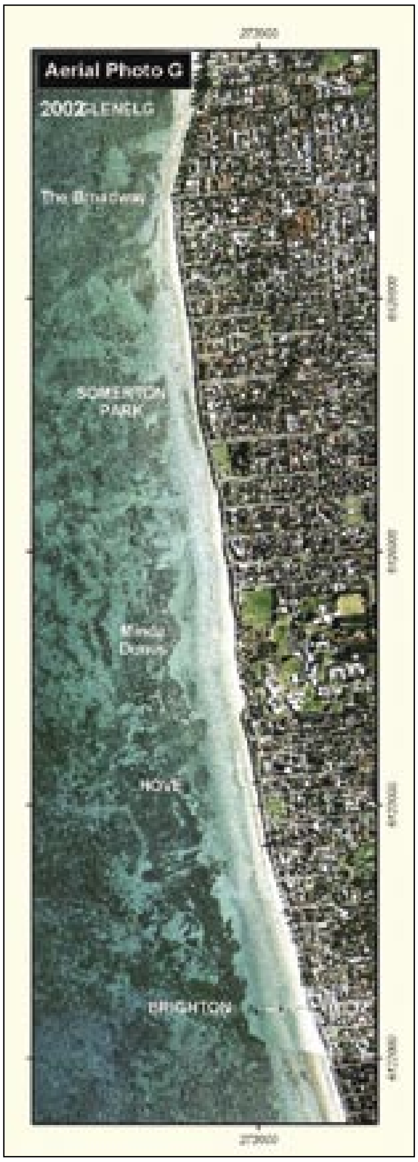


Figure 1.2g 2002

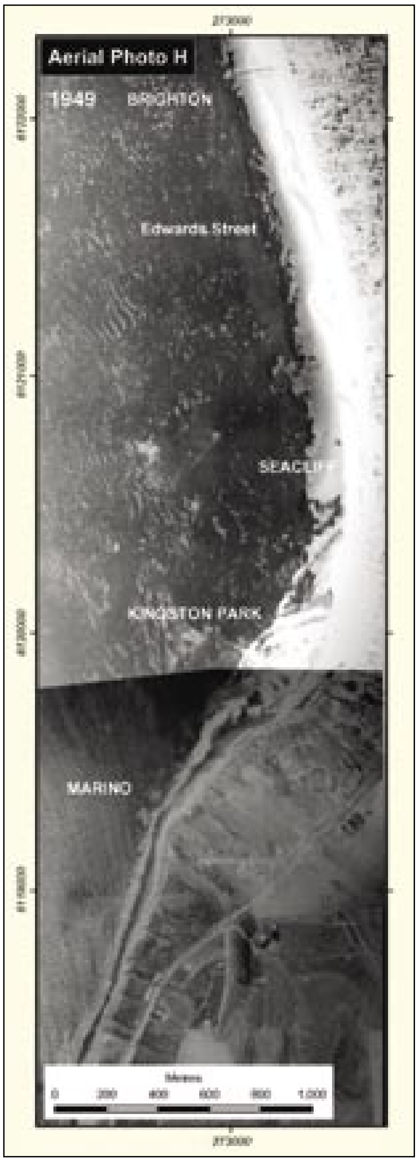


Figure 1.2h *1949*

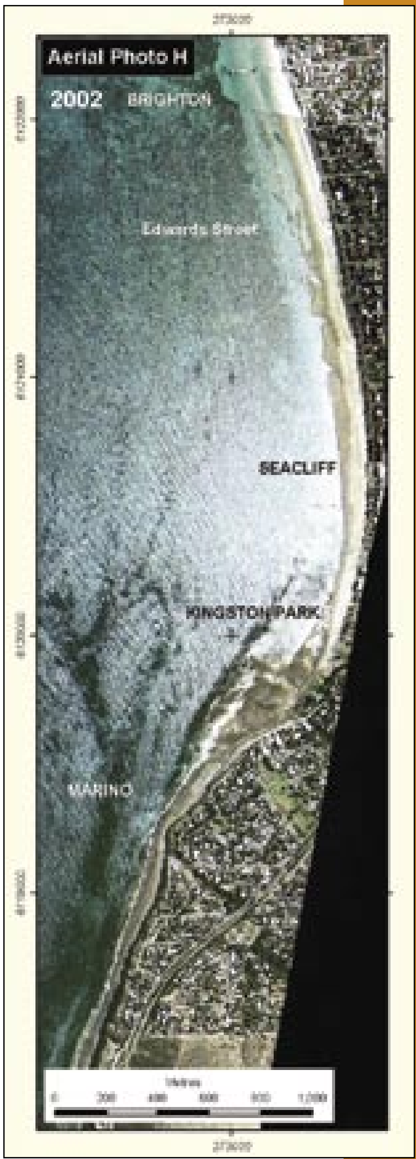


Figure 1.2h *2002*

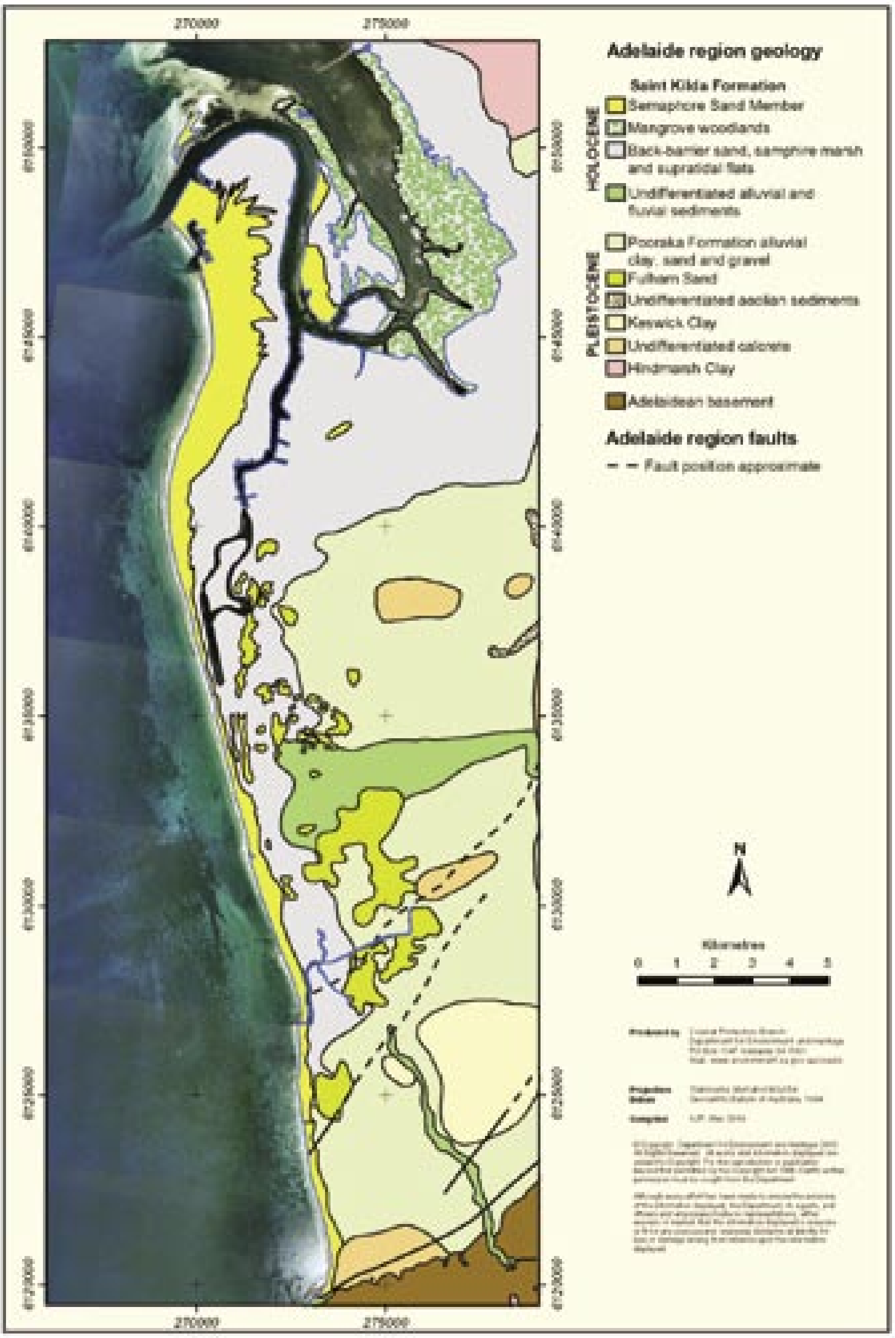


Figure 1.3 *Map of the Holocene St Kilda formation along the Adelaide metropolitan coast (adapted from Belperio 1995)*

At the base of the St Kilda formation is a thin veneer of intertidal sediments. This merges into sandy beaches and dunes consisting of loose, well-sorted, highly permeable, fine to coarse-grained shelly quartz sands. The quartz grains are generally rounded to sub-rounded. Between 3% and 30% of the sand is carbonate material (Culver 1970) derived from the breakdown of nearshore fauna and flora such as bivalves, bryozoans and red algae. A minor siliceous bioclastic component of the sand is derived from small algae called diatoms.

Off Adelaide's coast and around the Port River estuary and Barker Inlet, seagrasses have trapped sediments that can be up to 7 m thick. These consist of poorly sorted, bioclastic-rich, muddy sand bound loosely by seagrass fibres with numerous small foraminifera and mollusc shells.

Thin but extensive shelly, low intertidal sandflat facies have formed in the protected lee of Lefevre Peninsula. A significant build-up of Holocene sediments within the northern metropolitan beach region is more than 10 m thick in some areas.

At present very little new sand is being formed offshore or reaching the Adelaide coast via rivers, creeks or coastal cliff erosion. Most sand on northern metropolitan beaches and the Lefevre Peninsula has been transported northward from the southern beaches.

1.3 Sand attributes

The total amount of sand, sand type (i.e. grain size, composition, roundness or angularity, and mix with other materials) and sand distribution greatly influence the coastline we see today.

The total amount of active sand in the Adelaide coastal system (i.e. the littoral cell) is an important concept for the management of sand. Potential losses and sources of sand need to be identified, quantified, understood and managed when and where necessary. This concept – the sand budget – is also a recognition that sand neither 'vanishes' or 'appears'; it just goes somewhere else or comes from somewhere else. If a beach builds up in any one place, then somewhere else there is less sand, whereas if a beach erodes in any one place, then elsewhere sand builds up. For Adelaide, the littoral cell extends to a depth of around –5 m Australian Height Datum (AHD). This depth is found at varying distances offshore along the Adelaide beach as shown by the inner shore 5 m contour line in Figure 1.2.

1.3.1 Sand type

Sand composition, grain size and grain roundness or angularity all affect the physical movement of sand by waves and currents.

Adelaide beach sands consist predominantly of quartz (silica) grains and variable proportions of shelly fragments depending on the location. This mixture of silica and shelly material and the range in sand grain size are generally a result of natural sorting processes and 30 years of beach replenishment. Much of the silica sand is sub-angular to well rounded, whereas the shelly fraction consists of soft biogenic material and sharp shell fragments.

Figure 1.4 shows an increase in carbonate content and decrease in grain size of sand north of Semaphore jetty since 1964. This is due to the onshore movement of sand from the lost seagrass beds, estimated to be in the order of 80,000 m^3/year.

Sand grains on Adelaide beaches are generally rounded with a median grain size of 0.22 millimetres (mm). The grains do not tend to reduce in size as a result of the continuous impact of wave energy. This is because smooth particles of this size have low inertia in collision with one another and tend not to shatter or abrade (Coastal Management Branch 1984).

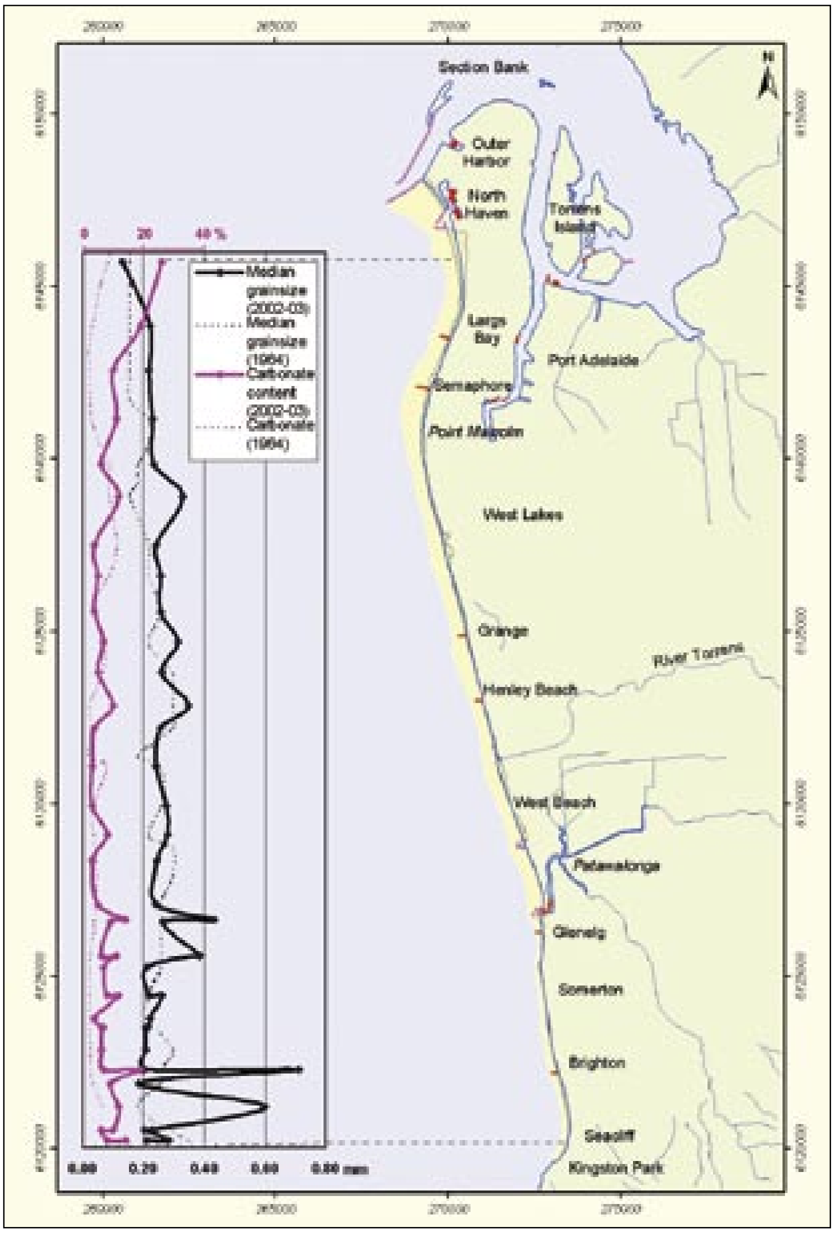


Figure 1.4 *Median grain size and carbonate percentage of sand along the Adelaide coastline*

Movement related to sand type (and overfill ratio)

Fine sand moves more rapidly along the coast than coarse sand. Fine sand is also more susceptible to wind action and forms dunes more easily.

If replenishment sand is finer than the original beach sand, it will be more easily moved by waves and wind and is therefore less stable.

One of the methods used to determine the suitability of sand for replenishing beaches is to calculate the overfill ratio, assuming that the sand is mineralogically similar. This indicates whether or not replenishment sand will be more, less or as stable as the sand native to the beach being replenished. For example, if the overfill ratio for a particular replenishment sand is 2, it indicates that every 2 cubic metres (m^3) of replenishment sand placed on the beach would be as effective as only 1 m^3 of native beach sand. Thus, the cost of this replenishment sand must be multiplied by two to determine the cost of replenishing the beach. Conversely, if the overfill ratio is less than one, the replenishment sand is more stable than native sand, and more cost-effective than sand with a higher overfill ratio.

Another aspect of replenishment sand suitability for beaches consisting of mostly silica sand is the proportion of carbonate or shelly sand in the mixture. North Haven beach sand is more than half carbonate, compared with only 3–10% for beaches south of Point Malcolm. This carbonate sand has settled out in northern Largs Bay for the same reason as the fine quartz sand – it is easily moved along the coast by wave action. It is also likely that there is an offshore supply of carbonate material to the northern beaches (Coastal Management Branch 1984). The carbonate sand is as unsuitable for replenishing southern beaches as fine quartz sand. Overfill ratios of more than 10 have been determined for sand from some areas north of Semaphore.

If grain size is doubled then movement alongshore reduces by only about 20%. However, the offshore movement occurring during storms reduces by 80% if grain size is doubled (Coastal Engineering Solutions 2004).

1.3.2 Sand distribution

The amount of sand distributed along the Adelaide coast is not uniform. A much greater quantity of sand has been deposited in some areas than in others. The northern beaches generally have more sand and a shallower, low-gradient seabed than areas such as Brighton where the seabed is deeper close to shore. The thickness of the sand layer in the seabed varies from less than 1 m in places to around 10 m deep, depending on the depth of clay and rock layers below the seabed.

In general, for a given wave environment, fine sand results in flatter, often multi-barred beaches while coarse sand results in steeper beaches. Therefore, in the northern part of the Adelaide littoral cell where the sand is finer, beaches tend to be wide with up to three or four sandbars along the shore. Southern Adelaide beaches tend to be narrow with single sandbars along the shore.

Similarly, for a given sand grain size, attenuated flat waves tend to produce steeper beaches whereas steep waves tend to produce flatter beaches.

1.3.3 Effective beach and dune width

A term used to describe beach condition that reflects sand distribution is *effective beach width* (the width of the dry sandy part of the beach). Effective beach width is quite variable in Adelaide due to the cyclic variation in tidal range. It also depends on beach slope, which is dependent on sand grain size and wave environment.

Effective dune width is a term that is useful in assessing whether a dune has built up to a high enough level for plants to colonise. In Adelaide, herbs and grasses are able to colonise and trap sand that has built up above approximately 2 m AHD. Tides and storm surges occasionally exceed this level and remove ephemeral foredune vegetation. More permanent dune vegetation requires dune heights of greater than 3 m AHD, which are seldom reached by storm tides although they can be undermined readily if the shoreline recedes.

1.4 Sand supply

Most of the sand along Adelaide's coast is sand eroded from the seabed and deposited along the shoreline around 7000–5000 years ago following Holocene sea level rise. From that time to present, the beaches and dunes formed. Sand moving northwards also formed Torrens Island and the prograding spits underlying Lefevre Peninsula (Figure 1.5).

The sand is still moving northward but the amount of mobile sand left in the littoral cell is very limited. Only with continual beach replenishment will this process be able to continue without causing irrevocable erosion in southern areas.

1949 aerial photograph showing building out of dune strandlines on the Lefevre Peninsula

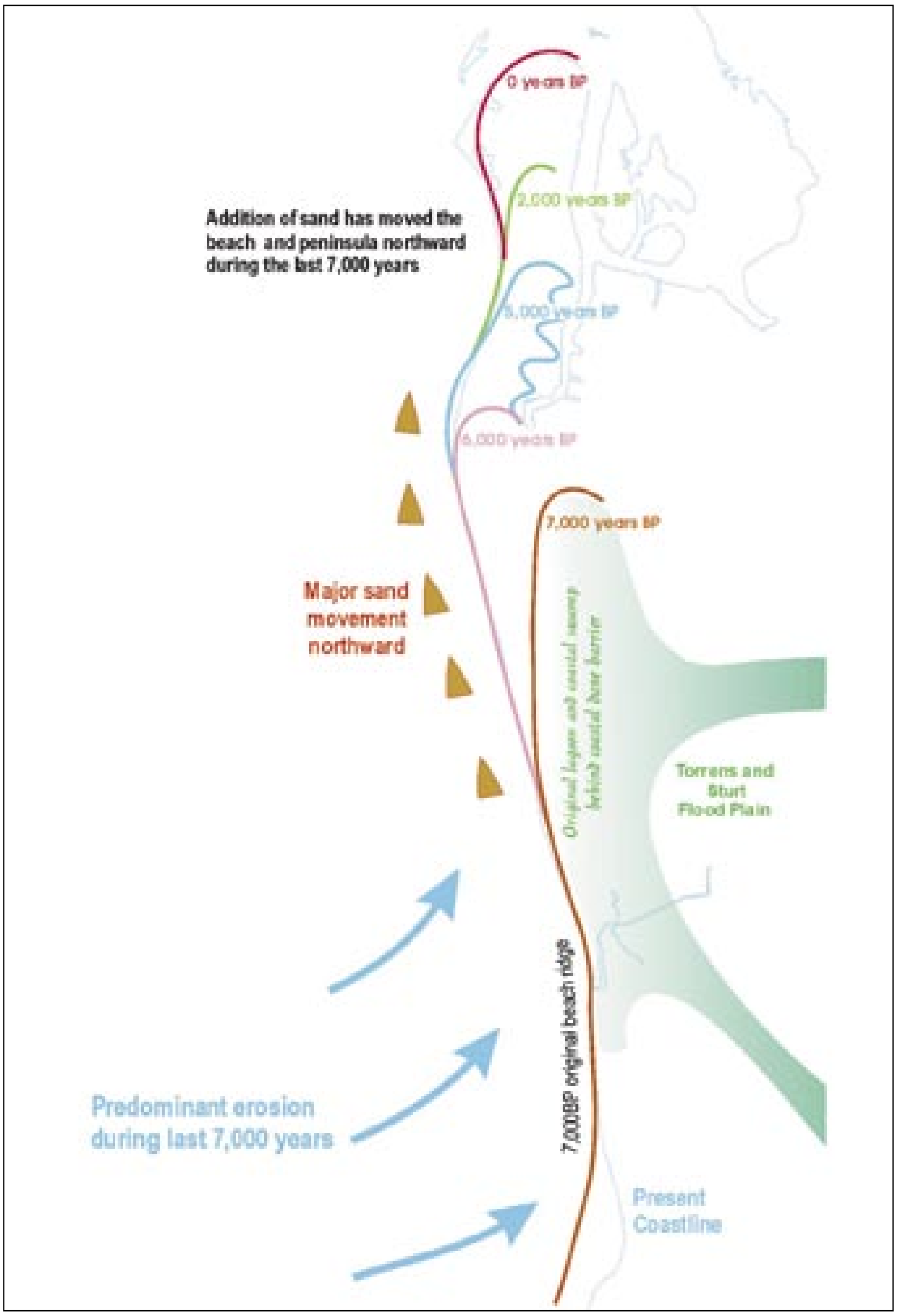


Figure 1.5 *Building out of the northern metropolitan coastline over the last 7000 years (BP: before present, based on 14C dating with present at 1950) (adapted from Gostin 2005)*

1.4.1 Geomorphological supply

Sand derived from geomorphological sources is generally not of sufficient quantity to contribute significantly to Adelaide's coast. Some is contributed from the erosion of coastal cliffs and nearshore wave-cut platforms in the south, which is then washed into the active beach zone.

Apart from the Onkaparinga River, which flows into its own sediment-trapping estuary, waterways along the Adelaide plains only periodically deliver fine silt and clay sediment to the coast during times of higher flow. In the past, Sturt Creek and the Torrens fed into wetland regions where most of their sediment was deposited. The Barcoo Outlet and Torrens channel have since been built to drain stormwater run-off into the sea.

1.4.2 In situ supply

In situ material is produced off Adelaide's coastline from the remains of organisms that live in seagrass meadows and intertidal beaches. Numerous small molluscs, foraminifera, coralline algae and other benthic fauna and flora inhabit the nearshore environment. Most of these are made up of carbonate material, which can contribute anywhere between 3% and 40% of the sand fraction, with the higher percentages mostly at the northern beaches.

Interestingly, sand further north of the metropolitan coast at St Kilda and Port Gawler consists predominantly of modern biogenic fragments, whereas the Adelaide coastal sand is mostly quartz sand with only a minor amount of in situ bioclasts. This highlights the differential migration of finer and lighter bioclastic sand from Adelaide's offshore seagrass areas to north of the littoral cell due to the significant northerly decrease in wave and swell energy.

1.5 Coastal processes

Adelaide's coastline results from an ever-changing, dynamic environment influenced by the interaction of numerous physical, geological and biological processes acting over different time and spatial scales. The following sections provide an overview of tides, currents, winds and waves, storms and surges, sand transport and biological activity (more comprehensively covered in chapter 2 of the 1984 *Adelaide Coast Protection Strategy Review* (Coastal Management Branch 1984)).

1.5.1 Tides

The tidal range on the Adelaide coast varies from about 2.4 m at spring tides to near zero at neap tides, although winds and atmospheric pressure gradients also cause significant changes in the sea level. Tidal currents in coastal Adelaide waters are essentially north–south alongshore, with speeds up to 0.2–0.3 metres per second (m/s).

Tide levels are measured from a local chart datum (CD), which is different for each major port. By international convention, the datum is set at the calculated lowest astronomical tide (LAT). Tide predictions and measurements for Outer Harbor were converted to this datum on 1 January 2001. At Outer Harbor, LAT is 1.452 m below the AHD, which is consistent across Australia. Table 1.1 shows commonly used tide levels, as determined by Flinders Ports Pty Ltd and published in the tide tables, for Outer Harbor in both CD and AHD.

Table 1.1 *Tide levels for Outer Harbor*

Level	Chart datum (m)	Australian Height Datum (m)
Lowest astronomical tide	0.00	–1.45
Mean sea level	1.30	–0.15
Australian Height Datum	1.45	0.00
Mean high water neaps	1.30	–0.15
Mean high water springs	2.40	0.95

Mean high water spring tides and mean high water neap tides

Tide tables commonly refer to other levels such as mean high water springs (MHWS) and mean high water neaps (MHWN). The former is defined as the average of all twice-daily high tides at spring periods, while the latter is averaged over neap tide periods. Spring tides refer to the periods when the predicted tidal range is at its greatest – when the solar and lunar influences on the oceans work together at or soon after the new or full moon. Neap tides are the periods when the tidal range is smallest, between the new and full moon – when the lunar and solar influences are opposed and cancel each other out to some degree.

The South Australian sea

The South Australian sea has resonance periods that influence the separate components of diurnal tidal constituents in such a way that an apparently peculiar tidal behaviour occurs. The effects are different in each of the two gulfs. In Gulf St Vincent, the entrance conditions create an apparent standing oscillation that causes high tide to occur at the same time everywhere in the gulf. Both gulfs also experience an unusual situation known as 'dodge tides', which occur near the equinoxes and are due to tidal modifications causing water levels to remain constant the whole day. The phenomenon, which also occurs to a lesser extent on other parts of the South Australian coast, is described by Bye (1976).

Coastal Management Branch 1984

1.5.2 Currents

Tidal and wind-generated currents are of secondary importance to waves in moving sand along the nearshore zone. They play an important role in dispersing pollutants that can affect seagrass health. Modelling of water circulation in Gulf St Vincent first carried out by Bye (1976) indicated a net northerly movement along the metropolitan coast. The reality is that there is a relatively complex circulation pattern in the area with seasonal variations.

Recent work for this review shows that winds from the south-west sector dominate, which can produce a northerly wind-set current of around 0.15 m/s for a 25 knot wind speed (Coastal Engineering Solutions 2004). When combined with the northerly tidal current, this can create a net northerly movement of sand brought by waves from seabed sediment into suspension.

1.5.3 Wind and waves

Culver (1970) described the wind pattern for Adelaide as follows:

> There appears to be a relatively regular pattern evidenced each year. In January, February and March the predominant wind pattern is primarily south-west with some south-east and north-east wind. Late March and April shows a well distributed wind pattern (right round the compass). In May, north-west and south-west winds begin to show longer durations and higher velocities. This pattern continues into June and July often with stronger north-west winds predominating (with some north-east activity). West to south-west winds begin to blow stronger in August and continue into September with increasing velocities. The equinox is traditionally squally and the September–October period shows strong winds between the north-west and south-west quarters. The distribution in November is again well round the card but with longer duration west-south-west winds evident. In December, wind velocities are lower with south-west winds predominating with some north-east activity closely paralleling the January and February pattern.

Sea waves reaching the metropolitan beaches are mostly generated by west-south-west winds. Together with swell entering Gulf St Vincent through Investigator Strait and wave refraction, the resultant net wind-wave direction is northward. Strong wind-waves in Gulf St Vincent have been recorded with periods of 4–6 seconds, heights up to 2.6 m and directions ranging from 250° to 310°, depending on wind direction (Culver & Walker 1983a).

Swell waves that propagate to the southern metropolitan beaches have 12–16 second periods, heights below 1 m, and directions close to 260° (Lawson & Treloar 1989). The importance of sea waves and swell in moving sand on the Adelaide coast is shown in Figure 1.6.

Sea breezes, created by the difference in land and sea temperatures in warm and hot weather, occur frequently on summer afternoons. The resulting choppy waves contribute to the multiple sandbar formations typical of Adelaide beaches in summer conditions.

1.5.4 Wave set-up and run-up

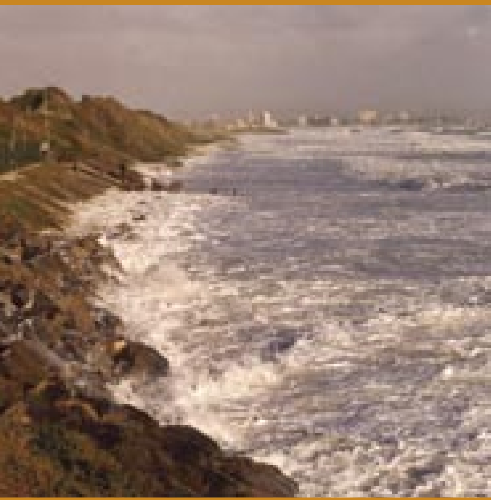
The still-water sea level inside the surf zone is slightly higher than that applying outside this zone or at the tide recorder locations. This is because breaking waves cause a build-up of water shoreward of the breaker zone. This build-up depends on the height of the breaking waves and on the beach slope, and cannot be predicted with great accuracy.

Wave set-up should not be confused with wave run-up, which is the height to which a particular wave will run up a certain slope. However, wave run-up computations usually include wave set-up. Calculation of wave run-up is not particularly useful for the Adelaide situation where seawalls are either rip-rap rock construction or older vertical concrete walls. However, wave set-up needs to be taken into account in determining the depth of water against seawalls and the water levels inside the surf zone at such places as the Patawalonga and North Haven. The tide staff at the Patawalonga locks is influenced by wave set-up, and during storms it indicates higher tide levels, by approximately 0.2 m, than those recorded at the Outer Harbor gauge (Coastal Management Branch 1984).

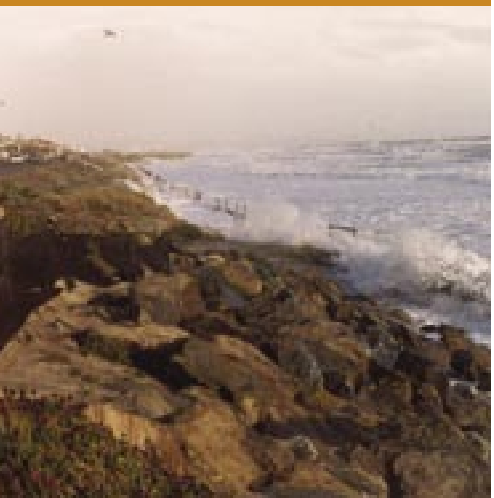
The wave climate at North Haven shows that the significant wave height exceeds 0.5 m around 20% of the time with a corresponding wave period of around 4 seconds. Based on wave hindcasting and the experience of the dredge operators in the past, the most suitable period of the year to operate a floating plant is between April and July.

Storm surge, Glenelg South, July 1995

Storm surge, the Broadway, Glenelg, July 1995



Storm surge, West Beach, July 1995



Storm surge, Henley Beach South, July 1995

1.5.5 Storms and surges

Storms have a considerable impact on beaches, beach infrastructure and sand distribution. The most apparent impact of storms is on sand dunes and the most severe impacts occur when storms coincide with a high tide or a surge. Surges, often associated with storms but also arising from other ocean-based phenomena, raise water levels higher than predicted tide levels and waves consequently wash directly into dunes. During these storms, sand is usually washed seaward into sandbars, from which it returns to the dunes under calmer periods. (Waves have an onshore and offshore motion component. Storm waves have less onshore than offshore movement than calmer flatter waves, which exhibit a greater onshore component.) Storm surges of over 1.5 m have been measured in Adelaide – a significant size compared with the normal tidal cycle.

A storm at high tide, particularly spring high tide, with a large surge can be very damaging to dunes and the foreshore including seawalls. A storm at low tide will have little impact on dunes but can wash sand offshore, potentially seaward of the normal sandbar location and to depths deeper than those at which ambient waves can readily return the sand to the beach.

Storms can also increase turbidity and erode seagrass meadows.

Storms surges are most pronounced if winds persist in a north-westerly to westerly direction. These winds force water into Gulf St Vincent, by deflection from Kangaroo Island, significantly raising water levels. This is called *wind set-up*.

Most significant storms on the Adelaide coast occur during May and June, with approximately half as many occurring during July and August. The few major storms in spring and early summer are rare events. January, February and March are the calmest months and obviously the best months for coastal works (Coastal Management Branch 1984).

1.5.6 Sand transport

Four actions are responsible for most sand movement on Adelaide beaches:

1. Wind-driven wave action (sea waves and swell) drives longshore drift. Since the resultant net wind-wave direction is northward, the net sediment transport direction is also to the north. This movement of sand on the eroding coast from Brighton to Semaphore is estimated to be 40,000–70,000 m^3 each year, depending on the location (see Figure 1.6). Only a limited amount of sand (in the order of 5000 m^3/year) enters the Adelaide beach system from the south at Kingston Park.
2. Waves transport sand in an offshore–onshore direction. The maximum amount of sand that might be expected to be lost from dunes by this action from a storm in the order of a one-in-100-year return period is about 40 m^3 per metre of beach length above the 1 m AHD level (around the toe of the dune at high-water mark). This was recorded at West Beach after a series of storms in 1981 that would have equated to such an event (see Coastal Engineering Solutions 2004 for a discussion of the investigation).
3. Tidal and wind-generated currents could transport up to 25,000 m^3/year of sand northward within nearshore areas where there is no seagrass.
4. Onshore winds blow sand to form sand dunes and winds from other directions move sand along the beach.

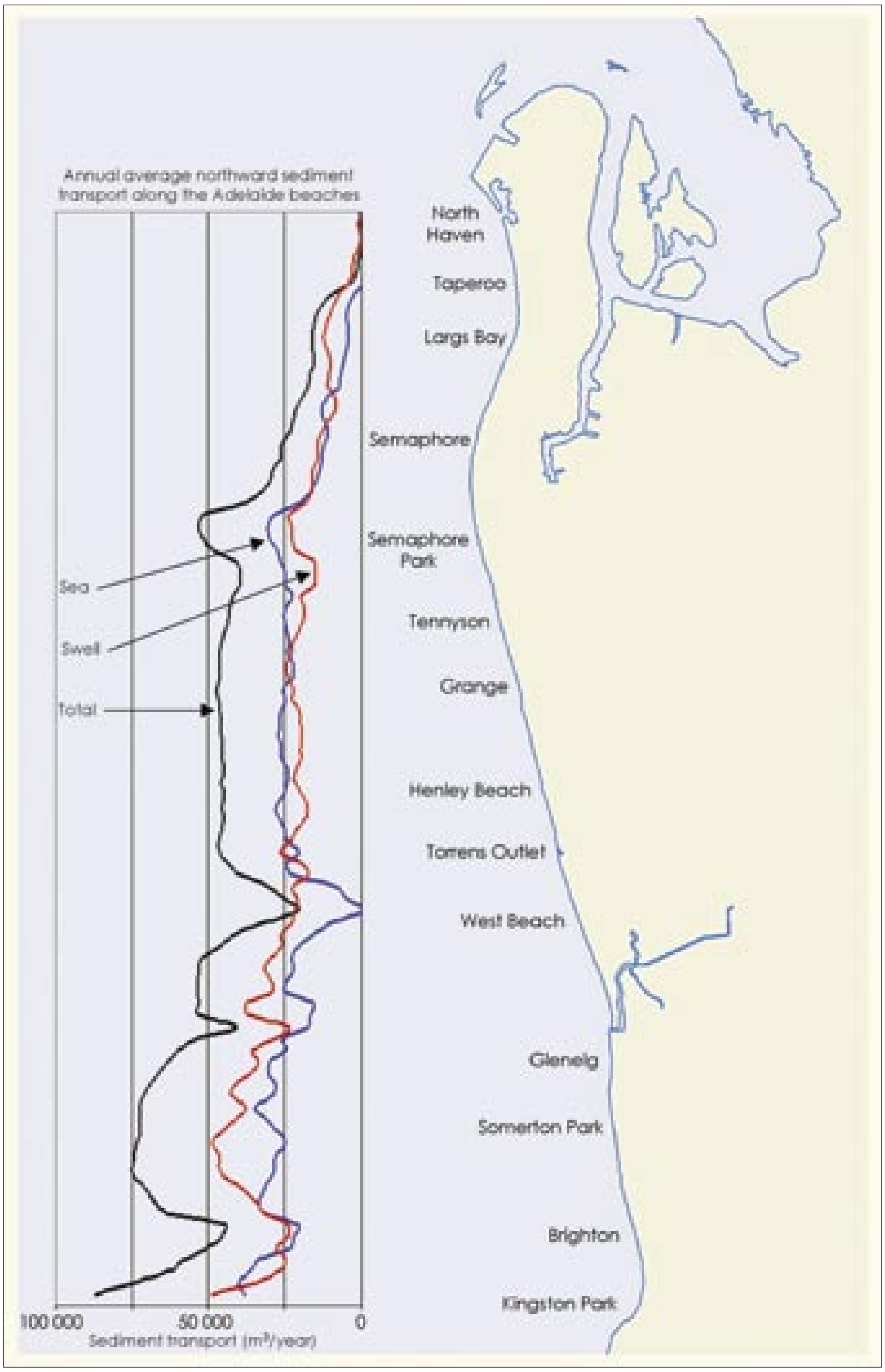
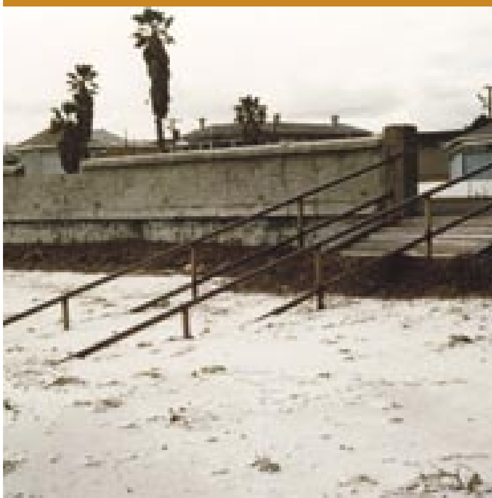


***Figure 1.6** Longshore sediment transport potential with sea and swell components (adapted from Coastal Engineering Solutions 2004)*

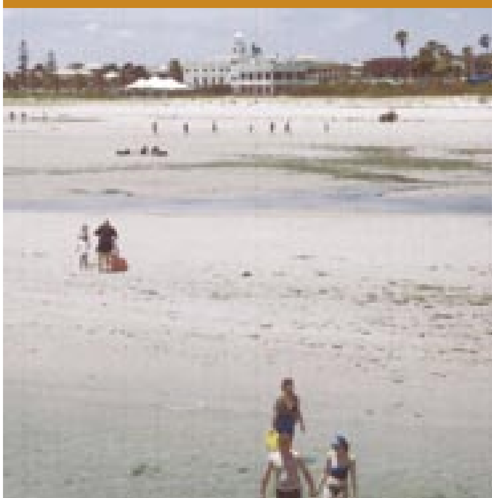
On the Adelaide coast, the months from September to January experience the most northerly drift, almost twice that in the winter months.

It is possible for sand to move without a long-term trend of erosion or accretion – this *dynamic equilibrium* has parallels with many other physical processes. At the southern and northern ends of the Adelaide coast, sand movement is not in dynamic equilibrium. Along with cyclic events, there are longer-term changes not often noticed on a day-to-day basis. For example, the long-term build-up of dunes at Semaphore due to sand moving north along the coast has gone unnoticed by many. This build-up comes at the expense of sand on beaches at Seacliff and Brighton.

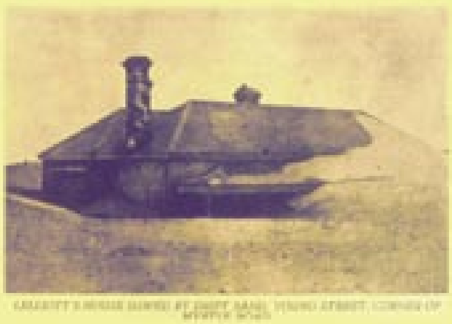
Semaphore, 1923



Semaphore, 1970



Semaphore, 2002



Early photograph of a house at Seacliff nearly buried by windblown sand

Did you know?

On most beaches, sandbars are formed as a result of winter storms, and sand moves back onto the beach in calmer summer weather.

Adelaide is special: sandbars are most often formed by summer sea breezes, which form choppy waves – the type that wash sand off the beach to form a sandbar. In Adelaide, the calmer conditions that rebuild the beach are the gentle rolling swells that come from the southern ocean – this is the gentle wave lapping on still days often following winter storms.

Have you ever noticed how often there are sandbars on Adelaide's beaches right throughout summer?

Windblown sand

Sand can be moved or lost from the coast by wind blowing over it. This process depends on the wind speed, size of sand grains, moisture content and the extent to which sand dunes or other features reduce wind flow. Windblown loss of sand from Adelaide beaches was previously estimated at 80,000 m^3 annually (Culver 1970); drift fencing and dune planting have now reduced the loss to far less significant quantities (Coastal Management Branch 1984).

1.5.7 Biological activity

The Adelaide coast has been an ideal environment for establishing diverse seagrass meadows in subtidal waters at depths of around 2–18 m. The more common seagrasses growing along the coast are *Posidonia sinuosa, Amphibolis antarctica, P. angustifolia, Heterozostera tasmanica* and *Halophila* species.

Seagrass meadows provide habitats for marine and benthic organisms. They function as nurseries for many species of commercially important fish and crustaceans. Numerous molluscs, sponges, ascidians, worms, temperate corals, foraminifera, algae, epiphytes and diatoms also live in Adelaide's temperate coastal waters.

Onshore, a mixture of native and exotic herbs, grasses and shrubs has colonised the dune system. The strandline dunes closest to shore consist of up to 90% herbaceous weeds such as *Cakile maritima**. Incipient dunes contain some herbs and low fast-growing grasses such as the sea wheat grass *Thinopyrum junceiforum** and the native *Spinifex sericeus*. Still further into the foredunes are the pioneer woody plant species including *Olearia axillaris* and *Acacia longifolia* var. *sophorae* (Figure 1.7).

* introduced species

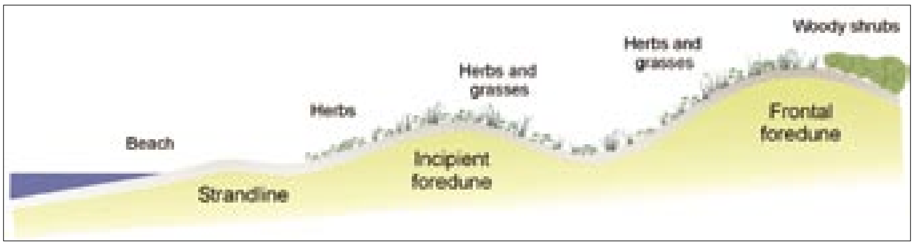
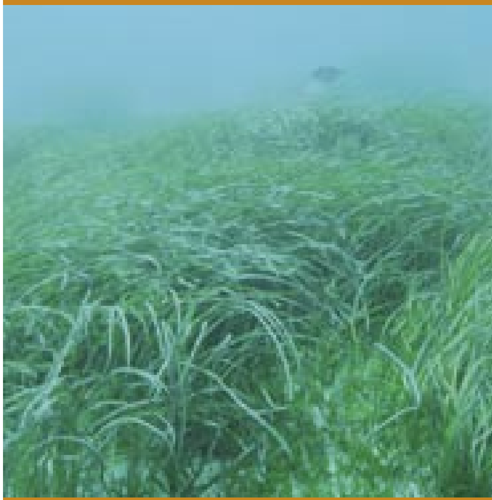


Figure 1.7 *Coastal dune cross-section showing vegetation zones*

The dunes support a small remnant population of native birds, such as the singing honeyeater and predator birds including the nankeen kestrel. Most birds, particularly those like the New Holland honeyeater and red wattlebird, are adapted for the urban coastal environment. A significant threat to insects and spiders living in the dunes, such as the ground-living wolf spider, are the Eurasian blackbird and European wasp. Butterflies and moths are found generally where specific food sources are available. A diversity of reptiles is supported by the dunes depending on the amount of shelter and consolidated soil. Native snakes are integral to the coastal ecosystem and cope well in disturbed areas. Other animals living in Adelaide's coastal dunes include introduced rabbits, cats, rodents and even foxes.

The seagrass, beach and dune communities have contributed substantially to sediment accumulation along the Adelaide coast. Before seagrass loss, the nearshore seabed had been raised by 0.2–2.4 m with material in the seagrass matte (Thomas & Clarke 2002).



Seagrasses – Posidonia and Halophila spp.

Dune vegetation – Spinifex sericeus

Blue swimmer crab

2. Human Impacts on the Coast

The shaping of Adelaide's coastline is controlled ultimately by the physical and biological processes of the coastal environment. Yet, within this system, human-induced changes over the long and short term have had a marked effect.

2.1 Coastal development

2.1.1 Dune encroachment

Dunes along the Adelaide coast are encroached on at two scales:

1. a mainly historic encroachment of predominantly residential development over dunes and beaches (impoundment of the pre-settlement dunes by development)
2. the non-structural encroachment of gardens and reserves onto dunes, which is changing the landscape, vegetation and fauna of the dunes, and often giving the impression of private ownership of public land.

Along the length of the Adelaide coast, historic subdivision and subsequent development have extended over the foredunes onto the beach. In some instances, title boundaries have extended to the low-water mark (Coastal Management Branch 1981).

Sand accumulated as a result of littoral drift has provided the basis for substantial urban encroachment, including the development of the suburb North Haven, starting in 1974, and large-scale subdivision on the beach and dunes at Tennyson Heights, Tennyson, since 1976, and more recently at Holdfast Shores, Glenelg, where the latest stage of development was approved in June 2004.

Had subdivisions been restricted to areas further inland, the natural recession of the coast would have been able to continue for many years from Brighton through to Semaphore, with the coastline alignment progressively adjusting inland at southern beaches (see Figure 2.1). The natural littoral drift of sand to the north would have been maintained, but the rate of drift would have gradually reduced as the coast became parallel to the prevailing wave crests.

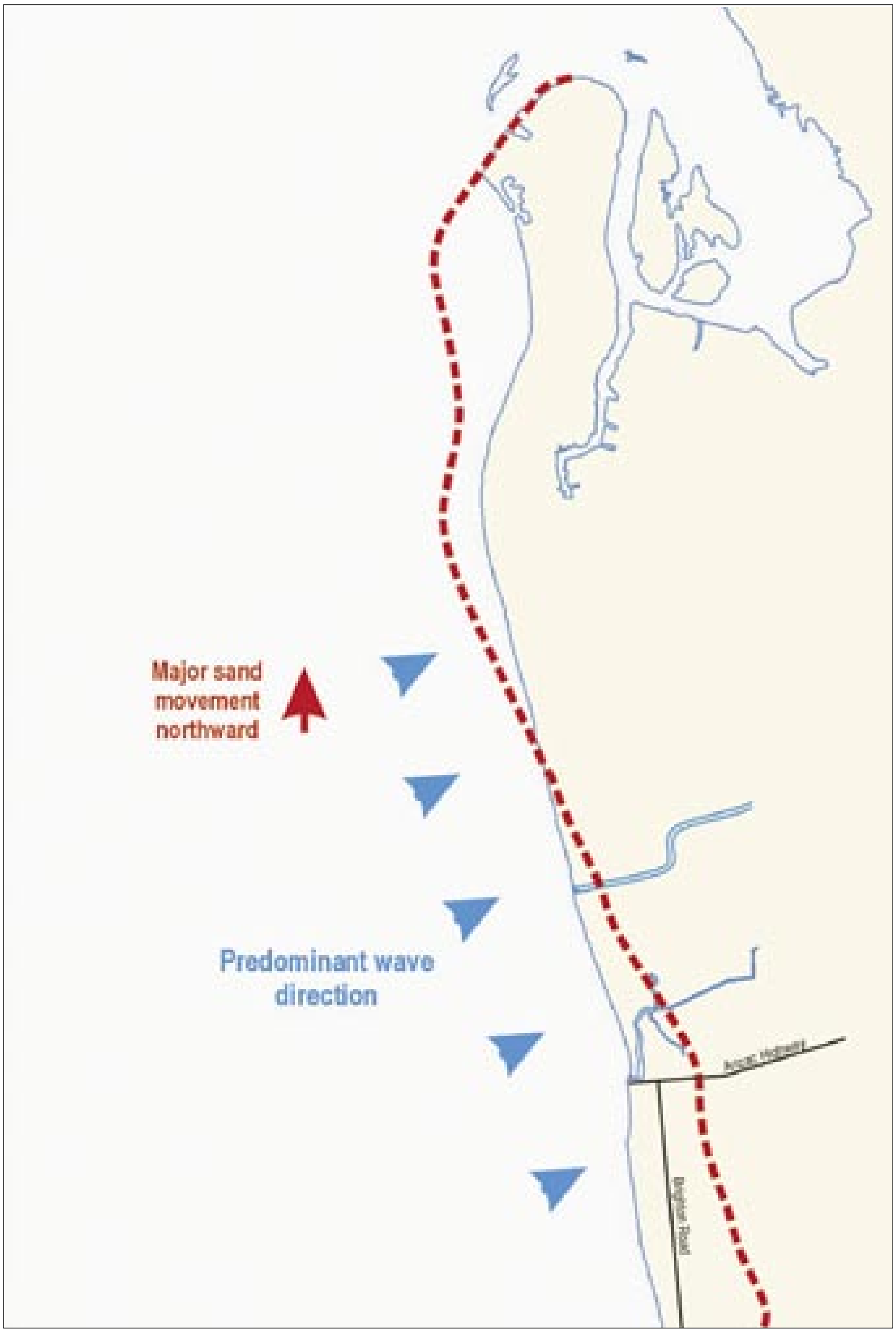


Figure 2.1 *A possible future alignment of the Adelaide coastline had development not taken place on dunes*

2.1.2 Land fill and development

In the 1960s, before any beach replenishment of the coast, sand from the dunes between Seacliff and Largs Bay was used as landfill to build up coastal swamps and low-lying regions for urban growth that included large areas of housing and Adelaide's airport. Before this, and before they were built on, several dunes were 200–300 m wide, with two or three parallel ridges averaging 10–12 m in height.

2.1.3 Sand excavation

Adelaide beach sand has, in the past, been mined commercially from the West Beach dunes, Glenelg South and adjacent to Point Malcolm, and used for glass production and landfill. Now sand is only taken for beach replenishment purposes. The Coast Protection Board has the power of direction over sand excavation on the coast (under section 37 of the *Development Act 1993* and schedule 8 of the Regulations under the Development Act).

In regard to development, the Coast Protection Board is a prescribed body under the Development Act. Pursuant to schedule 8 of the Development Regulations, certain development is required to be referred to the Coast Protection Board by the relevant planning authority. If the development comprises or includes:

i) excavating and/or filling land within 100 m landward of the coast measured from mean high water mark on the seashore at spring tide or within three nautical miles seaward measured from mean high water mark on the seashore at spring tide, where the volume of material excavated or filled exceeds 9 m^3 in total

ii) the placing or making of any structure or works for coastal protection, including the placement of rocks, stones or other substance designed to control coastal erosion, within 100 m landward of the coast measured from mean high water mark on the seashore at spring tide or within 1 km seaward measured from mean high water mark on the seashore at spring tide,

the Coast Protection Board may direct the planning authority to refuse the development application or to impose conditions on any approval granted by the planning authority. Otherwise, the planning authority is required to have regard to the Board advice.

Exemptions to the type of development that is required to be referred to the Board is development that:

a. comprises the construction or alteration of, or addition to, a farm building

b. in the opinion of the relevant authority is of a minor nature and comprises the alteration of an existing building or the construction of a building to facilitate the use of an existing building

c. complies in respect to the relevant development plan

d. is in a River Murray protection area under the *River Murray Act 2003*.

The current position is that sand mining should not be undertaken where sand is used for non-coastal purposes. Where sand is too fine and unsuitable for beach replenishment directly, it can be used for dune creation or other coastal management activities. The Coast Protection Board's policy 3.1 relates to the maintenance of adequate beach levels and precludes sand excavation for any purposes other than coastal management.

Coast Protection Board policies 3.1 and 3.2

Policy 3.1 – The Coast Protection Board will encourage the maintenance of adequate beach levels, both to prevent storm damage and to provide adequate beach recreation space.

Policy 3.2 – The Coast Protection Board will not oppose the construction of beach and nearshore structures (such as seawalls, groynes and breakwaters) where:

- **there is a demonstrated need in the public interest**
- **a comprehensive investigation to an appropriate standard has been carried out.**

Trends towards greater housing density in coastal areas have increased the extent of excavation of already built-on dune areas. Site excavation of this type is mainly for undercroft car parking. Established good practice is for clean sand from such work to be returned to the coast at locations agreed to by the local council and the Coast Protection Board. Through development applications in accordance with section 37 of the Development Act and schedule 8 of the Development Regulations, where more than 9 m^3 is excavated, the Coast Protection Board will direct that surplus clean sand from the development be placed on the beach.

There are no records of the volume of sand added to the coast in this manner but it is small compared with the quantities involved in the beach replenishment program. On average, a redevelopment site could yield in the order of 200 m^3 or 8 semitrailer loads.

2.1.4 Sand impoundment

Sand impoundment is interference with coastal processes that stops sand from moving within an active beach. Its main effect is to reduce the total amount of sand available along the coast. Seawalls constructed to protect development are one cause of sand impoundment.

Sand can also be retained in dunes that are excluded or protected from the erosion/rebuilding cycle. This occurs when coastal processes are altered by structures, circumstances or management practices that cause dunes to build up or prograde seawards, as in the following examples.

1. The southern groyne/breakwater at Outer Harbor constructed between 1903 and 1905 is very long and was intended to trap sand so that the shipping channel could be maintained. There is ample remaining capacity in this sand trap, although the breakwater itself leaks some sand into the shipping channel. The breakwater has trapped sand that would have otherwise washed into the Section Bank area. The beachface built out seaward along the breakwater by about 250 m in 30 years until the North Haven marina began to be constructed just south of it in 1974.
2. The large southern groyne/breakwater at North Haven constructed in 1974 was intended to trap sand so that the marina channel could be maintained. However, the sand trap is now effectively full with sand accumulated to the end of the groyne and spilling into the channel. It requires dredging. The beachface built out seaward by 200 m in this location along the breakwater in the 30 years since construction started.

Early photo of seawall sand impoundment that prevented dune erosion at Henley Beach

Early photograph of Outer Harbor breakwaters

North Haven breakwaters

The Semaphore South trial breakwater during construction, October 2004

The Torrens Outlet, 1949

The Torrens Outlet, 2001

3. At the trial offshore breakwater at Semaphore South, the construction of which commenced in 2004 and finished in 2005, a portion of the littoral drift sand is trapped before it reaches the accumulating beach area at Semaphore. The trapped sand is to be carted south to the eroding Semaphore Park beach. Some of the sand bypasses the breakwater on the seaward side, thus maintaining a supply of sand to beaches to the north (see section 4.2.1 for more detail).
4. The Torrens Outlet acts as a hydraulic groyne. Before the outlet was constructed in 1936, the Torrens River drained into wetlands behind the dunes. The sand trapping action of the outlet was not intentional but it has caused a large dune system to form south and, to a lesser extent, north of the outlet. In front of the Henley Sailing Club, just south of the outlet, the dune has built out seaward by 100 m in the last 50 years, although 500,000 m^3 of sand has been removed for beach replenishment since 1975. Over the 11 years from 1991 to 2002, the area from the West Beach Surf Life Saving Club (1 km south) to the Torrens Outlet accumulated 165,000 m^3 of sand.
5. The Adelaide Shores offshore breakwater at West Beach, which was constructed in 1998, traps sand to form a beach from which it is collected and bypassed mainly by truck to the West Beach dunes.
6. At the Patawalonga, Glenelg, groynes were initially constructed in 1964. Groyne extensions and an offshore breakwater were constructed from 1996 to 1997 as part of the development of Holdfast Shores. Sand is trapped by the breakwaters and groynes, allowing efficient dredging of sand to bypass the entrance to the Patawalonga.
7. At a small rock-groyne at the Broadway, Glenelg South, which was constructed in 1974, a small quantity of sand is trapped to maintain higher beach levels to the south where the seawall is vulnerable to undermining.
8. A small geotextile groyne at Somerton Park constructed in 2001 intentionally traps a small quantity of sand to improve beach access for dinghy launching.
9. The vertical piles of jetties along the coast slightly dissipate wave energy. The resulting small accumulation of sand to the lee of the jetties is minor compared with more solid structures such as groynes.

Sand impoundment can result in a loss of sand from the active beach if too much sand is trapped. This can happen in two ways:

1. Sand accumulates seaward into deep water and so is lost from the active beach. Waves can move sand on the seabed in deeper water but the rate of movement is very low compared with sand in the shallower active beach. Consequently, it may take years before the waves can move the sand back onto the beach rather than the weeks or months for sand in shallower water. Other than the circumstances in which sand has been deliberately placed offshore, surveys indicate that this is not a significant issue on the Adelaide coast.
2. A large dune system builds up, which holds more sand than can be reached by storms in the dune erosion/rebuilding cycle.

If a sand trap is large, the accumulating sand and seaward-building active beach will smother the seagrass meadows. This has been the case at North Haven where dredging has maintained channel depths for boating.

2.2 Recent coastal development

The most identifiable changes to the Adelaide coast since 1997 – the time of the last management review of the Adelaide metropolitan beaches – have been at Glenelg with construction of the Holdfast Shores marina and extension of the Patawalonga breakwater, and at West Beach with construction of the Adelaide Shores boat haven. These developments are referred to generally as the Glenelg and West Beach harbours. These structures obstruct the northerly movement of sand along the coast, so that sand accumulates on their southern side. In order to prevent subsequent erosion on the northern side of the structures, sand is bypassed from the southern side to the northern side.

2.2.1 The Patawalonga

The Patawalonga has had an influence for change on the coast since European settlement. Attempts to train the entrance and reduce flooding in low-lying areas began in the 1880s. A weir built at the entrance in 1886 was destroyed by floods in 1887. The original timber floodgates were replaced in 1960 by the present floodgates and lock, and the southern breakwater was built in 1964; a sheet-piled breakwater to the north of the entrance was constructed soon after. The present configuration, an extension of the 1964 southern breakwater and replacement of the sheet piling with a more northerly located rock breakwater, was constructed in 1996 and 1997.

The breakwaters caused sand impoundment to the south (almost to the Broadway, Glenelg South) until sufficient sand accumulated to spill around the end of the breakwater to form the notorious 'Pat sandbar'. Accumulated dry sand was manually bypassed and carted to elsewhere on the coast by truck at rates of up to 60,000 m^3/year (on average around 30,000 m^3/year from 1973 to 1996) to reduce wind-blown sand drift in the area. In 1979 a dredging campaign aimed to move approximately 30,000 m^3 of sand from the channel to Glenelg North beach and then excavate a channel into the clay and rock below. This was only partially completed and the channel concept was abandoned.

2.2.2 Holdfast Shores marina and the Patawalonga entrance

The Holdfast Shores marina at Glenelg, constructed during 1995 and 1996, incorporated and built upon the existing Patawalonga entrance. New aspects of the development include the marina precinct, extensions to the training walls and construction of the offshore breakwater sand trap. The sand management parts of the marina are now a set of three rock breakwaters. The offshore breakwater just to the south of the harbour entrance, with a top level of 1 m AHD, assists sand accumulation and protects the sand bypassing dredge from waves that could make its operation unsafe. The northern and southern rock breakwaters protect the marina from waves and trap sand to the north and south of the harbour entrance to minimise the amount of sand filling the boat channel.

The Holdfast Shores marina includes provision for sand bypassing by dredge to minimise its impact on sand movement along the coast. During spring and summer, the northerly littoral drift in this region is at a maximum. The dredging program aims to keep pace with sand arriving at the southern breakwater and yet avoid the main period of summer beach use. A small cutter suction dredge removes sand and seagrass trapped in the lee of the offshore breakwater. Sand and seagrass are also removed regularly from the entrance and inner harbour to maintain channel navigability.

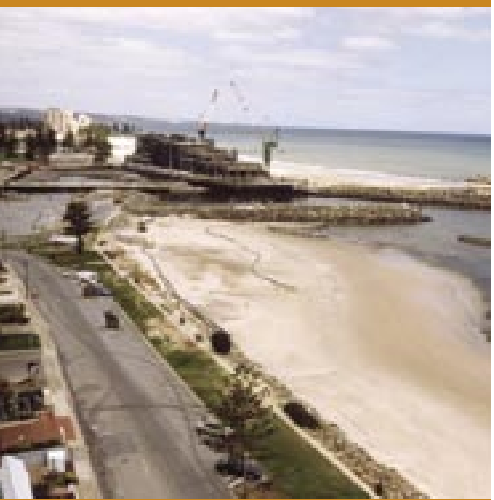
Adelaide Shores boat haven

Holdfast Shores marina and the Patawalonga entrance

Rock groyne at the Broadway, Glenelg

Patawalonga entrance, 1950

Patawalonga entrance, 1973



Parrawalonga entrance, 1997

There are concerns about the current sand bypassing operation:

- At times, the dredge cannot keep up with sand accumulation in the sand trap. The sand then spills over into the channel. This also results in insufficient sand being bypassed to Glenelg North, exposing stones on the beach from time to time.
- Dead seagrass is also trapped at the sand trap, contaminating the sand. To minimise odours on the beach, the sand is discharged offshore at Glenelg North. If the sand were not contaminated, it could be discharged onshore to maintain the beach at Glenelg North.
- The actual volume of sand and seagrass dredged is not accurately known because mass flow measurement devices in common use cannot measure quantities of sand or seagrass accurately, particularly when the two are mixed.

Approval for the development of Holdfast Shores was provided on the basis that the State Government would be responsible for the certification, ownership and maintenance of the harbour facilities and sand management, and that adequate funds would be made available to cover the cost of these responsibilities in perpetuity from 1997–98.

Up to 2004–05, sand bypassing at Holdfast Shores has been undertaken by Transport SA under direction from the Minister for Transport, who has been advised by the Minister for Environment and Conservation on the volumes of sand to be bypassed. The sand bypassing will be managed by the Department for Environment and Heritage from 2005–06 onwards.

Transport SA has been responsible for maintaining the breakwaters and navigable depth in the entrance only. Users of the inner harbour and marina are responsible for their operation and maintenance. The City of Holdfast Bay manages the surrounding beaches to low-water mark.

Schedule 1 of the *Environment Protection Act 1993* defines dredging as a prescribed activity of environmental significance and the Environment Protection Authority (EPA) has issued discharge licences for the sand bypassing to continue. These licences require sand to be pumped offshore when odours from dead seagrass are a problem.

2.2.3 Adelaide Shores boat haven

The Adelaide Shores boat haven was constructed at West Beach in 1998 as part of the overall Holdfast Shores development. It is located about 1.5 km north of the Holdfast Shores marina at Glenelg. It includes a 4-lane boat ramp sheltered by two rock breakwaters that enable small boats to launch in relatively calm conditions. An overpass was built over the beach to connect the breakwaters and boat ramp with the road and landward haven area, thus allowing uninterrupted public access along the beach. It has the added benefit of giving sand-carting trucks the same access.

Sand that accumulates on the beach on the southern side of the boat haven and within the facility is trucked along the beach just to the north in front of the West Beach dunes. Supplementary dredging of sand and seagrass to maintain navigable depths within the boat haven, and from the seaward side of the southern breakwater, continues.

Concerns about the current sand bypassing operation are similar to those at the Holdfast Shores marina:

- Sand and seagrass are dredged offshore, and the sand only slowly works its way onshore over many years, which does little to protect the West Beach dunes.
- Seagrass from the dredge spoil area could be drifting back into the boat launching area.

Transport SA currently owns and manages the structures seaward of the seawall (the bridge, breakwaters and timber landing) and is responsible for maintaining the breakwaters and channel area. Adelaide Shores (the West Beach Trust) manages the boat haven to low-water mark and is also responsible for the care, control and management of the West Beach dunes area under the *West Beach Recreation Reserve Act 1987*. The City of Charles Sturt and the City of West Torrens maintain adjacent beaches to low-water mark.

Up to 2004–05, sand bypassing at Adelaide Shores has been undertaken by Transport SA under direction from the Minister for Transport. The Minister for Environment and Conservation has advised the Minister for Transport on sand volumes to be bypassed and is also responsible for the state of the beaches in the area, under provisions of the *Local Government Act 1934* section 886BB – Coast Protection at West Beach. The sand bypassing will be managed by the Department for Environment and Heritage from 2005–06 onwards.

Adelaide Shores boat haven overpass

2.2.4 Groundwater changes

Elevated groundwater levels within coastal dunes have the potential to affect the rate of beach build-up within the dune erosion/rebuilding cycles. Alteration and management of the Patawalonga and West Lakes/Port River estuaries could have increased groundwater levels in nearby dunes and beach, and groundwater outflows can liquefy the sand thereby increasing erosion from the beach. However, investigations in these areas have not confirmed any such effect.

Local Government Act 1934 Section 886BB – Coast protection at West Beach

1. In this Section

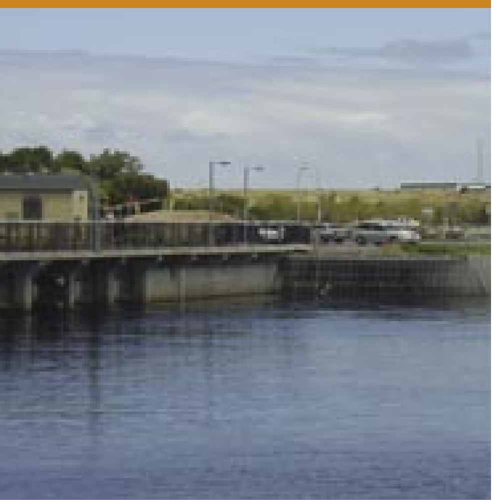
- **'boating facility' means a harbour, marina, boat mooring or boat launching facility**
- **'coast' has the same meaning as in the *Coast Protection Act 1972***
- **'the Minister' means the Minister to whom the administration of the *Coast Protection Act 1972* is committed**
- **'the West Beach area' means an area 500 m wide running along the coast of metropolitan Adelaide in Gulf St Vincent between the northern side of the entrance of the Patawalonga boat haven to the sea and the point where a westerly projection of West Beach Road meets the sea, and bounded on the east by the high water mark.**

2. The Minister must take reasonable steps to ensure the effective management of sand in association with the construction of any boating facility within, or adjacent to, the West Beach area

- **in order to maintain the navigability of any entrance or access channel associated with any such boating facility**
- **in order to protect or, if necessary, restore the coast on account of the obstruction of coastal processes due to the construction of any such boating facility**
- **in order to ensure that the enjoyment of the coast by the public generally is not materially diminished due to the construction of any such boating facility.**

3. The Crown is liable for the costs associated with any works or operations undertaken for the purposes of any sand management required under subsection 2.

The location of the Barcoo Outlet – the buried pipeline is marked by the black line



Trash rack covering Patawalonga Lake entrance into the Barcoo Outlet pipeline

Trash rack covering Patawalonga Creek and Airport Drain entrance into the Barcoo Outlet pipeline

2.3 Stormwater and sewage management

Adelaide's stormwater is discharged to the coast mostly from the Barcoo Outlet, the Torrens Outlet (Breakout Creek), the Port Estuary and many smaller coastal stormwater outfalls. There is generally little retention to settle out the fine sediment or provide for nutrient uptake. The stormwater filtering capacity was progressively lost with the filling of the back dune reed beds and swamps.

2.3.1 The Barcoo Outlet

The Barcoo Outlet discharges stormwater from the Patawalonga catchment through a 5 m diameter pipe laid below the beach. The stormwater discharges seaward of the active beach, and consequently does not greatly affect sand movement along the coast.

The Barcoo Outlet pipeline was constructed through seawall-protected land near the Glenelg wastewater treatment plant (WWTP). An estimated 50,000 m^3 of sand from the impounded dunes was returned to the coast during construction. Of this, approximately 40,000 m^3 was carted from Glenelg to replenish Brighton beach.

Construction of the Barcoo Outlet has resulted in reduced water clarity (increased turbidity and other debris) near the outlet due to the discharge of stormwater. Reduced water clarity formerly occurred adjacent to the Patawalonga entrance.

The Patawalonga Catchment Water Management Board has undertaken a program of catchment improvements to reduce the volume and improve the quality of water discharged. Details are available on its website at <www.cwmb.sa.gov.au/patawalonga/>. The EPA monitors water quality in coastal bathing waters mainly at jetties and at the beaches adjacent to the Barcoo Outlet. Its website has results of water quality monitoring along the coast: <www.environment.sa.gov.au/reporting/coast/barcoo.html>. SA Water has upgraded the Heathfield WWTP, higher up in the catchment, which will lead to significant improvements in water quality throughout the catchment and, consequently, near the Barcoo Outlet.

2.3.2 Smaller stormwater outfalls

The more than 85 stormwater outfalls into dunes and directly on to the beach along the Adelaide coast are mainly in the Seacliff to Glenelg, Henley to Grange and Semaphore to Outer Harbor areas. Catchment areas and consequently stormwater flows from these outfalls are much smaller than for the major outfalls.

The main issues relating to these outfalls are: sediment and nutrient loading into the gulf water; scenic and recreational amenity affected by stormwater discharges across the beach; and local redistribution of sand across the active beach – typically the erosion of dune areas or beaches in the vicinity of the outfall. The sand is washed into the nearshore zone, from where it returns to the beach downdrift. Consequently, these outfalls have minimal effect on broad-scale sand management. Future sand management needs to take into account stormwater discharge points and any changes in how readily their local effects can be managed.

Requiring most attention at smaller stormwater outfalls is prevention of water ponding and the risk of water becoming stagnant near the outlet, particularly during summer – for aesthetic and health reasons. There is room for improvement in the way in which stormwater is conveyed across the beach. However, this work is outside the scope of this report.

2.3.3 Sewage treatment discharges

SA Water operates the Bolivar, Glenelg and Christies Beach WWTPs and owns the Port Adelaide WWTP (operated by United Water), which treat sewage from the metropolitan Adelaide sewerage system. Bolivar, the largest WWTP, processes

130 million litres (L) of sewage per day, over half of Adelaide's wastewater. The remaining 110 million L is processed at the other three plants. Much of Adelaide's treated wastewater is discharged from Bolivar into Gulf St Vincent near St Kilda through the outfall channel.

Most of the discharged wastewater has undergone secondary treatment. Bolivar WWTP also gives tertiary treatment to industrial waste. In the past, Glenelg and Port Adelaide WWTPs discharged both treated effluent and digested sludge into the waters off the Adelaide coast. Discharge of digested sludge into coastal waters stopped in 1993.

Treated effluent and former sludge discharge locations are seaward of the active beach and thus have had minimal *direct* effect on sand. However, the high nutrient loading placed on gulf waters has led to an extensive loss of seagrass meadows. The reduced clarity of marine water has also lessened the visual attractiveness of coastal waters.

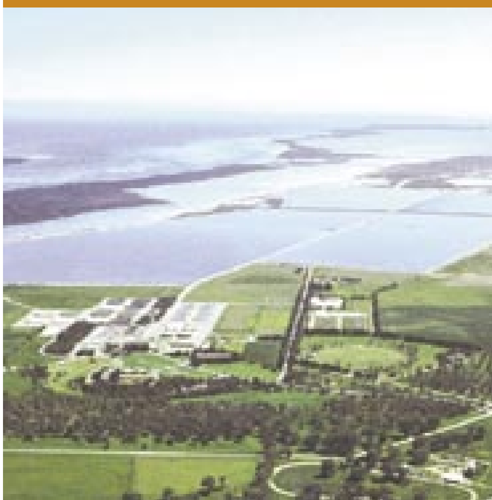
In 1995, as part of a $240 million Environment Improvement Program to improve the performance and quality of the metropolitan WWTPs and reduce nitrogen and phosphorus discharges into the Gulf, several WWTPs were upgraded and effluent re-use schemes introduced. Included was construction of a digested sludge pipeline from the Glenelg and Port Adelaide WWTPs to Bolivar. Currently, Port Adelaide WWTP is being replaced with a pumping station at its existing site and a new high salinity treatment plant at Bolivar WWTP to accommodate saline groundwater leakages into Port Adelaide sewers.

2.4 Loss of seagrass coverage

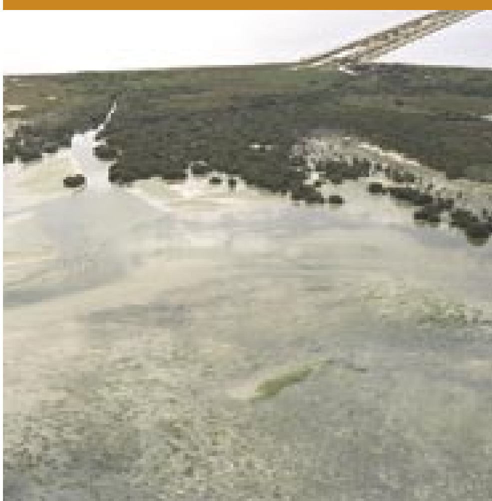
Over the last five to six decades, loss of seagrass meadows along the Adelaide coast has been extensive. Initial reports of seagrass loss along the Adelaide coastline were of a seaward retreat of the inshore seagrass margin (the 'blue line') near the former Glenelg and Port Adelaide sludge outfalls.

In all, at least 5200 hectares (ha) of seagrass meadows (about 25% of the total meadow area) have been lost from the greater Adelaide coastline (Seddon 2002), about 2700 ha between Marino Rocks and Largs Bay (Environment Protection Agency 1998). Much of this loss is linked to various sources of pollution and coastal development (Table 2.1). Nutrient loading from effluent and stormwater discharges and groundwater seepage has enhanced eutrophic conditions along the coast. This has led to an increase in phytoplankton in the water and epiphytes on seagrass leaves, both of which shade the leaves and reduce their capacity for photosynthesis (Kirkman 1997). The result is seagrass meadows that are unable to sustain themselves and thus large-scale patchiness and loss.

Foreshore stormwater outlet at Taperoo



Bolivar wastewater treatment plant (United Water)



Sewage effluent outfall channel near St Kilda

Table 2.1 *Summary of seagrass losses in eastern Gulf St Vincent (from Shepherd et al. 1989)*

Location	Period	Loss (ha)	Species*	Possible causes
Inshore area south of Outer Harbor breakwater	Before 1949	100	P	Sediment accretion due to updrift trapping by breakwater
Offshore area south of Outer Harbor breakwater	Before 1949	828	P, A	Sedimentation, turbidity, nutrients
Largs Bay	1949–81	80	P	Sedimentation from Outer Harbor breakwater and North Haven marina
Port Adelaide sludge pipeline	1977–82	15	P, A	Pipeline excavation and ensuing erosion
Port Adelaide sludge outfall	1978–82†	365	P, A	Nutrients, turbidity
		1135	A	
Glenelg sludge outfall	1968–82	23	P, A	Nutrients, turbidity
Glenelg sewage effluent outfall	1935–61	50	P, A	Nutrients
Brighton to Grange	1935–81	800	P, A	Blow-out expansion
Inshore seagrass regression Brighton to Semaphore	1935–85**	1926	P, A	Fragmentation of beds (effect of nutrients, turbidity, land-based discharges and erosion)
Intertidal area off Fork Creek	1965–68	130	H	Nutrients from Bolivar sewage outfall
Subtidal areas between St Kilda and the Gawler River	1965–85	355	P	Nutrients as above, sediment accretion or movement
		315	H	

* P=*Posidonia*; A=*Amphibolis antarctica*; H=*Heterozostera*
† pipeline decommissioned in 1993; ** continuing process

Remote-sensing monitoring between 1996 and 2002 indicates continued areas of seagrass loss as well as some areas of apparent gain (Figure 2.2). Where seagrass loss continues along the coast, it is accompanied by increasing expansion of blow-outs (see section 2.4.1). Consequently, much of the Adelaide offshore coastal environment that had been covered in seagrass is undergoing considerable seabed erosion.

Figure 2.2 *Permanent seagrass, seagrass loss and seagrass gain along the Adelaide metropolitan coastline between 1996 and 2002*

Diver monitoring the seabed depth adjacent to the escarpment edge of a seagrass blow-out

2.4.1 Blow-outs

Nearshore seagrass meadows along the southern Adelaide coast experience medium-energy wave conditions that can erode the seagrass matte and cause seabed blow-outs – a low-lying area of unvegetated sediment – to form.

Seagrass meadows along the Adelaide coast have become established over a thin veneer of Holocene sand that overlies older Pleistocene sediments. Along much of the southern and central Adelaide metropolitan coast, sand thickness is generally less than 1 m, whereas further to the north near Largs Bay it can be greater than 8 m. In areas of very thin Holocene sediments, such as at West Beach and Brighton, the seabed has already eroded to the base of the Holocene sediments and, in so doing, has exposed Pleistocene clays and calcrete (Thomas & Clarke 2002).

Aerial photography and diver observations along the Adelaide coastline indicate that blow-outs are migrating seaward at a rate of up to 0.5 m/year (Clarke 1987; Clarke & Thomas 1987; Fotheringham 1996; Hart 1996, 1997a, 1997b). If the formation and migration of blow-outs have increased in recent years, as appears to be the case, this indicates a decreased ability of the seagrass meadows to recolonise.

Of particular concern is where the fragmentation of seagrass meadows into smaller patches has occurred. This is because the length of eroding edges relative to seagrass meadow area becomes higher and any colonisation is unable to keep up with eroding meadow edges. Consequently, the risk of complete loss of the meadow is high.

Do you want to know more about seagrass and water quality conditions?

Information on seagrass dynamics and decline in Gulf St Vincent can be found in *The Biology of Seagrasses* (Larkum et al. 1989) and the *Adelaide Coastal Waters Study Technical Report No 2* (Westphalen et al. 2004).

Further information on water quality conditions and nutrient dynamics along the Adelaide coast can be found in the *Adelaide Coastal Waters Study Scoping Report* (Butler et al. 1997), *Adelaide Coastal Waters Study Technical Report No. 3* (Wilkinson et al. 2004), *Proceedings of the Seagrass Restoration Workshop for Gulf St Vincent* (Seddon & Murray–Jones 2002), and several SA Water and EPA publications (e.g. Environment Protection Authority 2003).

2.5 Seabed stability

Seagrass loss, particularly between Glenelg and the Torrens Outlet, has caused expanding erosional blow-outs, resulting in large quantities of sand being moved inshore, thus reducing the seabed elevation. This has led to a comparable increase in sand on beaches further north between the Torrens Outlet and North Haven.

To determine which areas have been undergoing net erosion or deposition, and to estimate the volume of sand transported shoreward due to seagrass loss, Fotheringham (2002) examined sand rod and profile records (see section 4.6.1) along the metropolitan coast from the Brighton, West Beach, Henley Beach and Semaphore regions from 1980 to 1999. The pattern of erosion offshore and deposition inshore is shown in the Adelaide coast seabed stability map (Figure 2.3).

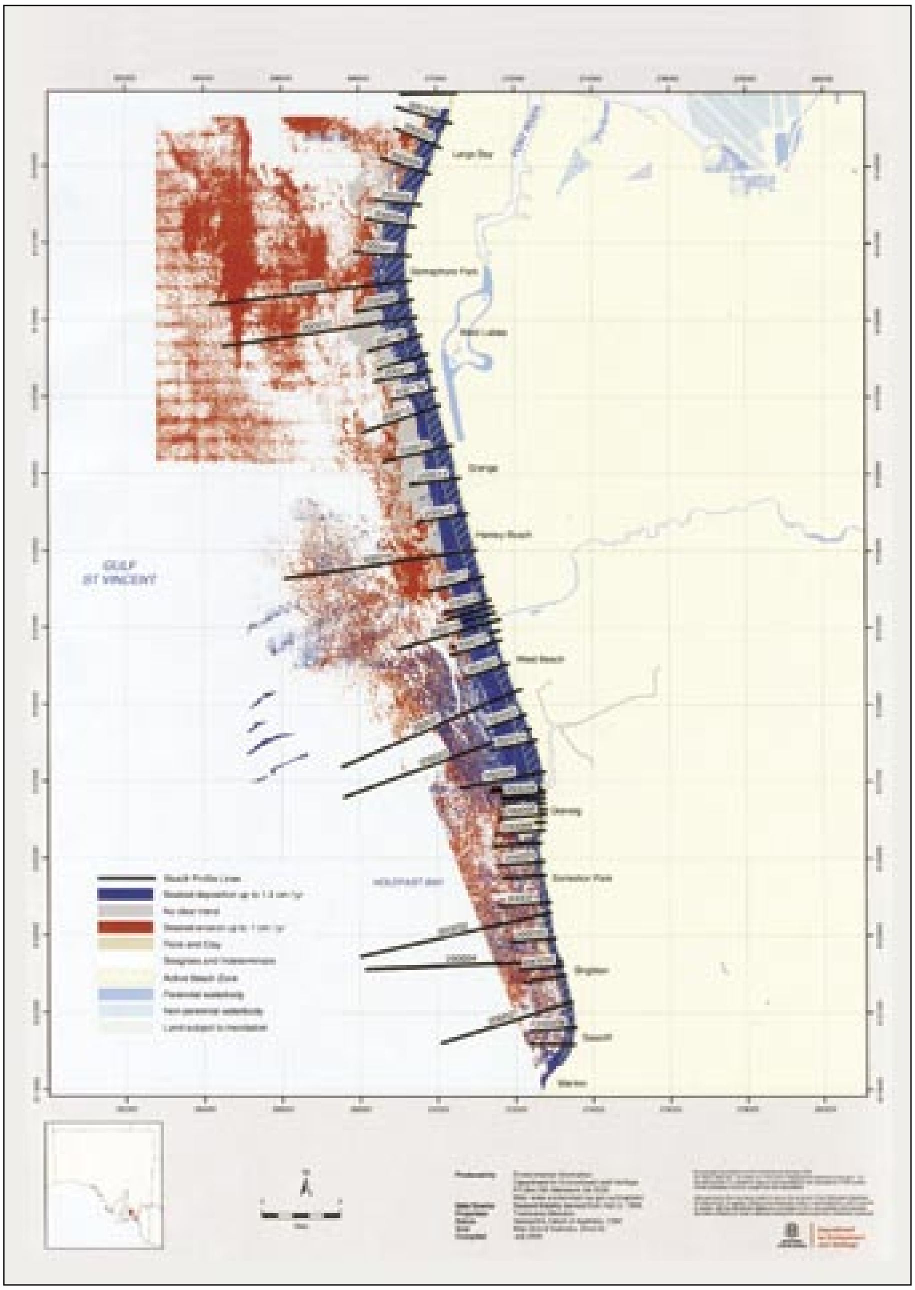


Figure 2.3 *Seabed stability indicator showing areas of erosion, deposition and no clear trend along the Adelaide coastline (from Fotheringham 2002)*

Significant changes were detected for the last 10 years of the analysis:

1. Profile records for the Brighton region revealed that erosion had been significant, particularly 300–600 m offshore at depths of –3 to –5 m AHD.
2. The pattern for the West Beach region was one of overall deposition, if the active beach zone to 400 m offshore is excluded. The cause for this is a combination of sand deposited by dredge 900 m off Glenelg North in 1991, the construction of several coastal structures able to entrap sand, and a supply of sand from eroding seabed/seagrass areas seaward of the monitored zone.
3. At Henley Beach, 1980–99 data exhibited overall erosion, whereas 1989–99 data exhibited deposition. Much seagrass had already been lost in the region up to 2 km offshore, and blow-outs had expanded to more than 4 km offshore. Thus, initial erosion was essentially followed by deposition as sand was transported from eroding seagrass areas offshore.

4. Mean seabed heights in the Semaphore region clearly showed a depositional trend since the area is the northern endpoint for sediment transported alongshore (although some sediment in the system is leaking past the North Haven breakwater). Extensive seagrass meadows, particularly in the southern part of this region, are still present within 1 km of the shore.

Using the rod and profile data, as well as extra sand mapping by Hart (1997a, 1997b) over seven time periods between 1949 and 1996, Fotheringham (2002) compared areas of seabed that lost seagrass over different time periods. The main trends were:

1. extra sand areas mapped from aerial photography since 1977 appear to be due to seabed erosion from seagrass loss
2. seagrass loss, apart from that associated with sludge outfalls, has generally expanded progressively offshore with time
3. deposition in inshore areas between 1989 and 1999 has been insufficient to restore the seabed in these areas to 1980 levels.

Beach profile data and topographic survey data were used to estimate sand volumes, and hence sediment budgets, for 1980–99 and 1989–99. The active beach zone, delineated in profile data as landward of the seaward edge of the beach, totalled 11 million m^2. To determine the total volume, mean beach-level change for each period was calculated and multiplied by beach area. Then the mean annual budget for seagrass loss was obtained by subtracting any replenishment volumes from sources outside the active beach zone (Table 2.2). This approach indicates that approximately 81,000–87,000 m^3 of extra sand is transported annually into the active beach zone. The most probable explanation for this is that, while the rate of seagrass loss has reduced, sand movement has increased, indicating that the seabed is still eroding and not yet in equilibrium with the wave environment (Fotheringham 2002).

Table 2.2 *Figures used to derive the mean annual sand budget (from Fotheringham 2002)*

Period	Profile points	Mean beach level change (m)	S.D.	Volume (active beach zone) (m^3)	External sand input (m^3)	Adjusted volume (m^3)	Mean annual sand budget (m^3)
1980–99	2,854	0.31	0.83	3,394,945	1,858,179	1,536,766	80,882
1988–99	3,538	0.24	0.60	2,628,345	1,758,814	869,531	86,953

S.D. standard deviation

The release of sand from the loss of seagrass has provided extra sand to the active beach along the central to northern part of the Adelaide coast for many years. If seabed erosion continues, this sand redistribution will continue to supply sand to the active beach and accumulation area. If seabed erosion stops – for instance if a hard layer is reached below the sand or the seabed deepens sufficiently that the depth limit of wave action is reached – sand movement will stop, and this sand supply to the active beach will stop.

2.5.1 Effects of changed seabed conditions

Because of the large amount of sand released and redistributed as seagrass has died, the nearshore seabed areas have eroded, making the water deeper and consequently affecting the waves passing over it.

Furthermore, the frictional properties of the remaining seagrass meadows and sandy seabed alter the effect of the seabed on the waves passing over it.

The following effects of the seabed are reduced:

- energy absorption of storm waves as they move across the seabed, allowing them to be larger and more powerful and destructive when they reach the shore
- energy absorption of ambient waves, allowing them to be larger when they reach the shore
- refraction of waves moving across the seabed, allowing them to strike the shore more obliquely.

The last two points both increase the rate of littoral drift.

Recent numerical modelling studies of these effects on the Semaphore Park to Semaphore coast have indicated that local erosion at Semaphore Park to Point Malcolm since the early 1980s is probably entirely due to the effect of seagrass loss in the adjacent nearshore area. The studies estimated a 10,000–15,000 m^3/year (approximately 30%) increase in littoral drift rates between 1970 and 2000.

Similar numerical modelling work has been undertaken to quantify the magnitude of these effects on littoral drift and storm waves at the shore for the length of the Adelaide coast (Coastal Engineering Solutions 2004). These studies examined historic and current seagrass coverage under various likely future seagrass–coverage/loss scenarios. They concluded that, between Glenelg North and Semaphore, sediment transport potential had been 10–15% lower than for present day conditions. In other words, since the loss of seagrass cover there has been an increase in littoral drift of around 6000 m^3/year.

2.6 Climate change

The Intergovernmental Panel on Climate Change (IPCC) is generally acknowledged as the world authority on climate change and sea level change. It was established by the World Meteorological Organisation and the United Nations Environment Programme in 1988. Its main role has been to undertake and coordinate the interpretation of various global climate models to determine likely temperature, sea level and other climate changes arising from the greenhouse effect. It has presented three assessment reports (in 1990, 1995 and 2001) on global climate change and its implications. The *Third Assessment Report* (2001) can be accessed on the IPCC website at <www.ipcc.ch/activity/ar.htm>.

The Coast Protection Board has based its sea level rise policy on the IPCC's recommendations. The main effects of climate change that are likely to occur on the Adelaide coast are sea level rise and changes to weather and hence wave conditions.

2.6.1 Global sea level rise

Mean sea levels worldwide are rising. Tide gauge data from around the world indicates that the rate of global average sea level rise during the 20th century was in the range 1.0–2.0 mm/year, an order of magnitude greater than the average rate over the previous several millennia (Intergovernmental Panel on Climate Change 2001).

The causes of this are twofold:

1. a combination of naturally occurring changes on a global scale, including the ocean response to global changes from water and ice loading arising from a warming of the atmosphere at the close of the Little Ice Age
2. an anthropogenic (human-induced) warming of the Earth known as the greenhouse effect.

Current IPCC projections for sea level rise under various emissions scenarios over the next 100 years are shown in Figure 2.4. These projections include both naturally occurring and anthropogenic influences.

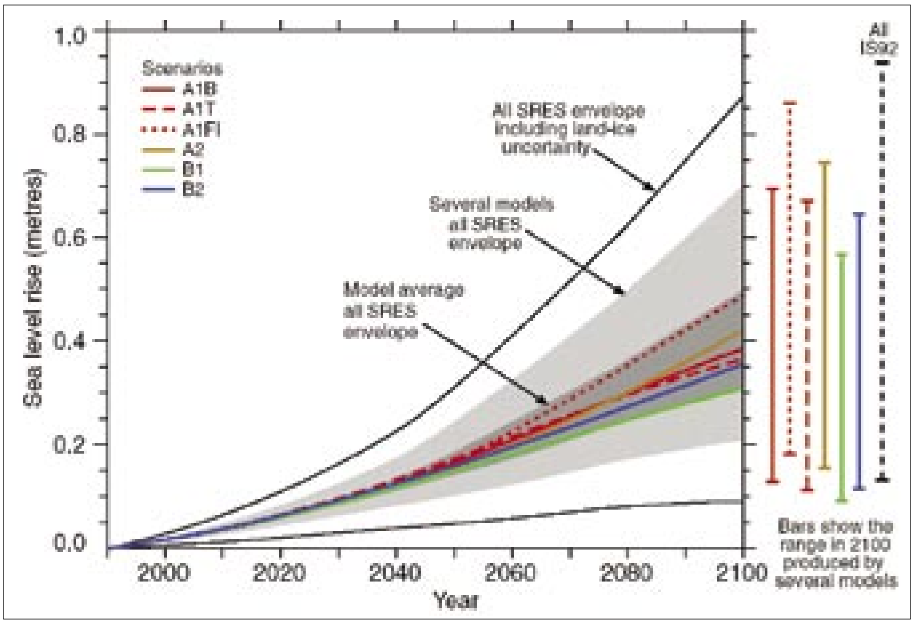


Figure 2.4 *Projected sea level rise (Intergovernmental Panel on Climate Change 2001)*

2.6.2 Changes in weather conditions

A recent CSIRO study that focused on specific climate changes likely for South Australia (McInnes et al. 2003) identified a likely increase in storminess for the Adelaide area in summer but not in the winter months when extreme storms most damage coastal dunes. Ambient wind conditions or weather patterns also do not appear to change markedly. The full report is available at <www.environment.sa.gov.au/sustainability/pdfs/csiro_report.pdf>.

2.7 Relative sea level rise

Changes in sea level can result from either eustatic sea level changes or vertical land movements. Eustatic changes are those caused by temperature changes which, for sea level rise, include the thermal expansion of water and melting of glaciers and the polar icecaps. Other oceanographic and climatic phenomena such as the El Niño Southern Oscillation also influence sea level. Vertical land movements are associated with the Earth's response to water loading (isostatic adjustment), tectonic activity, and human activities, such as groundwater extraction and land reclamation, that generally cause land subsidence.

The combination of these factors contributes to variations in sea level at different locations around the world. Thus, *relative sea level* is a more precise term that takes into account changes in sea level due to the relative influences of physical processes and human activities, in particular those in coastal regions.

2.7.1 Tide gauge data and sea level trends for Adelaide

Adelaide currently has tide gauges at Outer Harbor and Port Stanvac. Another tide gauge, operating at the inner harbour, Port Adelaide, was decommissioned in 1997. Before that, both the inner harbour and Outer Harbor tidal records were used to obtain regional sea levels that contribute to global sea level estimates. The sea level trend for the inner harbour until 1997 shows a sea level rise of 2.06 mm/year and the current trend for Outer Harbor indicates sea level is rising at 2.08 mm/year (Figure 2.5).

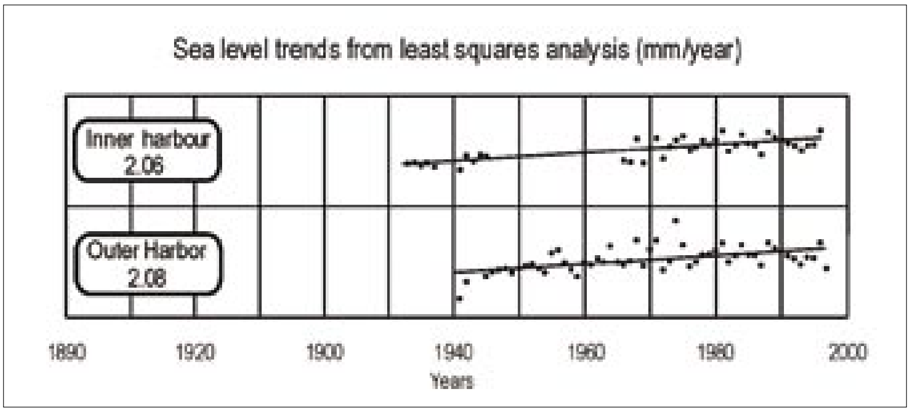


Figure 2.5 *Derived sea level trends for the inner harbour and Outer Harbor (National Tidal Centre)*

Sea level trends for Australia are processed by the National Tidal Centre of the Bureau of Meteorology. They are based on multiple least squares regression analyses using weighted monthly means derived from hourly tide gauge readings. A comparison of the predicted and actual tide gauge records enables corrections to be made for local atmospheric conditions.

Generally, only records longer than the lunar tide period of 18.6 years are suitable for trend analysis. The sea level trends for the inner harbour and Outer Harbor have over 40 and 55 years of data respectively, whereas the Port Stanvac tide gauge has only been operating since the early 1990s, not long enough for a meaningful trend to be derived. Each sea level trend is dependent on the length of the tidal record used and will vary with the addition of new tidal data. Interdecadal oceanographic and climatic processes will also significantly influence sea level trends. These variations can be readily observed in the scatter of points in Figure 2.5.

2.7.2 Land subsidence along Adelaide's coast

Many of the world's tide gauge records have been filtered for vertical land movements by using long-term records or geodynamic models. This approach has provided the best approximations of global sea level but does not account for localised or regional movements that affect individual tide gauges and their surrounding areas.

In the Adelaide region, several natural and human-induced causes of land movements have occurred over vastly different time scales.

Natural geological processes

- Long-term tectonic upwarping of parts of the Mount Lofty ranges since the last interglacial (<125,000 years ago) has resulted in differential uplift and subsidence around coastal margins of the Mount Lofty Ranges (Murray–Wallace & Belperio 1991).
- Land is subsiding along faultlines that run in a general south-west to north-east direction, principally along the foothills of the Mount Lofty Ranges.
- There is subsidence within the St Vincent basin, an Early Tertiary to Holocene graben containing over 500 m of sediment (Belperio 1993).
- Hydroisostatic rebound of the Earth's crust following Holocene sea level rise is uplifting the continental margin (Belperio 1993; Lambeck & Nakada 1990).

Anthropogenic causes

- Wetland reclamation in the Gillman area near the Barker Inlet initiated in 1894 and completed in 1974 has led to an artificial lowering of the watertable, subsequent coastal acid sulfate soil formation and associated subsidence.
- Landfill areas such as those along the Lefevre Peninsula and Port Adelaide areas have subsided as the weight of the overburden compresses subsurface low-density layers.
- The Barker Inlet/Port River estuary and surrounding land has subsided from large-scale groundwater extraction for industrial and agricultural purposes over more than a 50-year period (Belperio 1993).

Each of these processes has a varying effect on the amount and rate of land movement along the Adelaide coast.

2.7.3 Levelling surveys for Adelaide

Overall, land along the Adelaide metropolitan coast is slowly subsiding. Early levelling surveys of the northern Adelaide metropolitan coast between 1872 and 1969 indicated land subsidence in the order of 0.6 feet (Culver 1970), giving a subsidence rate of 1.8 mm/year. Much of this was considered to result from groundwater withdrawal and consolidation of coastal sediments in the surrounding area.

The Coastal Management Branch initiated a project in 1982 to install a stable network of benchmarks for levels throughout Adelaide (Coastal Management Branch 1984). More recently, levelling surveys of benchmarks along the whole Adelaide metropolitan coast between 1983 and 1994 have indicated subsidence rates ranging from 0.7 mm/year in southern and central coastal regions to 2 mm/year in northern areas (Department for Administrative and Information Services 1997). This implies greater subsidence and therefore relative sea level rise in the northern coastal zone than in the south.

2.8 Potential impacts of climate change and relative sea level rise

For the purposes of managing Adelaide's beaches, both now and into the future, it is prudent to estimate the impact of relative sea level rise and changes in local weather conditions that may result from global climate change.

Recession due to sea level rise

In the absence of other factors and assuming no change in wind and wave conditions, a sandy coast adjusts to increased sea level by maintaining nearshore depth. The extra sand – to enable the nearshore seabed to follow the sea level rise – is obtained from erosion of sediments behind the beach. Most methods of estimating coastal recession due to sea level rise are based on this sand balance.

Typically a sandy coast will erode a distance equal to 50–100 times the amount of sea level rise, though this depends on the width of the active beach zone and the height of sand dunes, and the figure may be much lower or higher.

Coast Protection Board policy requires an allowance to be made for recession due to a 0.3 m sea level rise if future protection would be practical and environmentally acceptable. Otherwise, the effect of a 1.0 m rise should be considered. In some situations local coastal processes and sea level rise can be considered separately. In others, they interact and need to be assessed together.

Coast Protection Board 1992

Coastal erosion, flooding and sea level rise policy

In 1991, the Coast Protection Board established South Australia as the first State in Australia to adopt planning policies and standards to minimise the risk to coastal development by climate change–induced sea level rise.

The Coast Protection Board policy, which has been included in the council-wide provisions of development plans, states that development should not be approved where building sites are lower than a height determined by adding 0.3 m (for 50 years of sea level rise) to the 1-in-100 year storm surge level and making an adjustment (where appropriate) for land level changes to 2050. For commercial or habitable buildings, floor levels should be no less than 0.25 m above this minimum site level. Development should not be approved unless it is capable, by reasonably practical means, of being protected or raised to withstand a further 0.7 m of sea level rise. This latter condition allows for a further sea level rise of 0.7 m from 2050 to 2100 for a total sea level rise of 1 m to 2100 (see Figure 2.6).

The Coast Protection Board's policies on flooding and erosion were incorporated in 1994 into the council-wide provisions of the State's development plans via a Minister's supplementary development plan (SDP). Since then, consistent with the intent of that SDP, the Department for Environment and Heritage has endeavoured to incorporate site-specific site and floor levels that comply with Coast Protection Board policies into the zone provisions of development plans via planning amendment reports as the opportunities arise.

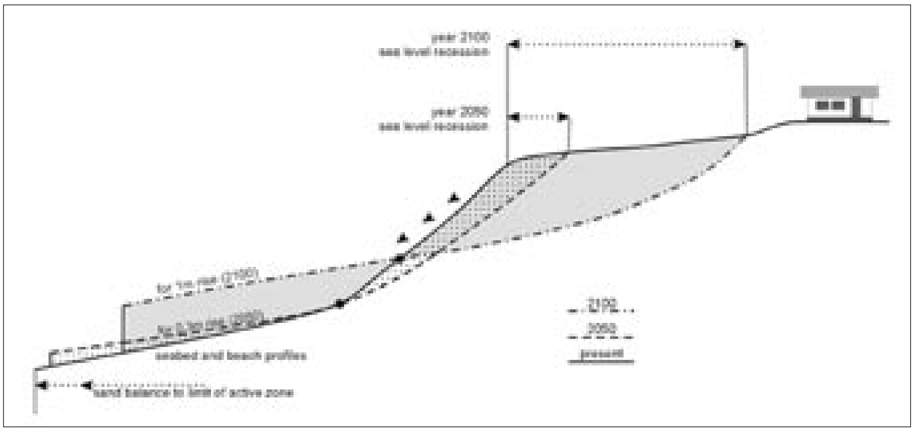


Figure 2.6 *Schematic diagram of coastal recession for a sea level rise of 0.3 m by 2050 and 1 m by 2100 (Coast Protection Board 1992)*

2.8.1 Beach width loss

Previous estimates of beach width loss due to rising sea level (Coastal Management Branch 1984) have been based on an assumed sea level rise of 2 mm/year. It was assumed this was analogous to scraping a layer of sand off the beach 2 mm thick over all of the active beach zone, which was estimated to have an average width of 300 m. This essentially gave an effective sand loss of 0.6 m^3/m beach length per year, or approximately 17,000 m^3/year for the coast between Seacliff and North Haven (Coastal Management Branch 1984).

The loss is more important to the middle and southern sections of the coast from Kingston Park to Semaphore Park, as the sand accumulates in the northern section. The loss of sand affecting beach width south of Semaphore Park is around 10,000 m^3/year. Further work carried out in the 1992 review on this impact gives a mid-range prediction of 27,000 m^3/year based on a 2 mm/year relative sea level rise. However, if sea level rises over the next 20 years are in accordance with the mid-range sea level rise predictions, an extra 47,000 m^3 per year will need to be provided within the next 20 years.

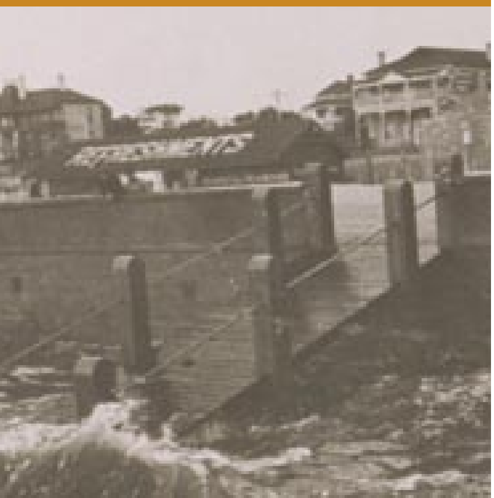
2.8.2 Increased rate of littoral drift

A rise in relative sea level is likely to alter the magnitude of waves and angle at which they strike the shore. Sea level rise was therefore anticipated to lead to increasing rates of littoral drift. To estimate the magnitude of this increase for the Adelaide coast, the Coast Protection Board commissioned a numerical modelling study (Coastal Engineering Solutions 2004). The study showed that the littoral drift rate response to climate change–induced relative sea level rise is variable along the coast. Consequently, erosion will increase and decrease at different locations, and 'hot spot' erosion is possible for scenarios of 20, 50 and 100 years into the future. Overall, however, the average littoral sediment transport potentials do not increase, provided the extent of seagrass meadows does not change significantly.

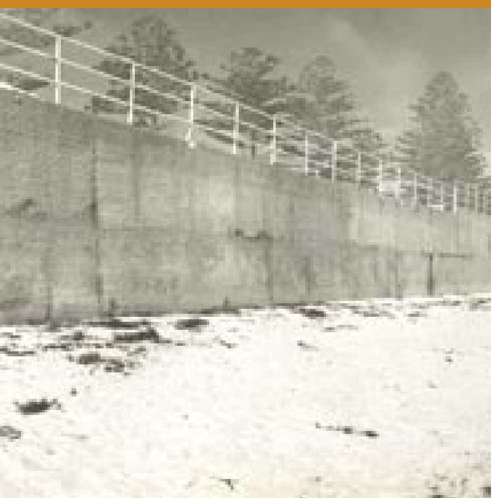
2.8.3 Changes in storminess due to climate change

McInnes et al. (2003) suggested that significant swell could become more frequent and the large sea waves generated within Gulf St Vincent could become less frequent but greater in height. Increased storminess would have a relatively small impact on littoral transport potential – around 10–15% for 100 years in the future (Coastal Engineering Solutions 2004). However, accompanied by sea level rise, increased storminess would have a significant effect on offshore sand motion, doubling the storm take from dunes (Coastal Engineering Solutions 2004).

Semaphore jetty, 1905



Semaphore seawall and ramp, 1923



Early seawall, Henley Beach

3. Coastal Management History

3.1 Early coastal development

Since European settlement, coastal development has encroached on the Adelaide coastal foredunes. The erosive nature of the coast was not sufficiently well recognised until the 1960s and even then development pressures at the coast continued. Building on dunes had the effect of 'locking up' the sand supply that had maintained beaches and allowed for the winter and summer exchange of sand between sandbars and the upper beach. Consequently, in some locations without dune buffers storms now erode beaches to lower levels than in the past.

3.2 Early coast protection works

Most of the early protective works up to the 1940s were built on an as-needs basis by either local councils or the South Australian Harbors Board. Tables 3.1 and 3.2 summarise the type of protection works constructed before the 1920s and between 1920 and 1945.

Table 3.1 *Coast protection works before the 1920s (Coastal Management Branch 1984)*

Year	Coast protection works
1856–60	Seawalls at Moseley Square, Glenelg
1859	The Semaphore jetty and the original Glenelg jetty
1880–83	The Largs Bay, Grange, Henley Beach and Brighton jetties
1836–1919	Seawalls at Brighton, Glenelg, Henley Beach, Semaphore and Largs Bay, and the Outer Harbor breakwater
1915–17	Timber wall at the Brighton jetty

Table 3.2 *Coast protection works between 1920 and 1945 (Coastal Management Branch 1984)*

Year	Coast protection works
1925–26	Concrete seawall between the Patawalonga and Margaret Street, Glenelg North
1926	Concrete seawalls at the Brighton jetty
1926	Concrete retaining walls at the Grange jetty*
1927–28	Concrete seawall at the Broadway, South Glenelg
1929	Concrete retaining walls at the Henley jetty
1920s	Concrete retaining wall north of the Semaphore Surf Life Saving Club*
~1930	Wheatland Street rotunda, Seacliff*
1933	Concrete seawall at the old (now filled in) Henley swimming pool*
1939	Concrete seawall at Terminus Street, Grange
1944–45	Timber-piled concrete and stone wall between Ozone Street and Henley Beach Road, Henley Beach South*

* These structures were still in place in 1984; the other structures were damaged in the 1946, 1948 and 1953 storms.

Local government committees were formed to better coordinate protection of the foreshore in response to several major storms in the late 1940s and early 1950s. In 1953, the Seaside Councils Committee was established (and assisted by the former Harbors Board) to provide coastal protection advice and designs for protection works.

By the 1960s, there was a growing awareness that coastal engineering designs needed to mimic natural systems to succeed in the long term. Vertical seawalls and groynes had been found to cause beaches to scour, so the emphasis was changed to more wave-absorbent measures such as energy-dissipative, placed-rock seawalls. Between 1945 and 1970, several seawalls were reconstructed, new ones were built or rocks were placed along the foreshore to provide greater protection for the coast (Table 3.3). Moulds (1981) described further details of these works.

Table 3.3 *Coast protection works between 1945 and 1972 (Coastal Management Branch 1984)*

Year	Coast protection works
1948	Timber piling at Portland Street, Brighton, and road repair at Somerton
1952–54	Seawall reconstruction at the Henley jetty*
1953	Seawall construction from south of the (now filled in) Henley swimming pool to South Street, Henley Beach*
1953	Rock wall from South Street to Henley Beach Road, Henley Beach*
1953	Timber sheet piling north of the Brighton jetty and at Seacliff
1953	Replacement of concrete seawalls at the Anzac Highway car park, Glenelg, and southward extension of the Broadway concrete seawall*
1953–58	Dumped rock along the foreshore length at Brighton
1955	Dumped loose rocks north of Marlborough Street, Henley Beach*
1960	Loose stone between South Glenelg and the Broadway
1964–65	The Patawalonga groyne*
1960s	Rocks in front of the concrete walls north and south of the Semaphore jetty*
1969–72	Gabion seawall along the frontal dunes near the Glenelg WWTP and rock, reno-mattresses and concrete outlet pipe protection

* These structures were still in place in 1984.

3.3 Major studies and reports on Adelaide coast protection

A number of significant reports and studies have guided the protection strategies employed on the Adelaide coast since the 1970s:

1. *Final Summary Report on Beach Erosion Studies* (Culver 1970)
2. *Adelaide Coast Protection Strategy Review* (Coastal Management Branch 1984)
3. *Metropolitan Coast Protection District Management Plan* (Coast Protection Board 1985)
4. *Review of Alternatives for the Adelaide Metropolitan Beach Replenishment Strategy* (Coastal Management Branch 1992)
5. *Report of the Review of the Management of Adelaide Metropolitan Beaches* (Department of Environment and Natural Resources 1997).

3.3.1 The 1970 Culver Report

In early 1965, a University of Adelaide study jointly funded by State and local governments was begun to determine the causes of beach loss and to propose remedies for it. In December 1970, Bob Culver of the Civil Engineering Department of the university presented the report of this study, now known as the Culver Report (1970). It made several important recommendations:

1. Stop any further encroachment (of development) onto the beach or dune areas as a matter of urgency.
2. Rehabilitate (replenish or protect) low areas as a temporary measure now, particularly Brighton, Glenelg North 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.

Following proclamation of the *Coast Protection Act 1972*, the Coast Protection Board was formed. The main protection strategy pursued since then has been beach replenishment in order to provide adequate sand for buffers and beach provision. This has been backed up by seawalls where necessary to protect development as a last line of defence. These seawalls complemented the seawalls constructed before the Coast Protection Act by councils and the Marine and Harbors Agency. The strategy also included stabilisation of dunes from wind-blown sand drift with vegetation and fencing.

Beach replenishment

Beach replenishment started in 1973–74, with Brighton beach receiving 15,000 m^3 of sand from Taperoo, and Glenelg North being replenished with nearly 25,000 m^3 from Taperoo and south of the Glenelg groyne. This was increased in 1977, so that between 1977 and 1984 an average of 105,000 m^3 of sand (135,000 m^3 of loose sand in trucks) was carted annually, mostly from Semaphore and Glenelg and to a lesser degree from Taperoo, Largs Bay, Point Malcolm, the Grange jetty and south of the Torrens Outlet. As the opportunity arose, sand was also obtained from coastal building sites. Most sand went to replenish the beaches at Brighton, Glenelg North and West Beach.

Rip-rap seawalls

From 1970 onward, seawalls have been constructed using an improved rip-rap design first approved by the Department of Marine and Harbors and later by the Coast Protection Board. The initial design included a two-layer stone filter to prevent fine materials from washing away. It supported an outer 2 m–thick layer of boulders 0.5–3.0 tonnes in weight (Figure 3.1a). After 1975, the design was modified to include a 5-tonne toe-stone to prevent undermining of the structure, and in some cases a filter fabric was used in place of the stone filter (Figure 3.1b). The seawall top has since been raised by 0.6 m, to 4.2 m AHD, to cover the predicted sea level rise associated with climate change and meet current Coast Protection Board sea level rise provisions.

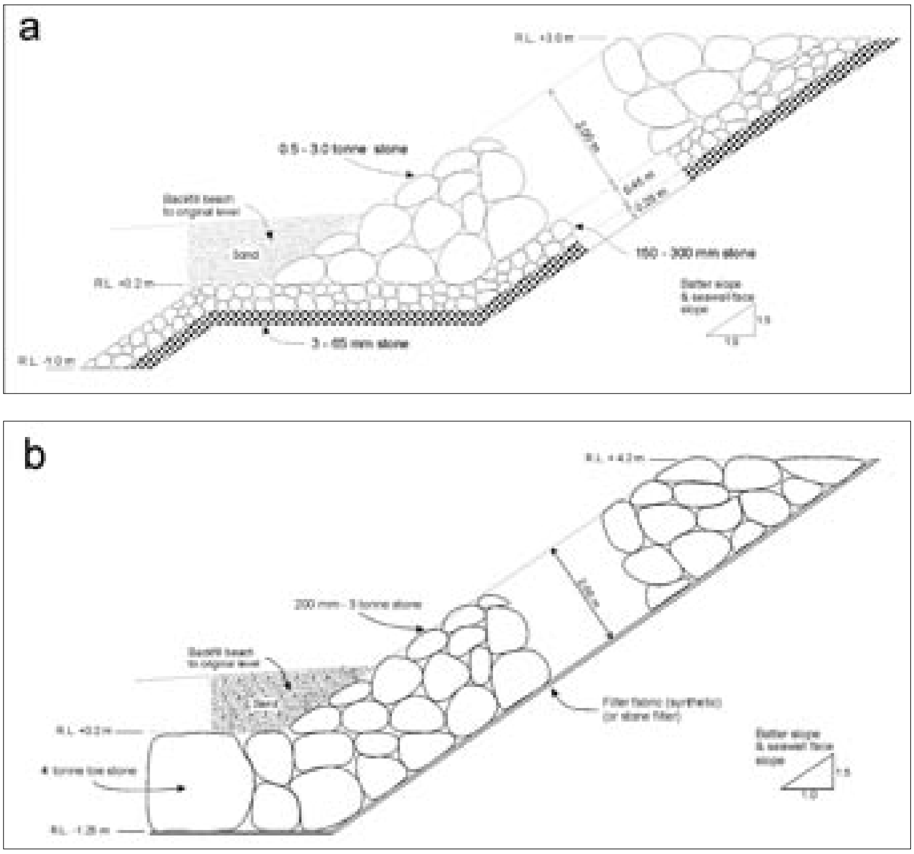
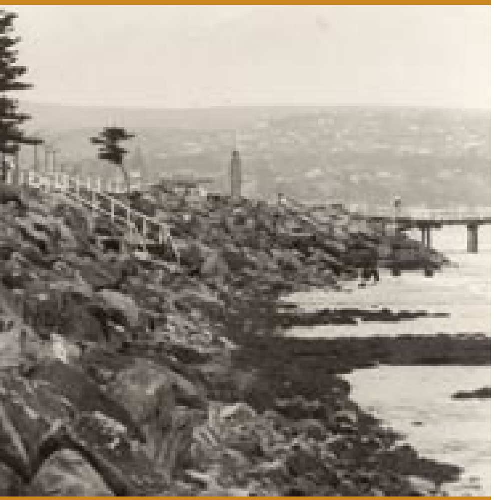


Figure 3.1 *Rip-rap seawall designs (a) before 1975 (b) after 1975*

Several seawalls have been strengthened or reconstructed since the 1970s (Table 3.4). In particular, some maintenance of the rip-rap seawalls at Glenelg North and in front of the WWTP was necessary for those with stone filters, due to slumping from sand being washed out from behind.



Early rip-rap seawall at Brighton

Table 3.4 *Rip-rap seawall construction between 1970 and 1983 (Coastal Management Branch 1984)*

Year	Location
1972	Rip-rap seawall between Kingston Park and Marino Rocks by the Brighton and Marion councils under DMH supervision
1973	Rip-rap seawall reconstruction of portions of the Brighton Esplanade protection at the jetty and between Downing Street and Gladstone Road by consultants and approved by the Coast Protection Board
1973	Rip-rap seawall reconstruction at Glenelg North from the Patawalonga Outlet to the WWTP by consultants and approved by the Coast Protection Board
1973	Northward rip-rap seawall extension at Glenelg North by E&WS to protect the WWTP
1973–74	Rip-rap seawall at Chetwynd Street, West Beach, north of the West Beach Recreation Reserve
1975–80	Rip-rap seawall reconstruction in the North Brighton and South Glenelg areas including reinforcing the stone wall between the Broadway and Glenelg jetty (the Coast Protection Board also recommended reconstruction south of Minda, as well as from Gladstone Road to Dunluce Road and at the jetty but the need lessened with beach replenishment)
1981	Rock protection in front of the Surf Life Saving Club at Somerton and at Henley between Marlborough Street and Grange Road after severe storms
1983	Temporary strengthening of dumped rock between Henley jetty and Marlborough Street until funds were available for its reconstruction

Figure 3.2 summarises the different periods when structures were built on the coast. Before 1920, the jetties and the Outer Harbor breakwater were the first large structures to be built out over the water. This period was followed by several decades of seawall construction along beach and dune areas most prone to erosion. By the 1960s, the design of seawalls had changed to better absorb wave energy and, while fewer seawalls were built, several were upgraded. Between 1972 and 1984, new seawalls were constructed in the West Beach area and breakwaters were built at North Haven as part of the marina development.

Dune stabilisation

The dune stabilisation program to prevent sand drift inland mostly comprised erecting sand-drift fencing and planting dune vegetation, with fencing being replaced when washed away by storms. Sand drifts were found to be a problem at times along the Esplanade at South Brighton, so extensive drift fencing and tree prunings were used to stabilise the dunes. Significant sand was also lost inland along the West Beach dunes. Therefore, between 1976 and 1979 and again in 1983 after maintenance was neglected, the dunes were reshaped with earthmoving equipment, a sprinkler system using effluent from the WWTP was installed, additional fencing and planting were carried out, and new pathways were made to the beach.

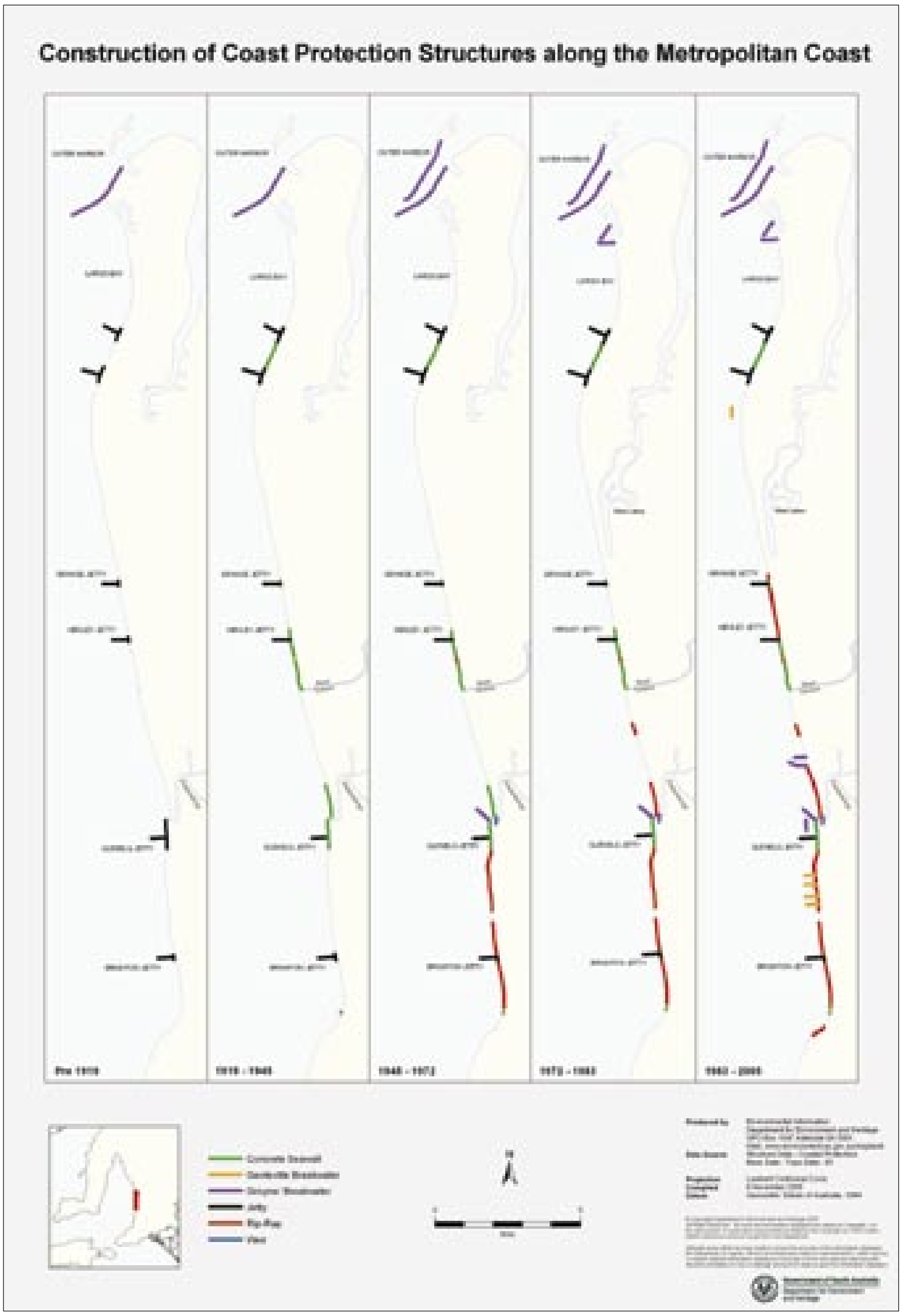


Figure 3.2 *Construction of coast protection structures up to 2005*

3.3.2 The 1984 Adelaide Coast Protection Strategy Review

The 1984 *Adelaide Coast Protection Strategy Review* by the Coastal Management Branch (Coastal Management Branch 1984) reviewed the rock protection and beach replenishment strategy adopted following the Culver Report (1970) and all practical alternative strategies. In addition, the 1984 review included findings from an offshore sand supply dredging study (Lange, Dames and Campbell & Pickands, Mather and Co. 1982), an alternatives study (Kinhill Stearns & Reidel and Byrne 1983), and wave studies by the Civil Engineering Department of the University of Adelaide (Culver & Walker 1983a, 1983b, 1983c, 1983d).

Erosion

The 1984 review recognised the lack of sand entering the metropolitan beach system from the south and the net northward alongshore sand movement as the main factors responsible for beach and dune erosion. Sea level rise due to the greenhouse effect was also considered an erosion threat. It was estimated that if management actions were not continued, several beaches and dunes would be lost and there would be significant costs, in the tens of millions of dollars, resulting from property damage.

The main protection strategy at that time involved annual beach replenishment. Sand was taken mainly from the northern beaches and at Glenelg and the Torrens Outlet, and replenished mostly to Brighton and Glenelg North beaches. However, sand-trucking programs were known to be unpopular and it was considered difficult to increase them. In addition, many of the existing sand sources were found to contain too much fine sand so they could not be used to the extent that had previously been assumed.

Sand sources

The 1982 dredging study, which was part of the 1984 review, considered the practical and economic feasibility of replenishing Adelaide's beaches with sand dredged from offshore sources. When the dredging study was commissioned, the two most likely possibilities were the areas offshore from North Haven and the Onkaparinga River. (The deposit in the Section Bank north of Outer Harbor had already been shown to be usable but not ideal because an additional 20–40% was thought to be needed to offset losses of its fine component from the replenishment beaches. The area was also in water too shallow for the most likely type of dredge to operate.) Recent dredging of the North Haven channel had shown that sand in this area was generally too fine to be used for replenishment purposes. The only evidence for a deposit offshore from the Onkaparinga River was seismic information published in 1983. Nevertheless, dredging from an offshore source was shown to be feasible and of a similar cost to the existing sand carting program. It was therefore recommended that sand surveys be extended to provide a complete assessment of offshore sources.

Onshore sand sources identified were the dunes on Torrens Island (considered to contain suitable sand for about 10 years of replenishment), local dune deposits at West Beach, West Lakes and Port Noarlunga (within recreation or conservation areas and therefore not considered feasible), and smaller deposits against structures at Port Stanvac and Glenelg. More costly onshore sources included washed sands from commercial sand pits south of Adelaide and, further afield, coarser sands at Lake Alexandrina and Mount Compass.

Locating sand from a source outside the metropolitan beach system was considered particularly advantageous, as it would increase the total amount of sand in the system.

Development controls

At the time of the 1984 review, the main legislation controlling coastal development was the *Planning Act 1982*, with controls also implemented through the Coast Protection Act. Inadequacies identified in the Planning Act included roads and drainage works, dredging, earthworks and low retaining walls being excluded from the approval process. In addition, emergency government coast protection works were not excluded from the time-consuming notification and approval process. The *Development Act 1993*, which addresses some of these inadequacies, has since replaced the Planning Act. An amendment to the Coast Protection Act was also implemented so that the Coast Protection Board could be given clearer legal authority for beach replenishment to avoid disputes over its redistribution of beach sand and to prevent beach sand being taken by others.

Protection strategies

Several protection strategies, which took into account the impact of climate change on sea level rise, were considered in the 1984 review:

- **No protection** was not considered a viable strategy. Property and beach amenity losses as a result of taking no action were estimated at $12 million and $28 million respectively, and it was predicted that most beaches south of West Beach would disappear within the 50-year study period.
- **Continuing present measures** of annual beach replenishment and some seawall construction. This was considered the only viable strategy if a suitable offshore sand deposit was not found. The aim of the strategy was to build up wider beaches and a strip of dunes in front of rock walls to act as storm buffers at the narrower southern beaches. It involved beach replenishment of 100,000 m^3 annually to Brighton and Glenelg North, regular moving of sand past the Torrens Outlet, and seawall construction at Henley Beach to be finished in 10 years. A disadvantage of the strategy was that it involved nearly three times as much truck travel as other alternatives.
- **Seawalls only** was a short-term solution not considered viable as it would most likely result in slightly more beach loss than taking no action. If important beaches were lost, opportunities for beach recreation would be reduced markedly and this would adversely affect tourism in the State.
- **Reduced status quo** version of the existing measures that would have replenishment quantities matching losses rather than establishing wider beaches and a dune system. This strategy had no significant benefit as it would not remove the cause of erosion problems and sand trucking would only be slightly reduced because replenishment would still be needed.
- **Major beach replenishment** was considered viable only if sufficient suitable sand was found. The cost of such a strategy was estimated at the time to be $19.1–21.6 million (at a 5% discount rate) depending on the sand source. Greater costs would be incurred for finer-grained deposits since 20–50% of replenishment sand could be lost from replenished beaches. The type of dredging and transportation method would also affect the cost.

- **Groynes or offshore breakwaters** were considered feasible if used in conjunction with major beach replenishment. By themselves, they would only redistribute scarce available sand and cause greater problems. Groynes and breakwaters can reduce alongshore drift but their effects are not entirely predictable, particularly for the Adelaide coast with its variation in wave-energy direction. In some cases, they could introduce an erosion risk and they should not be considered without a full-scale experiment first. The estimated cost of using groynes with replenishment was $2.8 million more than for replenishment alone, though this figure would be reduced if maintenance dredging of the Patawalonga were taken into account. Offshore breakwaters were estimated to cost more than groynes though their effects would not be as harsh.
- **Other methods**, such as floating breakwaters, artificial seaweed and shaped offshore dredging to modify wave refraction, were considered unsuitable for local Adelaide conditions or insufficiently developed to obtain reliable results.

After a cost analysis of these options in alternative combinations, the 1984 review recommended:

> … continuing the coast protection strategy of replenishing 100,000 m^3 of unbulked sand (135,000 m^3 of sand in trucks), and replacing existing seawalls only where adequate beach protection could not be provided by replenishment.

This was considered at the time to be the most effective and the least costly way of improving the beaches and level of protection until an adequate offshore sand supply could be found.

3.3.3 The 1985 Metropolitan Coast Protection District Management Plan

The *Metropolitan Coast Protection District Management Plan* (Coast Protection Board 1985) is one of five Coast Protection Board district management plans for the South Australian coastline. It covers the coastal area (as defined in the Coast Protection Act) from Port Gawler in the north to Sellicks Beach in the south.

It describes coastal management as

> … a process of making decisions on use of the coast, having first studied the environment and its capabilities as well as the issues involved and alternative solutions to them, and having sought and considered the views of the public. It will generally involve guiding development and recreation to less sensitive areas, while restricting access and use in more fragile parts.

While each district management plan contains the same general policies (Table 3.5), specific policies are included for each district derived from the study report for that district.

Issues and policies specific to the Metropolitan Coast Protection District were considered in terms of area classifications as distinguished by landform type, scientific importance or existing and potential land use. Overall, preservation area classification overlies other area classifications, which are based on landform only.

Table 3.5 *Coast Protection Board district management plan general policies*

Policy no.	General policies for coast protection districts
2.2	**State and local government responsibilities** The Coast Protection Board will work closely with local government in all aspects of coastal management (1), implement its policies through available legislation (2), and provide financial and technical assistance (3). It will also ensure that State welfare is considered when the impact of an activity is of State concern (4).
2.3	**Existing legislation affecting the coast** The Coast Protection Board will utilise existing legislation affecting the coast to perform its duties (1) including the Planning Act to implement management plan policies and avoid duplication (2). It will liaise with and advise other authorities and departments of its policies (3) and, where there is variance to these policies, will suggest and/or support necessary changes (4).
2.4	**Research** The Coast Protection Board will carry out comprehensive coastal research (1), which will form the basis on which management policies will be formulated and reviewed (2). It will make available the information it compiles to the public, and local, State and federal governments (3). It will assist those undertaking studies that improve understanding of the South Australian coast (4) and help coordinate coastal research (5).
2.5	**Use of the coast** The Coast Protection Board will encourage and optimise use of the coast, monitor the demand for its use and assess the capability for that demand (1). In determining priorities for use, areas will be identified that will require protection as preservation areas (2). Areas not classified for preservation will be assessed on their ability, in terms of landform classification, to cater for uses without undue adverse environmental effects; preference will be given to public over private use and to uses that need to be located close to the coast. Where serious conflicts exist, a restriction, segregation or relocation policy will be adopted (3).
2.6	**Provision of facilities** The Coast Protection Board will provide technical assistance and seek adequate funding arrangements for a wide range of facilities (e.g. toilets, car parking and boat launching sites) (1). It will support the restriction of vehicles on beaches as off-beach parking areas either become available or are just not possible (2 & 3). It will have regard to local government submissions and establish priorities for the provision of facilities (4).
2.7	**Access** The Coast Protection Board will study access arrangements on the coast with a view to rationalising existing and planned roads to best serve coastal users (1). This includes investigating the role of esplanade roads to assess the need for construction or closure to improve amenity (2).
2.8	**Development** The Coast Protection Board will support nodal urban development so as to reduce scattered or linear coastal development (1). It will liaise with those responsible for implementation of the Planning Act (*Development Act 1993*) to ensure that coastal management is adequately considered and to prevent duplication (2). It will consider development proposals for the coast by assessing the capability of the environment to support such proposals, particularly those proposals likely to affect or be affected by coastal processes (3).
2.9	**Coastal engineering** The Coast Protection Board will support the provision of adequate buffer zones between coastal development and the sea, preferably at the land division stage, and will investigate erosion rates and other information demonstrating a need for buffer zones (1). It will only assist in the provision of works to protect structures poorly located as a result of past mistakes (not new construction) (2). It will identify areas of the coast considered unsafe or unsuitable for construction purposes or over which special restrictions will apply to prevent foreshore erosion (3). It will coordinate with authorities responsible for the use of crown lands to ensure the coastal environment is adequately protected (4). Proposals for the development of public foreshore areas will be investigated to assess the need for the proposal to be located close to the sea (5).
2.10	**Appearance and design** The Coast Protection Board will assess the appearance and design of proposed developments in relation to the visual resource of the coastline (1). It will assess likely improvement to aesthetic value in considering applications for assistance (2). Guidelines around which controls may be implemented will be prepared and made available to local government and the public (3).
2.11	**Conservation and preservation** The Coast Protection Board will consider the purchase of areas necessary for preservation within coast protection districts (1). It will assist in the preservation or restoration of natural conditions of preservation areas (2). In association with local government, regular surveys of preservation areas will be undertaken to assess their condition and formulate adequate controls on public use (3), and for areas of special significance not classified as preservation areas, the Coast Protection Board will develop guidelines and principles of environmental protection (4).
2.12	**Waste disposal** The Coast Protection Board will liaise with agencies and authorities concerned with pollution and will monitor discharge effects (1). It will seek continued representation to authorities established for accidental pollution to ensure adequate safeguards exist (2). It will study the potential implications of oil spills with a view to prevention, recovery and dispersion (3). It will ensure proposals for future land-fill operations are adequately assessed for possible adverse physical and visual effects (4), and will assist in rehabilitating unsatisfactory coastal rubbish dumps (5). It will also assist in the provision of facilities and publicity programs for litter disposal (6).
2.13	**Mining** The Coast Protection Board will assess proposals for the mining of organic or inorganic resources to ensure adequate protection of the coastal environment (1).

Metropolitan District landform classifications

Metropolitan District landform classifications relevant to Adelaide beaches (between Marino Rocks and Outer Harbor) include coastal waters areas (3.1), and beach and sand dune areas (3.2) (Table 3.6).

Table 3.6 *Coast Protection Board district policies for the Adelaide beaches*

Policy no.	District policies for the Metropolitan Coast Protection District relevant to Adelaide beaches
3.1	**Coastal waters areas** The Coast Protection Board will support the preparation of baseline studies to document the environmental condition and water circulation patterns of the metropolitan coastal waters areas in locations where new outfalls are planned, where volumes from existing outfalls will be increased, and where the risk of accidental pollution is high (1). The Coast Protection Board will study the potential and implications of refuse and debris being discharged into the metropolitan coastal waters areas with a view to trapping and removing the material prior to discharge (2).
3.2	**Beach and sand dune areas** The Coast Protection Board will endeavour to maintain adequate beach levels to reduce storm damage, decrease the rate of erosion, and provide adequate recreation space (1). Rip-rap walling is considered to be the most appropriate type of protective work for use in the Metropolitan Coast Protection District. The Coast Protection Board will consider assisting in its provision where necessary (2). The sand balance of the Adelaide system will be monitored regularly so that necessary artificial replenishment and redistribution measures can be determined and undertaken (3). The Coast Protection Board will endeavour to retain sand within the Adelaide beach system by supporting restrictions and initiatives designed to: • retain natural sand dunes • prohibit the use of sand dunes and beaches as sources of filling material • encourage the growth of foredunes and reduce the loss of wind-blown sand by sand drift control fencing • assist in stabilising all areas of sand above the tidal range with coastal plants such as spinifex and marram grass • control pedestrian access in sand dune areas (4). Since the risk of damage from storms or interference with natural processes is great in the beach and dune areas, the Coast Protection Board will support strict controls on all construction proposals in these areas (5). The Coast Protection Board will support the selected closure of esplanade road reserves and the re-allocation of these for a more appropriate public use in areas that are unsuitable for traffic and roads (6). The Coast Protection Board will continue to monitor levels of seaweed build-up on Adelaide beaches and assist councils with the problem it creates (7).

Coastal waters issues

The plan (Coast Protection Board 1985) stated that one of the main issues affecting metropolitan coastal waters was pollution from waste disposal (see plan section 2.12). Treated effluent or stormwater discharged into coastal waters could result in disturbance to seagrasses and damage to mangrove areas. Metropolitan coastal waters were also vulnerable to accidental pollution by oil spills.

Significant management issues had arisen from the competition and conflict between users and activities on the coast (see plan section 2.5). Recreational pursuits would need restrictions extended to minimise danger and loss of enjoyment through conflict. Added to this was the need to carry out construction and other works (e.g. pipelines, conduits, ducts, dredging, dumping and marine harvesting) that were likely to have an impact on the seabed and coastal waters. The plan indicated that mining of sand, seagrass or mineral deposits might become viable in the future (see plan section 2.13), as might works for the protection, restoration and development of coastal waters (e.g. breakwaters, seawalls, boat havens, boat ramps, slipways and jetties). Proposals for such works would need to be assessed by the Coast Protection Board following preparation of an environmental report or, in the case of major projects, an environmental impact statement.

Beach and sand dune issues

The responsiveness of beaches and coastal sand dunes to the major coastal processes of winds, waves, tides, storms and seasonal change was also discussed in the plan. Sand dunes, in particular, were only as stable as the amount of soil or vegetation cover on them and their protection from erosive forces. Environmental stresses were particularly severe on beaches and sand dunes, and any vegetation needed to be very resilient to survive.

Studies on Adelaide beach erosion had indicated only a small amount of sand coming into the system from the south and little sand movement out of the system to the north past the Outer Harbor breakwater. In general, the beaches between Seacliff and Henley Beach were slowly declining in sand level (except for local build-ups at the Patawalonga and Torrens Outlets), while beaches north of Semaphore Park were accreting.

As well as being naturally sensitive, these areas were subject to a great deal of urban pressure. On many sections of the metropolitan coast, houses and roads had been built on top of the original sand dunes, thereby stabilising them and restricting the physical interaction between them and the beach. This had sped up the process of sand depletion on the coast and, because many dunes were no longer available to act as a buffer between development and the sea, it had been necessary to construct protective seawalls to prevent storm damage. Seawalls could compound the problem of falling beach levels in front of them unless carefully constructed using a rip-rap design.

Another complicating factor acknowledged by the plan was the slow rise of mean sea level and its effect of relative decline in beach levels.

In view of these processes, sand dunes had to be retained in their natural state or built up by the use of access-control measures, traps for windblown sand, and protection or encouragement of vegetation.

Beach and sand dune areas not in private ownership were either foreshore reserves allocated for specific purposes, usually recreation or the provision of roads, or in the ownership of the Minister for Marine. Demands for facilities (see plan section 2.6) were relatively high in this landform classification. Esplanade road reserves in many places were wide, up to 200 m, covering the strip of land between private allotments and high-water mark, and often included sand dunes and beach. The plan stated that the reserves should not be used for the allocated purpose since traffic or road construction would degrade the environment.

The Coast Protection Board (1985) recommended careful consideration of all construction, whether it be buildings, roads or engineering structures such as seawalls, in beach and sand dune areas. The potential for structures to interfere with natural processes, aesthetics and public access was high, and this, together with a risk of damage to the structure itself, indicated that siting and design were more critical than in inland areas. In many cases, development should be prohibited.

3.3.4 1992 Review of Alternatives for the Adelaide Metropolitan Beach Replenishment Strategy

Since the review in 1984, the Coastal Management Branch had been able to investigate beach replenishment sand sources, particularly those offshore, in more detail and collect better data on sand movement along the metropolitan coast. The Branch was able to better represent the metropolitan beach system in terms of volumes of sand movements, rates of movements, identification of erosion and accretion zones, anomalous behaviour along the coast, onshore/offshore movements and other aspects of the beach system. In addition, sampling and underwater investigations of the offshore beach replenishment sources were greatly assisted by trial dredging operations from 1989 to 1991.

In view of that information, particularly the opportunity to provide sand to the beaches by dredging offshore sources, it was time to reassess the beach replenishment strategy and update the 1984 review of the methods available to achieve the required level of protection for the Adelaide coast.

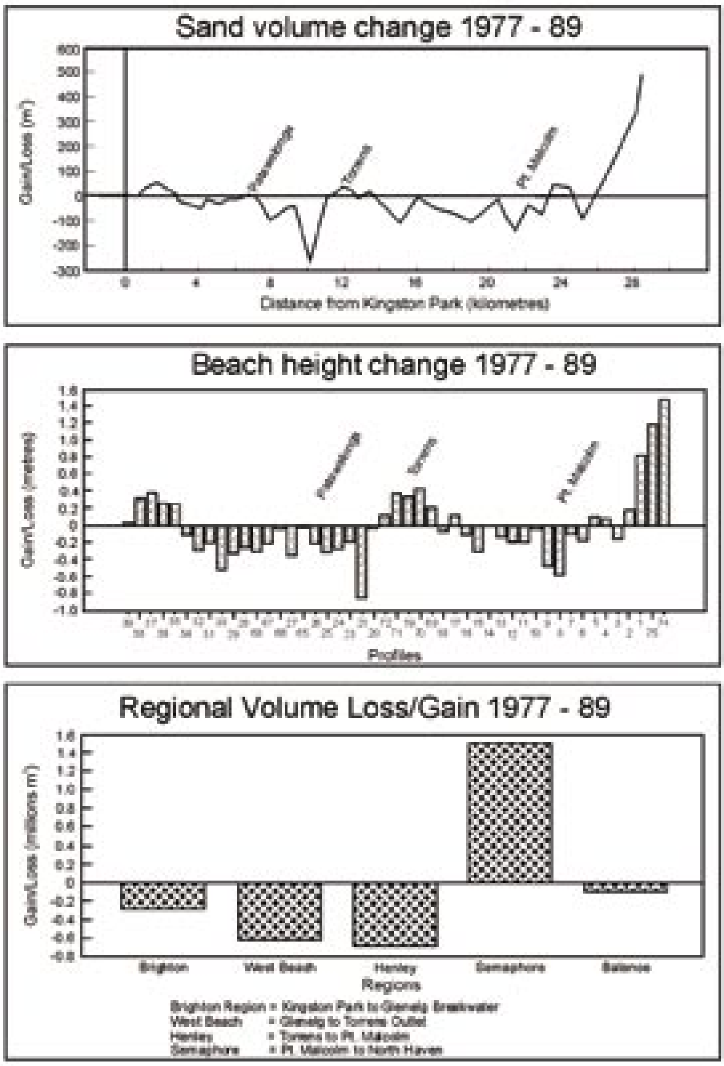


Figure 3.3 *Beach profile figures for 1977–89 (Coastal Management Branch 1992)*

Monitoring program

The Coastal Management Branch beach profile monitoring program, begun in 1975, established 47 beach profiles, each approximately 600 m apart, from south of Kingston Park to the North Haven southern breakwater. In 1989, the active beach zone in problem areas at Brighton and West Beach was monitored, with levels measured on a 50 m grid pattern. By comparing results, changes in sand volume and beach height along the coast could be detected (Figure 3.3).

In order to maintain stable beach levels where large losses had occurred, beach replenishment volumes in these regions needed to be adjusted or vulnerable beaches could be denuded of sand and their protection works undermined. The beach profile data showed that, in addition to the average annual replenishment of 101,800 m^3, a further 6600 m^3 was necessary for the Brighton region, 32,000 m^3 for the West Beach region, 7600 m^3 for south of the Grange jetty in the Henley region, and 8700 m^3 for Semaphore Park. In total, it was found that up to 160,000 m^3 of beach replenishment sand was required annually in order to maintain beaches to 1977 levels.

Major beach replenishment

In 1988, funding was allocated for a major beach replenishment program over a 3-year period, as the previous sand quantities were insufficient to reduce sand loss from Somerton Park, Glenelg North and the West Beach dunes. Between 1988 and 1990, around 190,000 m^3 of sand was trucked from Torrens Island to Glenelg North and 100,000 m^3 of sand was pumped ashore at North Haven by a suction dredge and trucked to Somerton Park.

In 1990, the Coast Protection Board recommended a trial dredging program to reduce the amount of sand carting by trucks. Government funding allowed Australian Dredging and General Works Pty Ltd to dredge approximately 100,000 m^3 of sand from an offshore sand source at North Haven using a small split hopper trailing suction dredge called the *Pelican*. The dredged sand was pumped ashore through a pipeline to the beach at Glenelg North.

A further dredging trial in 1991 saw Australian Dredging and General Works dredge 200,000 m^3 of sand from an offshore source at Port Stanvac.

In all, the replenishment program provided an average annual volume of 200,000 m^3 from 1989 to 1991 to build up beach levels in some of Adelaide's most vulnerable coastal areas.

Alternative replenishment strategies

The dredging of sand from offshore sand sources prompted a reassessment of alternative protection strategies. Eight strategies were considered for Adelaide's metropolitan coast in the 1992 review, several similar to those outlined in the 1984 review but using updated information and costings for their assessment. Treasury Department guidelines (Treasury Department 1990) directed that estimates of future cash flows should be converted to present values using a 7% discount rate, with 4% and 10% sensitivity discount rates. Each alternative was costed over a 20-year period to determine the most cost-efficient strategy for maintaining the metropolitan beaches.

- **No protection** was included for consistency with the 1984 review but was not considered viable because of the high cost of replacing inevitable property loss.
- **Maintain the status quo** of biennial replenishment of 200,000 m^3 using a dredge, combined with annual localised replenishment of 50,000 m^3 using trucks to top-up southern beaches. Coastal Management Branch beach profile data indicated that at least 150,000 m^3 of replenishment was required annually just to maintain Adelaide's beaches without any improvement to beach amenity or foreshore protection and without sea level rise.

- **Abandon replenishment and construct seawalls when necessary** was an alternative that would only be implemented if the primary aim became the protection of property and if beach loss was disregarded. Consideration of a period greater than 20 years was also necessary for the time sequencing and cost of repairs to existing seawalls or construction of new seawalls.
- **Major replenishment by dredge** comprised initial major replenishment of approximately 3,000,000 m^3 using a dredge and pump ashore procedure, followed by triennial replenishment of approximately 200,000 m^3. Two alternatives were given: a small dredge, such as the *Pelican*, would pump 3,000,000 m^3 of sand onto southern beaches during the first 10 years (1,000,000 m^3 from Port Stanvac followed by dredging from the North Haven and Outer Harbor sand source), with a top-up of 200,000 m^3 of sand every third year thereafter over the 20-year period; a medium dredge, such as the *WH Resolution*, would pump 3,000,000 m^3 of sand onto the southern beaches during the first five years, with a top-up of 200,000 m^3 every third year. Annual maintenance of existing seawalls, minor sand carting and other such works were assumed necessary. This option also assumed a maximum overfill ratio of 1.5, but more recent information suggests overfill ratios from 4 to over 10, which makes it even more expensive.
- **Major replenishment using a large pipeline from North Haven** comprised major replenishment of approximately 3,000,000 m^3 over three to four years using a large pipeline from North Haven and triennial replenishment of approximately 200,000 m^3. This strategy was similar to major replenishment by dredge. It would use a small suction dredge at North Haven (Lange, Dames and Campbell & Pickands, Mather and Co. 1982) to dredge 3,000,000 m^3 of sand over the first four years, and pump it ashore to a ponding area before pumping it southward through a pipeline laid along the foreshore. Annual maintenance of existing seawalls, minor sand carting and other such works were assumed necessary. The assumed maximum overfill ratio of 1.5 has now been suggested at over 10, which makes this option even more expensive.
- **Progressive construction of groynes** would be complemented by ongoing beach replenishment during the construction phase. The 1984 review discounted the use of groynes without major replenishment. However, with the move towards beach replenishment by dredging offshore sand sources, there was less of a problem of insufficient sand to fill the groynes. They could create a series of stable embayments along the metropolitan coast if there was no spillage of sand from one to another or adverse erosional effects. The 1984 option of using 20 x 200 m long appropriately spaced groynes was considered, with a construction program of groyne building either from the southern to the northern end of the metropolitan coast or from the northern to the southern end. For the south to north program, it would be necessary to maintain beach replenishment to southern beaches from the last constructed groyne until all the groynes were constructed. For the north to south program, it would be necessary to maintain beach replenishment immediately south of the last constructed groyne. In the latter, the embayments could be partly filled naturally due to a net northerly littoral drift. Construction of each groyne would also need to be coordinated with a biennial dredging program.
- **Construct a groyne field** of 20 groynes with major replenishment to stabilise beaches between the groynes would be as above combined with major replenishment either using a small dredge over a 10-year period or a medium dredge over a 5-year period. This method of groyne construction was found to be more expensive than for progressive construction.
- **Increased replenishment program** of initial replenishment of approximately 1,000,000 m^3 using a dredge and pump ashore procedure, and biennial replenishment of approximately 200,000 m^3, would initially replenish southern beaches to their 1977 levels and then maintain those levels. It would improve the amenity of the metropolitan beaches and initially minimise the impact of

sea level rise. Either a small dredge would pump 1,000,000 m^3 of sand onto the southern beaches over a 4-year period or a medium dredge would pump 1,000,000 m^3 of sand over a 2-year period. This would be followed by ongoing top-up of 200,000 m^3 biennially and localised trucking replenishment of 50,000 m^3 annually for localised losses in some areas.

Many assumptions were necessary to estimate expenditures for these options. For example, mobilisation and demobilisation costs of the small dredge were assumed to be $500,000 ($800,000 for the medium dredge); the Port Stanvac to Brighton dredging rate was assumed to be $8/$m^3$ ($6.50/$m^3$ for the medium dredge); the North Haven to Brighton dredging rate was assumed to be $11/$m^3$ ($9/$m^3$ for the medium dredge); and overfill ratios of 1.2 and 1.5 were applied to the sand volumes dredged from North Haven to compensate for finer sands from this source.

Top-up trucking costs were estimated at $2/$m^3$; seawall reconstruction rates were estimated from $1200 per linear metre (/m) and new construction at $2200/m; the foreshore pipeline, dredge, booster pumps and other equipment capital costs from North Haven to southern beaches were estimated at $16.2 million; and groyne construction costs for rubble mound groynes of 200 m length were estimated at $4500/m ($900,000 per groyne) or $2500/m for a lesser-standard geotextile groyne ($500,000 per groyne).

The assumed expenditure patterns for each alternative were tabulated over the 20-year period and then equated to present-day values for 1992. Figure 3.4 summarises the present-day values at 0%, 4%, 7% and 10% discount rates. The status quo strategy was found to be the least costly, and would provide for no further loss of beach amenity and maintain beach levels. Construction of seawalls was the next most cost-efficient strategy but over the long-term would lead to sand erosion and loss of beach amenity. The increased replenishment strategy would provide for improved beaches but was 40% more expensive than the status quo strategy. The progressive construction of groynes strategy represented a significant visual intrusion and was 60% more costly than the status quo strategy. In addition, while major replenishment by dredge was more cost-effective than major replenishment by pipeline, it was still nearly 100% more costly than the status quo strategy.

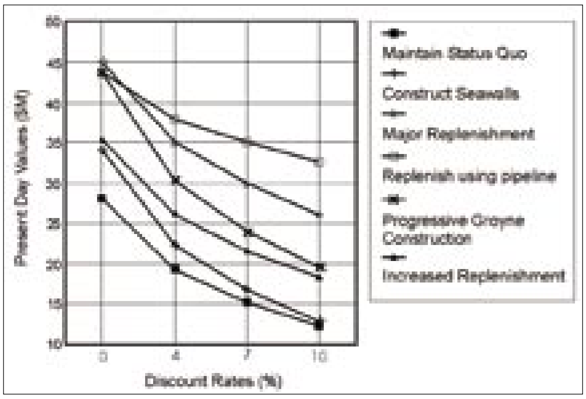


Figure 3.4 *Summary of costs for alternative strategies considered in the 1992 review (Coastal Management Branch 1992)*

Main recommendations

- The Coast Protection Board recommended that $2.5 million be allocated in the 1992–93 capital works budget for beach replenishment and thereafter for every 2-year period until the offshore sand source at Port Stanvac was depleted, and then an ongoing commitment of approximately $2.9 million biennially for the remainder of the 20-year period, based on 1991 present-day costs. The funding would enable 200,000 m^3 of sand to be dredged and pumped ashore from an offshore sand source, and some remedial beach replenishment at localised erosion zones along the metropolitan coast. This was in accordance with the Board's protection strategy for the metropolitan coast. The Board considered this the most cost-efficient minimum ongoing replenishment necessary to maintain the beaches in their condition and to provide adequate protection against storm damage.
- The proposed 2-year replenishment cycles equated to an average annual volume of approximately 160,000 m^3. This allowed 102,000 m^3 for the existing annual replenishment program and additional annual replenishments of 7000 m^3 at Brighton, 32,000 m^3 at West Beach, 8000 m^3 in the Henley to Grange area and 9000 m^3 at Semaphore Park. However, the program did not account for future possible increases in the rate of sea level rise from the greenhouse effect. If the mid-range predictions were accurate, then an additional average of 40,000 m^3/year would be required over the next 20 years.
- The replenishment strategy adopted was the most cost-efficient means of recovering offshore sand sources. However, dredging costs were approximately 2.5 times more expensive than previously used trucking methods. As the Minister for Environment and Planning announced when the dredging method was being trialled in 1989, the benefits over trucking were elimination of damage to roads and noise in residential areas, and minimisation of conflict between trucks and beach users. Coastal councils and local residents showed enthusiastic support and preference for the dredging method. A further benefit was that the source of the sand was not naturally available to the existing beach system. The current metropolitan beach sand source was finite and diminishing due to natural losses and ongoing sea level rise. The offshore source was generally better quality sand and provided a new injection of sand without jeopardising the beaches from which sand was taken in the past.
- Various protection strategies were examined in the report, including the establishment of a groyne field. The comparisons showed that the beach replenishment strategy proposed was still the most cost-efficient means of maintaining metropolitan beaches. The strategy was still significantly cost-effective even if a groyne field was considered over a 50-year period.

The adopted strategy and the costs incurred have been applied to the present time (2005), with some important variations as a result of the 1997 review.

3.3.5 Report of the Review of the Management of Adelaide Metropolitan Beaches, 1997

By 1997, the main issues along metropolitan beaches were viewed in terms of particular sections of the coast rather than the coast as a whole. Figure 3.5 illustrates the type of issues affecting the different coastal regions within the context of a net northward sand movement.

A reference group was appointed by the then Minister of Environment and Natural Resources, the Hon. David Wotton, to conduct a public inquiry into the management of Adelaide's beaches from Port Noarlunga to North Haven. The scope of the inquiry was to have particular regard to:

1. the protection of private and public property from erosion and storm-surge flooding through major or minor beach replenishment programs, rock protection works, offshore breakwaters and groynes, or strategic retreat in certain areas
2. planning implications of development approvals and consultation processes so as to include the coastal zone as it relates to planning considerations, urban design and land-use zoning
3. the cost and means of payment by the community for management of the coast examining existing and potential funding sources, setting of priorities in funding allocation, and a 'user pays' principle for specific uses and for benefits received by beachfront property owners including seawall construction.

A public consultation process integral to the 1997 review began in 1995: the initial publicity and consultation phase commenced on 2 September and the closing date for submissions was 27 October. Further consultation followed in 1996 with the circulation of an issues paper, feedback from the earlier submissions, and two community workshops held at Noarlunga and Semaphore in April.

The reference group also commissioned three consultancy projects – the *Adelaide Beach Replenishment Dredging Options Study* (Patterson, Britton & Partners 1996), *Potential Impact of Beach Sand Replenishment Dredging on the Adelaide Northern Beaches* (Cheshire & Miller 1996), and *Northern Beaches Environmental Impact and Management Study* (Hassell Pty Ltd 1996) – to address sand removal and environmental impacts from Semaphore to Outer Harbor, funding and administrative arrangements for coastal protection, and opportunities for community participation and public education.

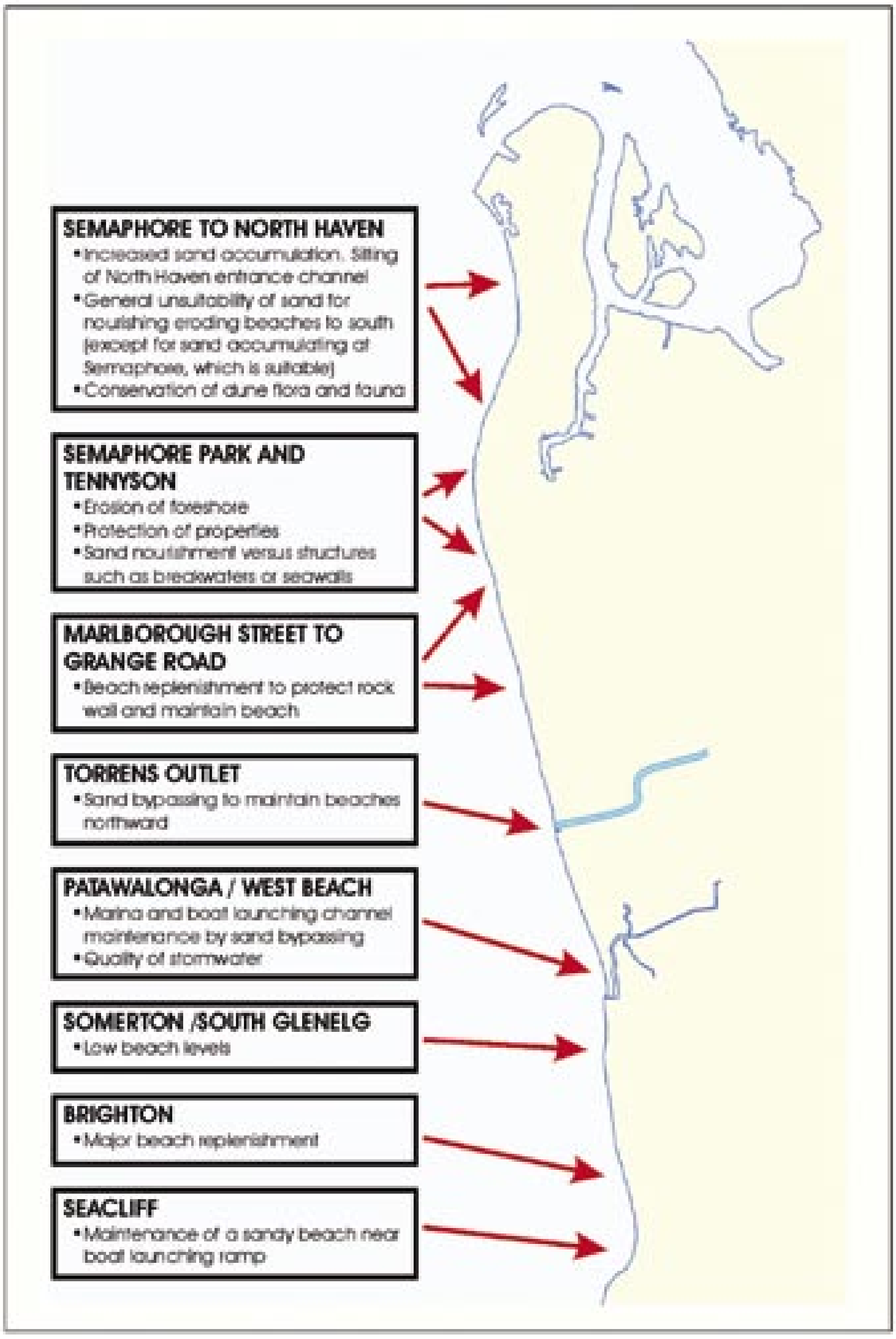


Figure 3.5 *Management issues along the Adelaide metropolitan beaches as considered by the 1997 review*

Actions since 1997 taken to implement the report recommendations

The following section records recommendations of the 1997 review, and the outcome of the actions taken.

Rationale for beach improvement: recognition of recreational value

Recommendation:

- Recreational benefits be given due regard in State Government budgeting and in providing grants to local councils.

2005 status:

1. The Coast Protection Board is funding projects such as the beach replenishment at Seacliff, which is partly for recreational benefit.

Seagrass loss

Recommendation:

- Further study into seagrass loss be urgently undertaken.

2005 status:

1. The Adelaide Coastal Waters Study has prepared a report on seagrass change from 1949 to 1996.
2. The Department has continued to monitor seabed changes.
3. There has been continued laboratory and numerical investigation on understanding seagrass loss and links with coastal processes. The information was used in the recent numerical modelling study (Coastal Engineering Solutions 2004) to determine what effect this might have on beach sand erosion for the Adelaide coast as a whole.
4. A significant workshop and report on seagrass restoration was prepared based on the best information available nationally and worldwide.
5. A laboratory and field study on seagrass rehabilitation techniques in conjunction with the SA Research and Development Institute is in its second year, and is producing encouraging results.

Sand sources for beach replenishment

Recommendations:

- More offshore sand be found for beach replenishment and proved up as a matter of urgency.
- Methods for using the Outer Harbor sand source be investigated.
- The deposit of coarser sand close to the southern Outer Harbor breakwater be resurveyed to establish how much of the better quality sand is left.
- Further investigation be conducted into the coarser sands thought to be underlying much of the Lefevre Peninsula and into whether it may be practical to use this sand for beach replenishment.
- Use of fine sand continue to be investigated in light of any new knowledge or experience elsewhere.
- The services of an appropriate marine geologist to lead an offshore sand search be obtained by the Department of Environment and Natural Resources.

2005 status:

1. The Board has carried out a study of the seabed south of Port Stanvac to Moana, which did not reveal a suitable sand supply. Exploration will not be pursued further in this area at this time.
2. Further coring work to examine the sand quality in greater depth at the Section Bank is in progress, in accord with a geological assessment of previous work.
3. A wave impact study on mangroves, a benthic survey, a mangrove survey, a dredge plume study (in conjunction with the EPA) and a seabed depth study have been completed.
4. A geological assessment of onshore sand supplies within 150 km of Adelaide capable of providing 100,000 m^3 annually for more than five years has been completed.
5. A geologist has been employed in the Branch to undertake and supervise sand investigations both on and offshore, and a sand search program is in progress.

Beach management between Kingston Park and Glenelg

Recommendations:

- The coast between Brighton and Somerton Park continue to be replenished on a biennial basis with sand dredged from Port Stanvac, until this source is exhausted.
- Sand continue to be trucked as required southward from these replenished beaches to maintain sand levels at Kingston Park and at the Brighton and Seacliff Yacht Club.
- The southern replenishment not be extended north of the Minda dunes at this stage (to be reviewed in two to three years time).
- Short inexpensive groynes be considered after a groyne trial at Semaphore Park.

2005 status:

1. The sand source for Brighton to Somerton Park was considered exhausted but, since the closure of Port Stanvac Refinery, further exploratory work is being planned nearer the jetty.
2. Sand is trucked as required through the Board's annual works program.
3. Southern replenishment has been studied as part of the current review work, and recommendations made.
4. A protection strategy for Semaphore Park using offshore breakwaters has been developed, and a trial breakwater has been constructed at Semaphore South.

Beach management at Glenelg North and West Beach

Recommendation:

- Cost advantages be considered in combining contracts for dredging for sand management at Glenelg with entrance dredging at North Haven.

2005 status:

1. The Department for Environment and Heritage is taking on sand management associated with the harbours, following transfer of this role from Transport SA during 2005. The strategy for 2005–2025 recommends integrating harbour management at Glenelg and West Beach with metropolitan beach management but North Haven has been excluded as being discrete harbour management.

Beach management from West Beach to Tennyson

Recommendations:

- Erosion at Tennyson continue to be held by restoring the beach and dune buffer as required and sand for this be trucked the short distances along the beach from north of the Grange jetty and from the beach in the vicinity of Estcourt House.
- The Henley–Grange sandbar be investigated as a possible source of sand for redistribution to nearby beaches.

2005 status:

1. Restoration at Tennyson has been carried out as required using sand from the beach adjacent to Estcourt House.
2. The Henley–Grange sandbar has been studied but excluded from further consideration as it consists of fine sand, is part of the active beach zone, and provides protection to the Henley–Grange area.

Beach management from north of Tennyson to Outer Harbor

Recommendations:

- Erosion at Semaphore Park be managed by maintaining a sand buffer with sand obtained from Semaphore beach.
- Before using any sand from Semaphore beach for replenishment, DENR ensure that all interested parties are consulted and that procedures for future management and consultation as recommended in this report are explained.
- Geofabric groyne be trialled at Point Malcolm as a precursor to a possible groyne field as a last resort option if required in the future.
- Investigations be undertaken into: sediment processes between West Beach and Outer Harbor; seagrass and sediment dynamics; and links between these especially for the northern part of the metropolitan coast.
- The Coast Protection Board work with the EPA to consider how present or proposed studies by the EPA could be extended to provide information on coastal processes.
- Attention be drawn to an urgent need to review pollution controls that the EPA is applying to dredging for sand management.

2005 status:

1. Semaphore Park erosion is being managed as required.
2. Extensive public consultation was carried out to explain the Semaphore Park protection strategy, which is now being implemented.
3. As addressed above, a breakwater protection strategy for Semaphore Park is being implemented.
4. Adelaide Coastal Waters Study includes some of these studies and this review has had a consultant study completed on sediment transport.
5. Pollution controls that apply to dredging for sand management are yet to be reviewed.

Christies Beach

Recommendation:

- A combined strategy of groynes and beach replenishment and the availability of replenishment sand be fully explored by the Noarlunga Council and State Government before proceeding further.

2005 status:

1. A trial groyne has been completed at the boat ramp.

Hallett Cove

Recommendation:

- Dredged sediment pumped northwards into the nearshore zone be a requirement for all future dredging at Port Stanvac and the O'Sullivan Beach boat ramp.

2005 status:

1. The Board places this as a condition on all such dredging applications.

Biological impacts of dredging in the northern beaches area

Recommendation:

- Biological communities in the region and the susceptibility of seagrasses to reduced water quality be further investigated (if required) before any dredging operations in the northern beaches are authorised.

2005 status:

1. Biological communities will be investigated when required, if dredging is recommended in the future depending on the current sand source investigations.

Enhancing community participation

Recommendation:

- Community consultation and public education be paid more attention by the various agencies active in management of the coast.

2005 status:

1. This has been adhered to. A communications officer has been appointed to assist with community consultation and public education. An extensive community consultation program was carried out during development of the Semaphore Park Coast Protection Strategy and implementation of its first stage.

Northern Beaches Study – Biological conservation

Recommendation:

- The Taperoo foreshore area between the North Haven development and Largs Bay be afforded local 'protected area' status as a Crown Land reserve dedicated for conservation and managed by the council.

2005 status:

1. The Port Adelaide Coastal Management Plan, produced in 2000, examines community concerns and coastal management strategies for the region's coastal dune system. The Urban Forest Biodiversity Program has produced a draft vegetation management plan for the Taperoo dune reserve and has been working closely with the City of Port Adelaide Enfield to implement rehabilitation works within the reserve since October 2003.

Northern Beaches Study – Dune management

Recommendation:

- The value of the dunes as a feature of natural or cultural significance be balanced against the fact of their recent formation along an accreting coastline and the need to export limited amounts of sand from the intertidal zone as part of the regional beach management strategy endorsed by the review.

2005 status:

1. The Board has provided funding for dune planting and noxious plant removal. The Urban Forest Biodiversity Program has produced vegetation management plans for the Semaphore Dune Reserve and the Semaphore South Dune Reserve and has been working closely with the City of Port Adelaide Enfield to implement these plans.
2. A reduction of the dune width in the Semaphore South Dune Reserve will occur as a result of the Semaphore Park Coast Protection Strategy.

Northern Beaches Study – Community involvement

Recommendation:

- The City of Port Adelaide Enfield and its local community be actively encouraged and supported in developing a local coastal management plan, as a statutory document under the Development Act.

2005 status:

1. The City of Port Adelaide Enfield has prepared a regional coastal management plan.

Northern Beaches Study – Management of beached seagrass

Recommendation:

- Beached seagrass only be removed from areas of excessive build-up next to breakwaters, adjacent to access paths to improve access to the shore, and areas where sand is removed for sand management purposes.

2005 status:

1. Current operations accord with this recommendation.

Management and Funding – Recommendations on management

Recommendation:

- A management committee, reporting to the Coast Protection Board, be established and consist of the chief executive of each of the three metropolitan coastal councils, a nominee of each of these councils to represent the community, and the Chairman of the Coast Protection Board.

2005 status:

1. The Chairman of the Metropolitan Seaside Councils Committee has been appointed to the Board under the 'advisory committee' provisions of the Coast Protection Act, to provide for better communication between the councils and the Board.

4. The Existing Management Strategy

The existing management strategy

Key actions in the current strategy for coast protection at Adelaide:

1. ***Beach replenishment*** **manually moves a high level of sand necessary to maintain a moderately even spread of sand along the coast and includes:**

   – recycling – removal of sand generally from more northerly sand accumulation areas to more southerly erosion areas

   – external replenishment – addition of sand onto the coast from dredging offshore or land-based resources

   – sand excavated from development sites on the coast returned to the beach.

2. ***Sand trapping*** **entraps mobile sand at constructed groynes and breakwaters. A trial breakwater constructed recently at Semaphore South will slow and trap some littoral drift sand which can then be carted back to Semaphore Park to counter erosion.**

3. ***Sand bypassing*** **is a manual operation of moving sand around the built obstacles along the sandy coast, i.e. the Holdfast Shores marina, the Adelaide Shores boating facility, the Torrens Outlet and the North Haven marina.**

4. ***Seawall protection*** **is construction of seawalls as a 'last line of defence' against storm erosion. The integrity of the seawalls relies on their establishment over a hard layer or on sand maintained at their base to prevent damage from waves undermining the structure.**

5. ***Dune management*** **encompasses the use of drift fences, public-access pathways and revegetation to reduce the amount of sand that blows away from the foreshore.**

6. ***Monitoring*** **includes beach profile surveys, surface difference modelling and harbour bypass monitoring.**

The existing management strategy is summarised in Figure 4.1.

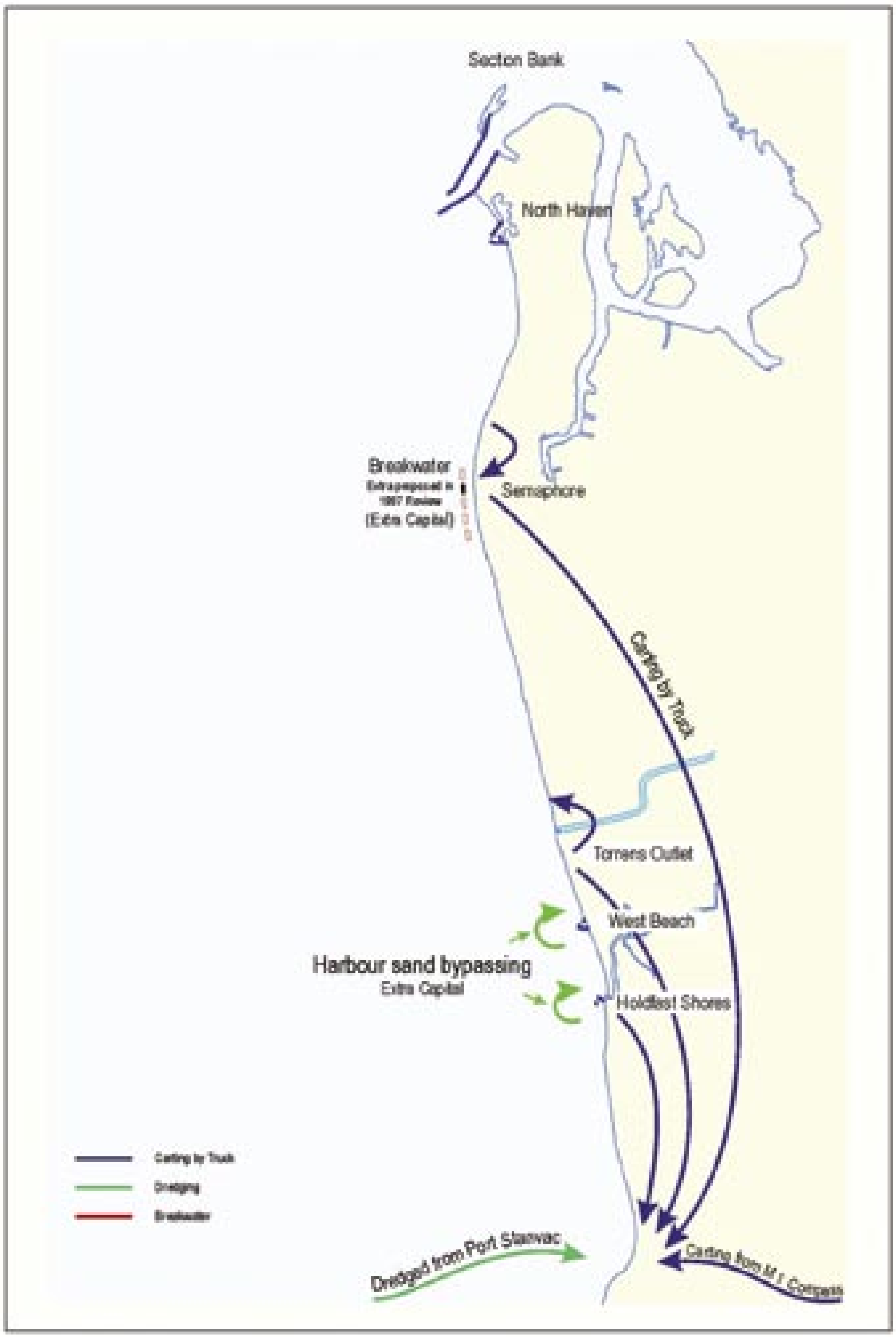
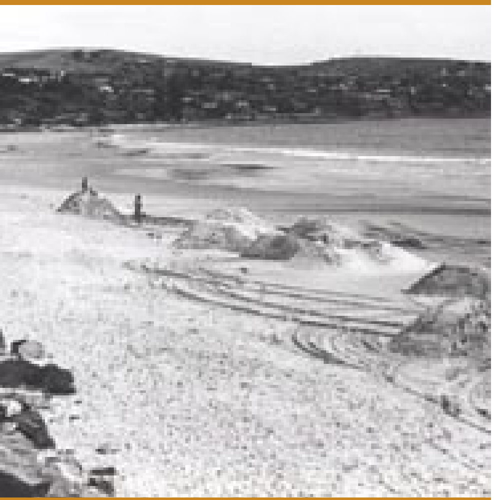


Figure 4.1 *Summary of the existing beach management strategy*



Beach replenishment, Brighton, 1982

Beach replenishment, Glenelg North, 1989

4.1 Beach replenishment

The Coast Protection Board has taken on full responsibility for funding beach replenishment at Adelaide. This was necessary because seafront councils benefit to varying degrees, because the costs and benefits cannot be apportioned, and because of the large scale of projects and the coordination required.

Under the provisions of the Coast Protection Act, section 21A:

> The Board is authorised (and shall be deemed always to have been authorised) to remove sand and other material from one part of the coast (not being private land) to another part of the coast for the purpose of protecting, restoring and developing the coast or any part of the coast.

This authority was needed to ensure that the Coast Protection Board could redistribute sand from one council area to another for the overall benefit of managing the Adelaide beach system. Furthermore, in accordance with Regulations under the Development Act, schedule 14, section (e), the Coast Protection Board is exempt from obtaining development approval for beach replenishment, defined as:

> The excavation, removal or placement of sand and other beach sediment by or as authorised by the Coast Protection Board on land which is owned by, or under the care and control of, a council or Crown agency or instrumentality, where the land is between mean low water mark on the sea shore at spring tide, and the landward limit of any sandy beach or sand dune.

This facilitates the operational activities of the Coast Protection Board on a day to day basis.

Beach replenishment is the manual addition of sand to a beach to match or exceed alongshore drift rates and erosion. On the Adelaide coast, beach replenishment has been in the form of either sand recycling or replenishment from an external sand source.

Sand recycling 'borrows' sand from an area of accumulation and places it at an area of erosion to temporarily increase the amount of sand at the eroded area. Replenishment from an external source brings in sand from elsewhere to increase the total amount of sand on the Adelaide coast. This is achieved by carting sand from onshore and dredging sand from offshore resources.

Sand recycling is supplemented with sand from external sources to make up for losses from the Adelaide beach system occurring primarily because of relative sea level rise.

Over a 30-year period since 1973, the Coast Protection Board recycled over 2,500,000 m^3 of sand either by sand carting or dredging within the Adelaide coast littoral cell. It also brought in nearly 1,500,000 m^3 of sand from external sources, mostly from offshore of Port Stanvac with lesser contributions from Torrens Island, Port Stanvac beach and Mount Compass.

Beach replenishment necessarily has major effects on the distribution of sand along the coast. It can greatly affect the type of sand on the coast, its composition, grain size, the rate of littoral drift and beach slope. Coarse sand will slow littoral drift but produce a slightly steeper beach, while a high proportion of finer particles can cause water turbidity and affect marine life.

The frequency of beach replenishment has significant effects on the variation in sand distribution over time. With frequent small amounts of beach replenishment, stable beach widths are more likely to remain over time; with infrequent larger beach replenishments, a few years of wide beaches will be followed by a period of narrowing beaches. These variations affect how the beach is perceived and used.

Why is sand taken from some beaches and placed at others?

The Adelaide metropolitan coastline has historically had hotspots of beach erosion. Most notably, Brighton beach to the Broadway, Glenelg North, Henley Beach and Semaphore Park have suffered major erosion after severe storms, and consequently have needed the most replenishment of all metropolitan beaches.

Prevailing south-westerly winds and the influence of swell in southern Gulf St Vincent push sand northwards from Marino to Outer Harbor. Over time, this has denuded many of the southern metropolitan beaches of naturally available sand. Early development over existing dunes in some coastal areas also locked up sand from the active beach zone. With less mobile sand to act as a buffer to storms, beach levels have dropped, which further exacerbates the erosion process.

Some beaches are also less protected from wind and swell waves. The overall angle of the Adelaide beaches is such that there is an overall drift from south to north. The average angle difference of the coast from equilibrium (at which there is no net drift) is approximately 10° clockwise between Brighton and Tennyson.

Where sand has been deposited and accumulated sufficiently, limited amounts can be removed from the beach without greatly upsetting beach transport processes. Sand is then carted back to those beaches that have been eroded the most, and the process of littoral drift can continue.

Beach replenishment, Somerton Park, 1989

Beach replenishment, Seacliff, 2004

Table 4.1 ranks Adelaide's beaches in terms of the amount of replenishment each has received and the related expenditure. The costs are given as actual costs at the time the activity took place and adjusted to present-day values using consumer price indexing (CPI) to 2004.

Table 4.1 *Coast Protection Board beach replenishment, 1973–2004*

Rank	Replenished beach	Volume (m^3)	Main sources (recycling and external replenishment)	Cost ($)	Cost x CPI 2004 ($)
1	Brighton	1,519,000	Offshore Port Stanvac and Glenelg	12,964,000	17,646,000
2	Glenelg North	920,000	Torrens Island, offshore North Haven, Glenelg and Semaphore	4,342,000	8,322,000
3	Seacliff*	311,000	Glenelg and onshore Port Stanvac	1,282,000	2,679,000
4	Semaphore Park	292,000	Semaphore	871,000	1,025,000
5	Somerton	184,000	Offshore North Haven and Torrens Outlet	1,171,000	2,101,000
6	Henley Beach South	179,000	Torrens Outlet	432,000	552,000
7	West Beach†	164,000	Torrens Outlet	214,000	707,000
8	Semaphore South	120,000	Semaphore	330,000	330,000
9	Tennyson	112,000	West Lakes Shore (Estcourt House)	224,000	275,000
10	North Haven onshore‡	98,000	North Haven offshore	364,000	588,000
11	North Brighton	90,000	Glenelg	331,000	994,000
12	Henley Beach	72,000	Torrens Outlet	115,000	324,000
13	Grange	34,000	Point Malcolm and Semaphore	91,000	222,000
14	The Broadway	33,000	Glenelg construction site	8,000	17,000
	Total	**4,128,000**		**22,739,000**	**35,782,000**

* includes Kingston Park; † includes West Beach, West Beach Trust and West Beach North; ‡ as the first stage of recycling sand to beaches further south (see section 4.1.1)

Figure 4.2a shows sand placement and removal volumes along the Adelaide coast from 1973 to 2004. Figure 4.2b, showing costs along the metropolitan coast, directly relates to the quantity of sand placed at different locations.

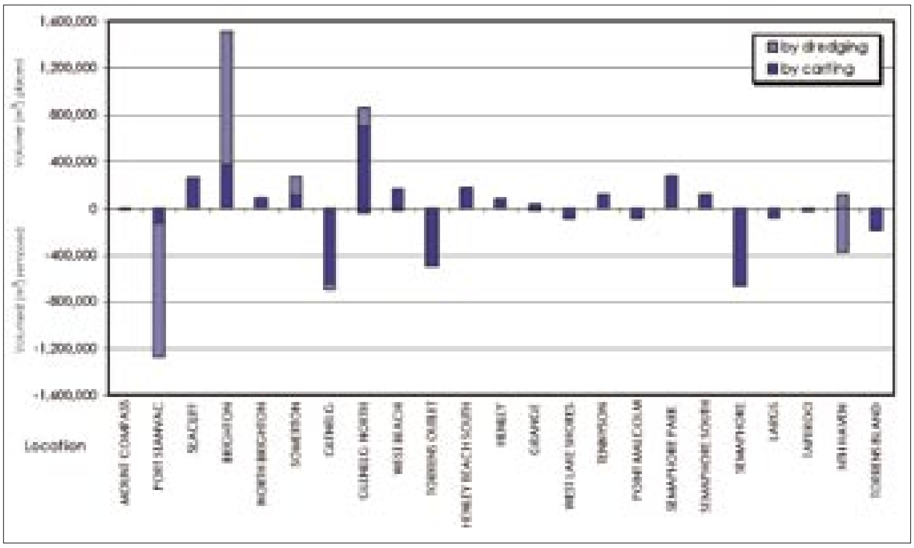


Figure 4.2a *Beach replenishment from 1973 to 2004 – comparison of volumes placed and removed along the metropolitan coast*

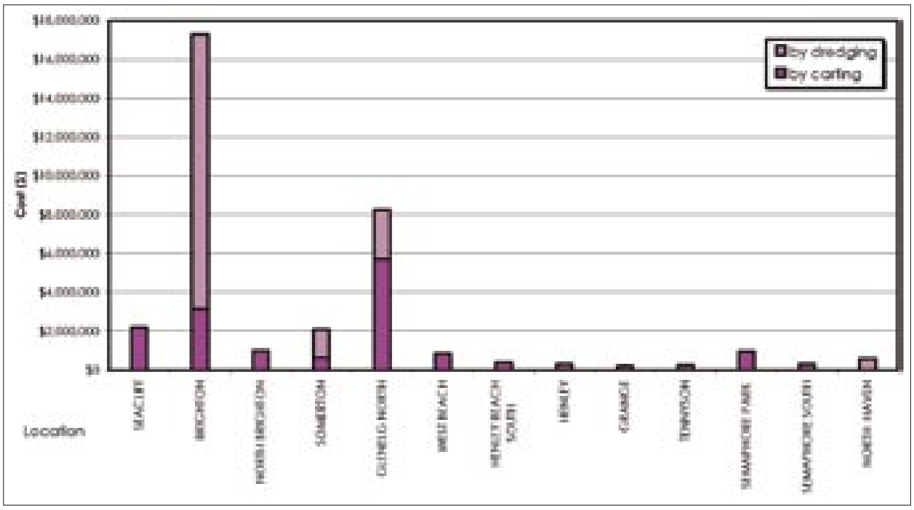
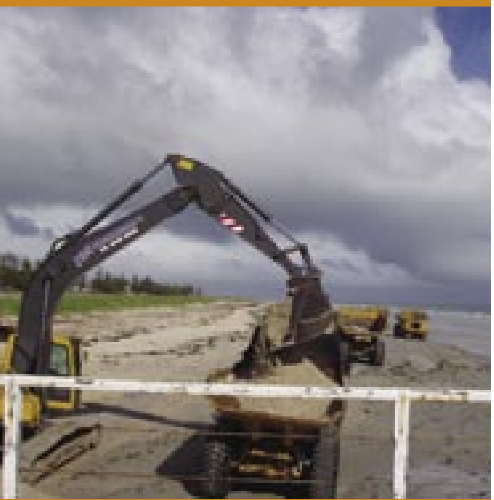


Figure 4.2b *Total costs of sand placements along the metropolitan coast*

Sand carting from Semaphore to Semaphore Park, 2004



Sand carting from Semaphore to Semaphore Park, 2004

Sand carting from Semaphore to Semaphore Park, 2004

4.1.1 Sand recycling

Much of the sand for Adelaide's beach replenishment has been carted from metropolitan beaches where it has accumulated over time. Substantial quantities have come from Semaphore, Point Malcolm, south of the Torrens Outlet and Glenelg, and sand from other beaches has been used when appropriate.

The total amount of beach sand recycled for replenishment of Adelaide's beaches since 1973 is over 2,000,000 m^3 (Table 4.2). This is the lowest cost method of managing Adelaide's beaches.

Table 4.2 *Beach recycling sand sources (1973–2004) including the compacted* sand volume removed from metropolitan Adelaide beaches*

Metropolitan beach sand carting			
Sand source	**Volume (m^3)**	**Program dates†**	**Main destination**
North Haven	105,000	1981	Glenelg North
Taperoo	29,000	1973	Glenelg North, Somerton, Brighton North and Seacliff
Largs Bay	71,000	1980–91	Glenelg North, Henley Beach, West Beach and Seacliff
Semaphore	684,000	1977–2004	Semaphore Park, Brighton and Glenelg North
Point Malcolm	95,000	1982–93	Grange, Glenelg North and Brighton North
West Lakes Shore	85,000	1995–2002	Tennyson
Grange	21,000	1975, 1980, 1997	Tennyson and Henley Beach
Torrens Outlet	493,000	1975–2004	Henley Beach South, Glenelg North, West Beach Trust, Somerton, Brighton North and Seacliff
West Beach	8,000	1986	Henley Beach South
Glenelg	572,000	1973–2004	Brighton North, Brighton, Seacliff, Glenelg North and the Broadway
Total	**2,163,000**		

* Compacted sand volume is in situ on the beach; the volume loaded into trucks increases by 30%.
† Program dates indicate when a source was used, not the duration of the work.

Metropolitan sand dredging projects

Sand recycling has been implemented along Adelaide's beaches in several dredging projects. Between 1989 and 1990, the Coast Protection Board approved the removal of nearly 200,000 m^3 of sand offshore from North Haven for replenishment at Somerton Park and Glenelg North, as well as for an additional supply at North Haven beach (Table 4.3). Dredging also cleared the sandbar at the Patawalonga, and took sand during construction of recent Glenelg and West Beach breakwaters from those locations to be mostly pumped ashore at Glenelg North and West Beach, respectively.

Table 4.3 Sand dredging projects within the metropolitan Adelaide littoral cell

Metropolitan coast sand dredging			
Sand source	**Volume (m^3)**	**Program dates***	**Main destination**
North Haven	198,000	1989–90	Onshore North Haven, Somerton Park and Glenelg North
West Beach	22,000	1998	West Beach North
Patawalonga	110,000	1980, 1992–96	Glenelg North
Glenelg	120,000	1991, 1996–99	Glenelg North
Total	**450,000**		

* Program dates indicate when a source was used, not the duration of the work.

4.1.2 External replenishment

Tables 4.4 and 4.5 summarise the amount of sand taken from outside of Adelaide's littoral cell and placed at different locations along Adelaide's beaches. Between 1974 and 1982, the beach south of the Port Stanvac breakwater was used on an annual basis to replenish sand mostly to Seacliff beach. A significant amount of sand (187,500 m^3) was also taken from the dunes at Torrens Island from 1988 to 1990 to replenish Glenelg North beach.

Table 4.4 Onshore and land-based sand sources outside the metropolitan Adelaide littoral cell

Non-metropolitan beach and land-based sand sources			
Sand source	**Volume (m^3)**	**Program dates***	**Main destination**
Port Stanvac beach	158,500	1974–85	Seacliff, Brighton, Brighton North and Somerton Park
Port Noarlunga beach	1,000	1980	Seacliff
Torrens Island sand dunes	187,500	1988–90	Glenelg North
Mount Compass sand mining	25,000	1988, 2004	Seacliff and Brighton
Total	**372,000**		

* Program dates indicate when a source was used, not the duration of the work.

In the 1990s, the emphasis on beach replenishment changed to using offshore sand deposits; 1,140,000 m^3 of compacted sand was dredged offshore from Port Stanvac and used for beach replenishment at Brighton from 1991 to 1997 (Table 4.5). This was primarily in response to community concerns about sand carting and the number of trucks on the beaches and roads, as well as a need to increase the volume of sand in the beach system.

Table 4.5 Major offshore sand source outside of the metropolitan Adelaide littoral cell

Offshore dredging			
Sand source	**Volume (m^3)**	**Program dates***	**Main destination**
Port Stanvac	1,144,000	1991, 1994–97	Brighton
Total	**1,144,000**		

* Program dates indicate when a source was used, not the duration of the work.

Brighton beach replenishment via dredging offshore from Port Stanvac

Recently, sand has been sourced from Mount Compass and delivered to the Edwards Street, Brighton, dumping platform for redistribution onto Seacliff and Brighton beaches. A small quantity of sand, 25,000 m^3, has been provided from the sand pits at Mount Compass after the finer-grained sand (less than 0.5 mm) had been removed for the glass-making industry.

The overall amount of sand brought in to replenish Adelaide's metropolitan beaches from external sources is nearly 1,500,000 m^3. External sand is necessary for continuing management of Adelaide's beaches, particularly to adjust for losses due to sea level rise. Potential sand sources include the Section Bank near Outer Harbor, North Haven, Port Stanvac and several land-based sand deposits in and around the greater Adelaide and regional area including sand from Nalpa at Lake Alexandrina and Glenshera at Mount Compass. Ancient sand deposits at Mount Compass are the most favourable, being composed of rounded to sub-rounded quartz sand very similar to beach sand at Seacliff and Brighton (see section 5.1).

4.1.3 Costs of historical beach replenishment

The cost of beach replenishment by trucking includes loading, hauling, spreading and ancillary works such as track construction. Indicative values based on current knowledge and typical past projects are shown in Table 4.6.

Table 4.6 *Beach replenishment costs for sand recycling and replenishment from an external source*

Beach replenishment	Volume (m^3)	Duration	Actual cost ($)	Cost x 2004 CPI ($)	Average cost per m^3 (2004 CPI) ($/m^3)
Sand recycling					
Overall metropolitan beaches sand carting	2,161,000	1973–2004	7,169,000	14,217,000	6.60
Glenelg – Brighton/ Seacliff/Kingston Park	44,000	2004	361,000	361,000	8.20
Estimated future cost for sand bypassing using various methods, Glenelg – Glenelg North	90,000 /year	2005			6–10
External replenishment					
Beach sand carting – Port Stanvac to southern beaches	127,500	1974–85	435,000	1,231,000	9.65
Land-based sand carting – Torrens Island to Glenelg North	187,500	1989	1,393,000	2,235,000	11.90
Land-based sand carting – Mount Compass to Seacliff	11,000	1988	77,000	128,000	11.60
Land-based sand carting – Mount Compass to Brighton	5,100	2004	187,500	187,500	36.75
Offshore dredging (*Pelican* dredge) – Port Stanvac to Brighton*	541,500	1991–96	6,753,000	9,015,000	16.65
Offshore dredging (large dredge) – Port Stanvac to Brighton†	603,000	1997–98	4,400,000	5,251,000	8.70

* dredging carried out in three separate operations
† dredging carried out in one larger-scale operation

The total cost for beach replenishment from 1973 to 2004 adjusted to present-day values is nearly $36 million, or on average around $1.2 million/year, to distribute over 4,000,000 m³ of sand along the metropolitan coast either by sand carting or dredging.

Based broadly on these figures, the cost of dredging sand is very competitive with trucking particularly when the dredge can easily access sand without additional stockpiling to feed a supply.

Figures 4.3a and 4.3b show annual breakdowns of volumes and costs for Adelaide's beach replenishment over time.

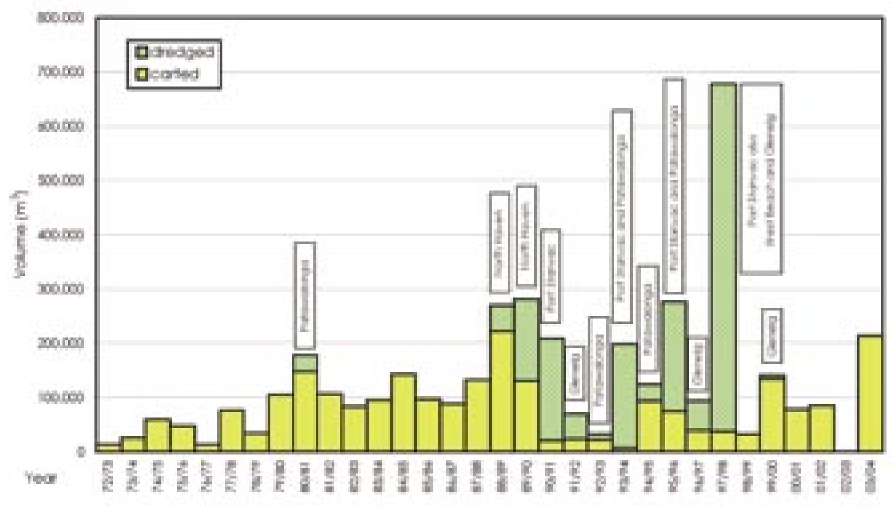


***Figure 4.3a** Adelaide beach replenishment program – volumes over time*

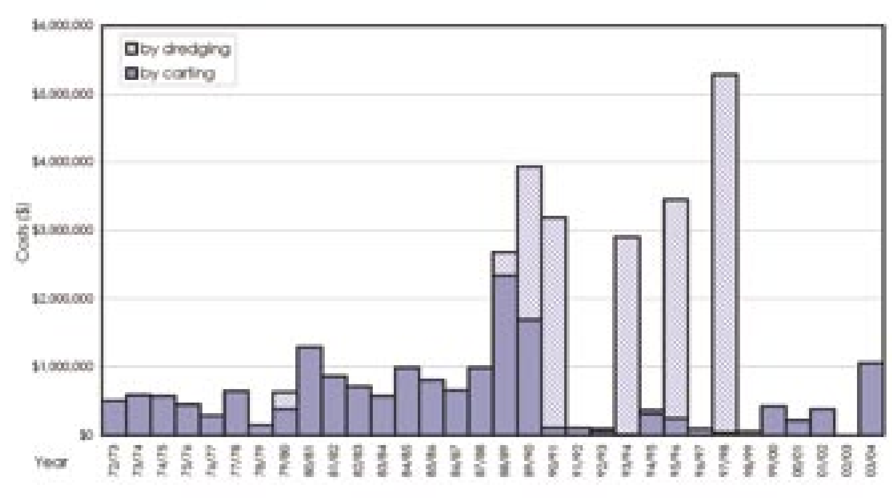


***Figure 4.3b** Adelaide beach replenishment program – costs over time (2004 CPI indexed)*

4.2 Sand trapping

Sand trapping accumulates sand, either for some intended and predefined purpose or incidentally from structural change on the coastline. Sand can be trapped using coastal structures such as groynes or offshore breakwaters, although features such as a flow of stormwater discharge across the beach, known as a hydraulic groyne, will also trap sand. Dune drift fencing is also a form of sand trapping, except that drift fences cannot hold sand when exposed to waves during storms (see section 2.1.4 on sand impoundment).

Sand is trapped at various locations along the Adelaide coast including Semaphore South, Henley Beach (Torrens Outlet), West Beach, Glenelg and North Haven. Sand trapping and bypassing at the latter four locations is discussed in section 4.3.

4.2.1 Semaphore South trial offshore breakwater

Semaphore South is shoreward of the natural feature of Wonga Shoal, a calcrete reef 3 km offshore, which reduces wave energy reaching the coast in much the same way as a constructed breakwater. Near the Semaphore jetty in the 1970s, high tides washed up to the seawall. The rate of sand accumulation in the area has been so great that the beachface is now 100 m seaward of the seawall, despite at least 700,000 m^3 of sand having been removed to replenish southern beaches.

The area just south of where the sand naturally accumulates was selected as the location for a trial offshore breakwater, the construction of which commenced in 2004 and finished in 2005. The aim of the breakwater is to trap sand to be used for beach replenishment. The trial breakwater is Stage 1 of a proposed 3-stage strategy to protect the eroding foreshore at Semaphore Park, approximately 1 km to the south of the structure.

The coast at Semaphore Park was assessed as being stable or even accreting in the Culver Report (1970). However, its foreshore began visibly eroding in the early 1980s. In particular, two closely spaced storms in 1981 eroded sand at up to 30 m^3/m length of dune, resulting in the dune scarp moving inland by 10 m.

This transition from stable to eroding coast has been attributed to the loss of seagrass offshore (Coastal Engineering Solutions 2000). Between 1972 and 1975, an area of seagrass 1 km wide disappeared from the nearshore seabed at Semaphore Park. As the newly exposed sandy seabed adjusted to the wave climate, sand was washed onshore and alongshore, and beach levels were maintained throughout the 1970s. After the seabed stabilised at a new equilibrium depth, the imbalance of sediment transport along the coast (the transport rate northwards out of Semaphore Park exceeded that entering from the south) led to the visible signs of an eroding foreshore.

Semaphore Park Coast Protection Strategy, 1981–2003

The Coast Protection Board adopted beach replenishment, in line with its overarching protection strategy for the Adelaide coast, to maintain a sufficient buffer of sand between the beach and development. This buffer is 80 m^3/m along the beach above +1 m AHD and measured beginning 5 m seaward from the development line (see Figure 4.4 for measurements of the buffer volume through the 1990s).

The sand source for replenishment was mostly the accreting beach adjacent to the jetty at Semaphore, approximately 2 km to the north. By the late 1990s, the volume of sand being taken from Semaphore beach was greater than the rate of accretion and eventually the beach and dunes would have been depleted. In order to keep replenishing Semaphore Park under the existing strategy, sand would have to be imported from outside the Adelaide beach system.

In October 1999, a strategy review was initiated by the Coast Protection Board to devise a more sustainable method of managing the Semaphore Park foreshore.

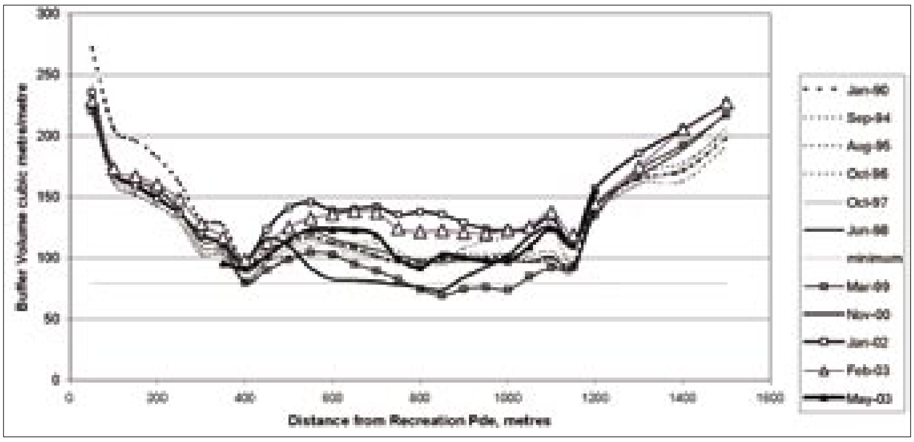


Figure 4.4 *Semaphore Park sand buffer volumes*

1999–2000 Semaphore Park Protection Strategy Review

In March 2000, the Coast Protection Board released a report describing the processes at work at Semaphore Park and concept designs for foreshore protection (Coastal Engineering Solutions 2000). It was made publicly available as part of the community consultation component of the strategy review. The Coast Protection Board recommended a protection strategy to the Minister for Environment and Heritage, who endorsed it in November 2000. The three stages of the strategy were:

1. the construction and monitoring of a trial geotextile sand-trap breakwater offshore from Point Malcolm combined with ongoing beach replenishment from the sand trap to Semaphore Park (Figure 4.5a)
2. the option to armour this trial structure with rock to create a permanent sand trap should the trial be successful
3. allowance for the later adoption of a full field of breakwaters if required (Figure 4.5b).

Figure 4.5 *Aerial photographs illustrating the stages of the Semaphore Park Coast Protection Strategy (a) Stages 1 and 2 (b) Stage 3*

The Semaphore South breakwater during construction, 2004

Stage 1 – Trial breakwater design, implementation and costs

After detailed design and environmental assessment of Stage 1 was conducted in 2001 (Carley et al. 2001; ID&A 2001), the Minister for Environment and Conservation authorised the implementation of Stage 1 in December 2002.

The breakwater was designed to trap only a portion of the sand drifting northward along the coast. It is located 200 m seaward of the mean water level mark on the beach, just inshore of the most seaward bar off the beach. Since sandbars are conduits for sand transport, sand will still bypass the structure. The crest is approximately 1 m above mean sea level, which means it is overtopped on spring tides and during storms. The likelihood of adverse effects downdrift (to the north) is minimised by allowing some sand to bypass the breakwater.

The breakwater is constructed from large tubes, or geocontainers, of specialised material called geofabric, and is 200 m long. It has a design life in the order of 10 years. The nature of its construction allows modifications to be made to optimise its performance should this be found to be lacking. If, for example, the breakwater were to trap too much sand, the top layer of geocontainers could be removed to lower its crest height, thereby allowing more overtopping by the sea to reduce its sand trapping ability.

The size of the breakwater was determined by the amount of sand required to be trapped each year to allow ongoing replenishment at Semaphore Park without depleting the salient (the accumulation of sand between the breakwater and the beach). The filled volume of the salient was predicted to be 112,000–150,000 m^3, with more sand possibly accumulating below the low-water mark. Beach replenishment at Semaphore Park using sand from the salient was predicted to be sustainable up to volumes of 40,000 m^3/year. The volume of sand removed from the salient for replenishment also influences the scale of downdrift effects. If the salient is full, sand will bypass the structure to the northern downdrift side more readily than if the salient is accumulating sand.

Other important design factors were:

- minimisation of downdrift effects
- constraining the crest height as much as possible while maintaining the structure's effectiveness
- obtaining a balance for the total number of structures that might be required by Stage 3 (influenced by how far north the initial structure was located)
- the cost of replenishment from the trial breakwater's salient (influenced by how far south it was built).

The last consideration also has a bearing on the likely scale of downdrift effects. The further north the initial breakwater, the closer to the end of the erosion area and the smaller downdrift effects would be. The decision to place the trial breakwater directly west of Bower Road was aided by testing the different scenarios using numerical modelling techniques (Carley et al. 2001).

Figure 4.6 shows that the distance to cart sand from Bower Road to replenish Semaphore Park is approximately half that from Semaphore jetty. Essentially, the cost of beach replenishment (determined by the total volume multiplied by the distance carted) is reduced by carting from the breakwater salient rather than from Semaphore jetty, even allowing for downdrift replenishment of up to 10,000 m^3/year.

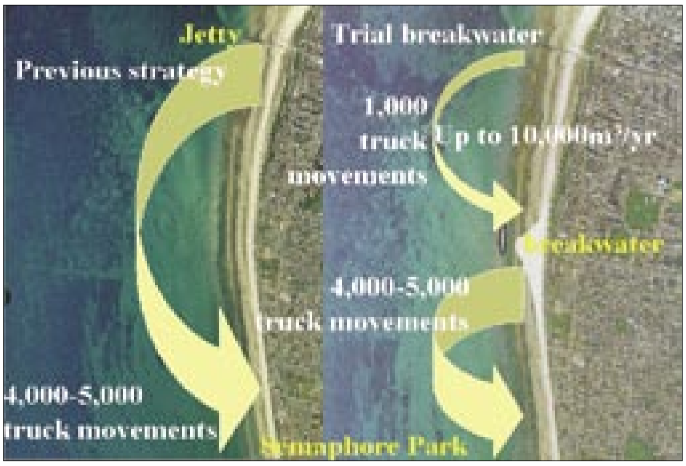


Figure 4.6 *Distances and number of truck movements for sand to be carted to Semaphore Park from (a) south of the Semaphore jetty (previous strategy) (b) the Semaphore jetty and south of the Semaphore South breakwater (Semaphore Park Coast Protection Strategy)*

Table 4.7 shows the annual cost comparisons and net present-value calculations for previous and current strategies.

Table 4.7 *Previous and current Semaphore Park Coast Protection Strategy cost comparisons*

Strategy	Annual sand carting cost	Net present cost (20-year period, 7% discount rate)
Previous strategy (sand carting), Semaphore sand source	$120,000–200,000	n.a.
Previous strategy (sand carting), alternative sand source	$1 million upwards	n.a.
Previous strategy – Semaphore sand until depleted, then import sand – alternative source	n.a.	$6.95 million
New strategy, Stage 1	$80,000–100,000	n.a.
Completed new strategy, through to Stage 3, total of 5 breakwaters – costs based on staged construction immediately following completion of Stage 2	Full field will not require replenishment of Semaphore Park, some downdrift replenishment required, approximately $15,000–20,000	$5.49 million

Results from monitoring during the 4- to 5-year trial period will inform the decision on proceeding to Stage 2 but also have implications beyond implementation of later stages of the Semaphore Park Coast Protection Strategy. Similar physical conditions along the length of Adelaide's beaches may mean that the results from the Semaphore Park trial apply to the design of breakwaters at other locations to the south of Semaphore Park.

Stage 2 – A permanent breakwater

Stage 2 would convert the trial breakwater to a permanent structure with the same critical dimensions of length and height to ensure that its effect on the coast is not altered. Thus, rows of geocontainers would be removed from the trial structure, a layer of protective filter cloth placed, and the rock then layered over the remaining 'core' to replicate the original dimensions of the breakwater.

In the event that the decision is made not to proceed, the sand can be emptied from the geocontainers and the breakwater removed.

Removing sand from south of the Torrens Outlet, November 2004 (City of Charles Sturt)

Placing sand north of the Torrens Outlet, November 2004 (City of Charles Sturt)

Stage 3 – Additional breakwaters

The third stage of the strategy would construct a field of breakwaters to directly protect the Semaphore Park coast. It is possible that, in the future, sand carting to maintain the Semaphore Park foreshore could become unsustainable because of increased sand requirements associated with sea level rise, increased costs (including financial, environmental and/or social) or other impediments.

The proposed full field of breakwaters would directly protect the Semaphore Park foreshore, in which case sand carting would not be required, other than possible ongoing downdrift replenishment north of the first structure.

4.3 Sand bypassing

When sand becomes trapped by structures built within the littoral beach system, sand bypassing manually moves the sand from one side of the structure to the other, with the intent that the sand continues to move along the coast as if unhindered.

Sand bypassing operations include sand carting and dredging. The aim of moving sand past structures as if unhindered is, in practice, practically impossible and the resulting variations in sand distribution have a corresponding effect on beach use and dune stability.

Accumulations of sand along the Adelaide coast usually have dead seagrass within them, and when sand is bypassed the decomposing seagrass is exposed and redistributed. The consequent odours can affect beach users and nearby communities. Sand bypassing by dredging also affects water quality. These effects are managed through marine discharge licences under the Environment Protection Act.

Dredged seagrass usually needs to be discharged offshore, inevitably meaning that a mixture of sand and seagrass is pumped offshore, although the sand may migrate slowly back onshore. This process can also affect offshore navigational depths.

Inadequate sand bypassing allows large sand accumulations, forcing sand further seaward into deeper water where it is less useful in the active beach since the waves cannot readily return it. Ineffective sand bypassing can thus affect total sand volume in the active beach.

4.3.1 Torrens Outlet

The Torrens Outlet at Henley Beach was built in 1936 by diverting the River Torrens flow from its natural outlets of the Port River and Patawalonga directly by channel through the barrier dunes to the sea. The flow of water from the outlet across the beach creates a 'hydraulic groyne' effect, obstructing the drift of sand past the outlet to the north. A large dune system has built up south of the outlet, resulting in much of the sand being excluded or protected from the erosion/rebuilding cycle. This is called sand impoundment. The main effect of sand impoundment is that it reduces the total amount of sand available along the metropolitan coast.

To limit further sand impoundment and maintain beach levels at Henley Beach South, the City of Charles Sturt undertakes manual bypassing averaging approximately 20,000 m^3 of sand every year. In addition, large volumes of sand have been taken from the area in the past on an 'as needs' basis to replenish North Glenelg, Somerton Park, Seacliff and West Beach. Overall, including the bypassing, 500,000 m^3 of sand has been recycled from the Torrens Outlet.

4.3.2 Holdfast Shores marina and Adelaide Shores boat haven

Transport SA has undertaken depth maintenance and sand and seagrass management in the Holdfast Shores marina, Glenelg, since 1997–98 and in the Adelaide Shores boating haven, West Beach, since 1999–2000. The main tasks are dredging sand and seagrass from the inner harbour, entrance channel and sand trap at both facilities at an average cost in the order of $1.3 million annually. At Holdfast Shores the dredging, and the cost, includes sand bypassing, but at Adelaide Shores sand is bypassed by truck at an additional cost of $500,000/year. Thus the total budget of Transport SA for sand bypassing at both harbours (including overheads) was $1.89 million in 2004–05.

The volume of sand and seagrass removed from the harbours varies each year. This is because mass flow measurement devices in common use cannot measure quantities of sand or seagrass accurately, particularly where the two are mixed. The volumes shown in Tables 4.8 and 4.9 are an estimate of the amount of sand and seagrass removed based on dredging rates and duration. Seabed levels are also periodically checked by surveys but these produce quite different results.

The dredging contract currently being negotiated by the Department for Environment and Heritage is aiming to circumvent the problems of volume estimation. Previously, rates quoted for volume of sand discharged have been 50% higher than the rates quoted for pumping time, because of the difficulties of measuring dredged sand accurately. The new contract provides for two methods of pricing, one based on pumping time, the other on volume of sand discharged. In the first year the contractor will be paid on a pumping time basis, on the condition that sand quantities pumped during this time will be calibrated and used as the basis of payment in the second year.

Table 4.8 *Holdfast Shores, Glenelg – estimated annual sand and seagrass dredging volumes, and sand movement to the north beach (±20%)*

Activity	Sand volume (m^3)	Seagrass volume (m^3)
Maintaining target depth at inner harbour and entrance channel	17,500	40,000
Maintenance of sand trap	70,000	15,000
Sub-program		
Stockpiling of sand at south beach for bypassing	30,000	
Movement of stockpiled sand to north beach	30,000	

Table 4.9 *Adelaide Shores, West Beach – estimated annual sand and seagrass dredging and carting volumes, and seagrass deposition at northern dunes (±20%)*

Activity	Sand volume (m^3)	Seagrass volume (m^3)
Maintaining entrance channel (dredging)	15,000	30,000
Maintenance of sand trap at West Beach (dredging or carting)	70,000	15,000
Sub-program		
Sand carting to West Beach dunes	45,000	
Dredging from the sand trap	30,000	
Removal of seagrass from beach		6,000
Deposition of seagrass at base of northern West Beach sand dunes		6,000

At Glenelg, approximately 70,000 m^3 of sand is bypassed annually from the sand trap at the Holdfast Shores marina southern breakwater to maintain sand flow to the north. Much of this sand and a mixture of sand and seagrass are pumped seaward of the beach, although part of the process also involves stockpiling 30,000 m^3 of relatively clean sand on the southern beach, which can then be pumped to the beach immediately north of the harbour. The current sand bypassing operation using a dredge is relatively inefficient. The dredge usually has to pump both sand and seagrass as a mixture because the breakwater that protects the dredge area also acts as a trap for seagrass. The dredge cannot on its own draw the sand accumulating on the southern beach because of the limited depth of sand over bedrock and therefore the operation also involves an excavator loading a truck from anywhere between the harbour and the Glenelg jetty and transporting it to the dredge where it pumps from the stockpile.

The littoral drift process is again interrupted by the Adelaide Shores boat haven. Sand and seagrass dredged from the entrance channel and harbour are pumped into the nearshore zone just north of the harbour. However, sand trapped on the beach by the southern breakwater, estimated to be about 90,000 m^3 annually, is carted periodically immediately north to the West Beach dunes and used for beach replenishment. About 6000 m^3 of seagrass wrack tends to accumulate on the Adelaide Shores beach each year. This is removed and trucked north to the West Beach dunes where, combined with sand, it acts as a buffer for the dunes. Storm events erode the material from the buffer zone and it is transported generally in a northward direction along the coast.

The Holdfast Shores and Adelaide Shores sand bypassing programs are being transferred from Transport SA to the Department for Environment and Heritage in 2005.

4.3.3 North Haven

The southern breakwater at North Haven, which was constructed in 1974, traps sand so that the boating channel can be maintained. The build up of sand to the south has now reached a level that allows around 20,000–30,000 m^3 of sand to move into the channel. This sand is very fine and unsuitable for beach replenishment. It is independently managed solely for channel maintenance.

4.4 Seawall protection

Seawalls act as a 'last line of defence' during storm events and at some locations (e.g. Somerton Park and Brighton North) at high tide. They have a number of effects on beaches. Principal among these is that of sand impoundment (or locking away of sand under and beyond the seawall); other effects relate to the distribution of sand in the vicinity of the seawall.

Seawalls are often thought to cause erosion. Certainly, seawalls are almost always built in response to erosion, but they do not alter the eroding forces of the sea. These forces will continue to move sand from underneath, seaward of, or at the end of, seawalls which can thus be undermined if the beach in front of or at the ends of them is washed away.

Sand redistribution effects of seawalls can be reduced by using rip-rap or rubble-mound seawalls (Figure 4.7), which are better at absorbing wave energy than solid concrete structures. Current seawall designs are required to incorporate Coast Protection Board policy on coastal erosion, flooding and sea level rise standards and protection (see section 2.8; see also Coastal Management Branch 1984 section 4.2 for details of rip-rap construction).

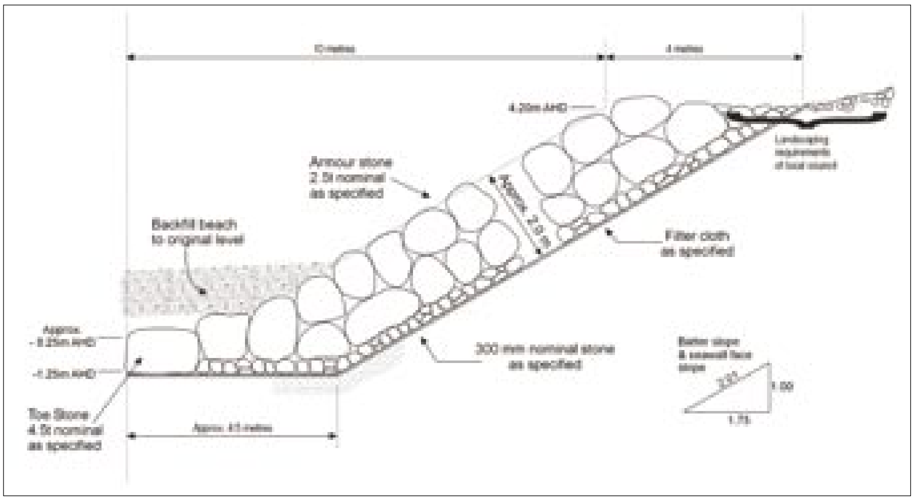
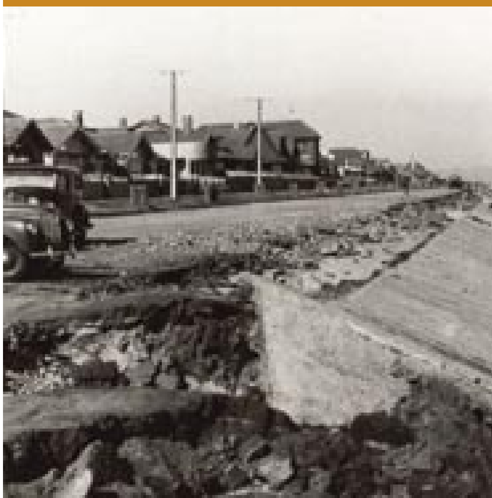
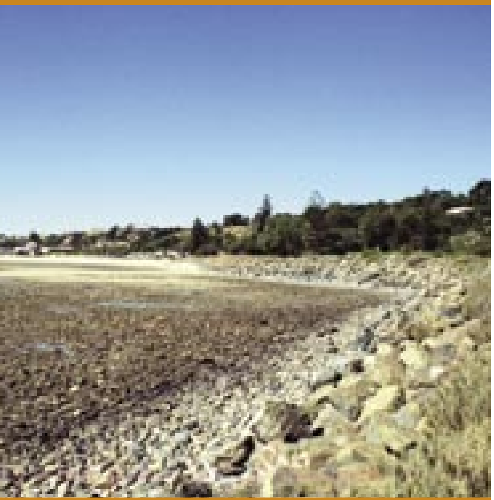


Figure 4.7 *Current seawall design*

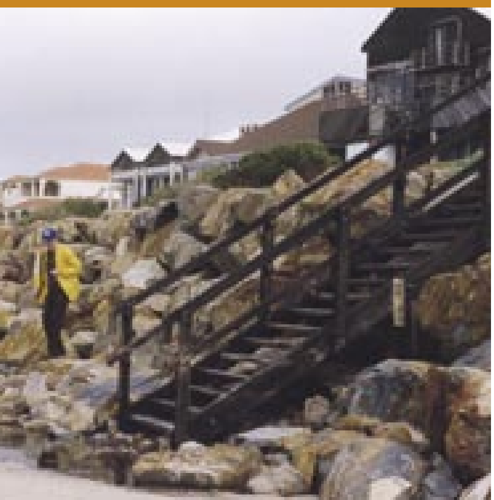
Seawall at Henley Beach during the 1953 storm



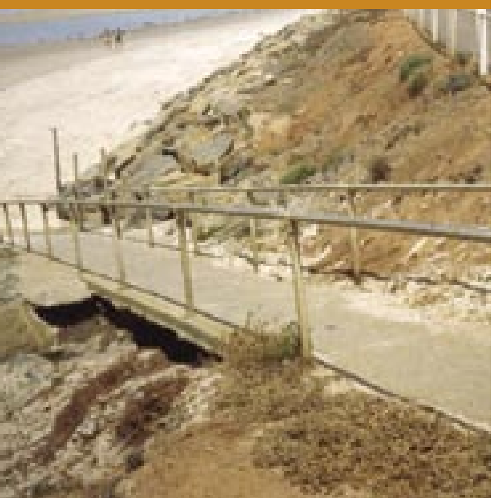
Seawall at Henley Beach after the 1953 storm



Rip-rap seawall at Seacliff, 2004



Beach access – steps in a seawall



Beach access – ramp in a seawall

4.4.1 Design height of seawalls

The design height of seawalls on the Adelaide coast is dependent on the exposure to wave forces although generally on the open coast the top level is set at 4.2 m AHD. This allows for a 0.3 m sea level rise in accordance with Coast Protection Board policy (see section 2.8). The other components are the 1-in-100 year average return interval storm surge level of 2.4 m AHD plus 0.1 m for land level subsidence to 2100, 0.3 m for wave set-up and 1.0 m for wave run-up.

The base level of the toe-stone is set at –1.25 m AHD; it is calculated on the level that is unlikely to be undermined and is derived from the beach monitoring program. Achieving this level requires care in construction, due to the ingress of seawater, and it needs strict supervision to be consistently maintained. The use of a geotextile filter cloth beneath the rip-rap reduces the loss of sand through the rock layer and thus minimises the threat of collapse. It also allows for some rotation downward of the seaward portion if the beach level drops below the base level, so that structural integrity is maintained.

Seawalls can alter the amenity and recreational use of a beach. Beauty is in the eye of the beholder – and seawalls can be either visually intrusive or desirable by bringing the sea closer to viewing areas such as reserves and cafes. Walking over seawalls can be hazardous, and steps or ramps should be provided for safe access to the beach.

4.4.2 Responsibility for and cost of seawalls

Each of the seaside councils retains responsibility for implementing coast protection works including seawall construction or repair. The present-day cost of seawall construction is in the order of $2500/m and reconstruction costs are around $1200/m.

Coast Protection Board policy

Most coast protection works are carried out by councils or privately. With the exception of renourishing the Adelaide beaches, the Coast Protection Board provides councils with grants of up to 80% of the cost of approved coast protection works and up to the same amount for storm damage repairs.

Policy 3.3 – The Coast Protection Board will provide grants to local councils towards approved coast protection works in accordance with the *Coast Protection Act 1972*.

(In doing so, the Coast Protection Board will take into consideration state-wide priorities and the availability of funds within the Coast Protection Fund. The grant shall not exceed 80% of the total cost of the works.)

The remaining funding is usually provided by the councils themselves.

4.5 Dune management

4.5.1 Sand dune protective buffer

Dunes on the metropolitan Adelaide coast are viewed by many members of the community as having inherent value, as well as providing habitat and a coastal buffer.

The value of the dunes as a feature of natural or cultural significance needs to be balanced against the fact of their recent formation and the need to redistribute limited amounts of sand from the intertidal zone as part of the regional beach management strategy. This will lead to loss of some sand dunes in response to changes in sand distribution.

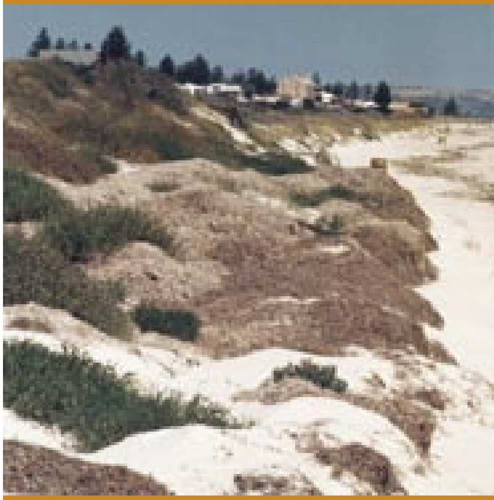
The overall volume of sand in the metropolitan Adelaide coast is finite, and the beach system is managed to ensure there are sandy beaches from Kingston Park to North Haven. The dune buffer is managed to provide for storm protection against twice the 1-in-100 year average return interval storm. This dune buffer must be seen as expendable in extreme events, and dune management such as revegetation needs to take account of the dynamic nature of this area. The conservation values developed within these dunes must be seen in the same dynamic way and cannot be considered as permanent, or requiring protection against storm events.

Any dune accretion seaward of the protective buffer is considered appropriate for redistribution by recycling to other beaches. However, this is done indirectly by removing sand from the intertidal beach zone, leaving the dune more exposed to erosion at a later date.

The sand dunes adjacent to Estcourt House, Tennyson, are the last remaining dunes in the metropolitan beach system between Kingston Park and Outer Harbor with natural topography and vegetation. The dunes at the Onkaparinga River mouth and at Moana have also remained relatively undisturbed, while the dune area at Minda, Somerton Park, provides opportunities for rehabilitation. These are the only dune areas in the greater metropolitan region that can be managed for their landscape, cultural and conservation values as stable systems suitable for longer-term preservation, because their significant landward extent provides for such longevity. In other areas, dunes may still have varying degrees of landscape, cultural and conservation values but will require management as dynamic elements contributing to an overall discontinuous coastal dune strip with a variable make-up over time. The vegetation management plan for the Semaphore South dune reserve (Petherick 2004) provides a recent example of a management approach that recognises these limitations.

Tennyson, 1981

Tennyson, 1995



Tennyson, 1996

4.5.2 Sand drift and public access control

Adelaide's seaside councils are responsible for dune management programs in their coastal areas. As for other coast protection works, Coast Protection Board grants of up to 80% can be used to cover the costs of dune management.

The three main techniques of dune management used to improve sand dune condition and stability are:

1. drift fencing – to reduce the loss of windblown sand inland
2. revegetation – to stabilise dunes and control or eradicate pest plants
3. access control – to restrict public access to formal pathways and provide car parks and public amenities.

The greatest effect of dune management on the sand resource is in trapping sand and hence minimising wind-blown sand loss from the coast. Revegetation and drift fencing can be very effective in trapping windblown sand but have minimal effect in resisting erosion by waves and water during storms. By retaining sand on the coast, they contribute to overall coastal stability to the extent that sand would otherwise be blown away and lost from the active beach zone.

Educational signs and viewing areas have been placed at various locations along the coast where the public can learn about coastal issues and appreciate coastal vistas.

A critical component of maintaining dune vegetation and dunes themselves is to restrict public access by limiting pedestrian traffic to public walkways.

The many benefits of dune management include improved access to the beach, especially for the less agile, increased biodiversity of dune vegetation and fauna dependent on it, and scenic improvements such as a more landscaped or more natural-looking coast depending on the nature of the area.

Sea wheat grass dunes, West Lakes Shore

Native spinifex dunes, West Lakes Shore

Dune weeding program, Semaphore

4.5.3 Non-indigenous coastal plants

Many non-indigenous plants alter the distribution of sand within the active dune zone and are effective in reducing wind-blown sand losses along the Adelaide coast. Common pest and non-indigenous plants include marram grass, sea rocket, gazania, arctotis daisy, succulents, boxthorn and sour sobs. Of these, marram grass, *Ammophila arenaria*, has been used extensively to stabilise dune blow-out areas, e.g. at West Beach between 1976 and 1979, and in 1983.

More recent plant arrivals include sea wheat grass, *Thinopyrum junceiforme*, and dune onion weed, *Trachyandra divaricata*. The native coastal spinifex, *Spinifex sericeus*, is a coloniser of the foredune forming a wide flat foredune, whereas sea wheat grass forms steeper dunes. The spread of sea wheat grass has led to areas of steep seaward-facing dune build-up, specifically at Henley North, Tennyson South and Semaphore.

Non-indigenous plants pose a serious threat to indigenous plants. They are generally invasive species that threaten the biodiversity of dunes along the coast. Coastal councils have prepared regional coastal management plans that propose ways to either minimise the risks of pest plants being spread or limit the damage from their spread. The Urban Forest Biodiversity Program is working closely with councils to develop reserve-specific vegetation management plans that feature weed distribution maps along with control and containment strategies. In partnership with the Urban Forest Biodiversity Program and Coast Park, the Coast Protection Board published *Garden Plants that are Known to Become Serious Coastal Weeds* in 2003 to inform the community about protecting South Australia's coastal environment and biodiversity.

4.6 Monitoring

4.6.1 Seabed monitoring

Sediments and seabed levels have been continuously monitored by the Coast Protection Board and/or Department for Environment and Heritage along the Adelaide coast and offshore since 1975, as part of the beach management program. In addition, several investigations by others have been conducted on sediments and seabed dynamics.

Three methods are employed: beach profiles, sand level rods and surface difference modelling.

Beach profiles

A network of beach profiles approximately 500 m apart was established along the shore in 1975, and these have been regularly surveyed since. Levels are taken from fixed survey marks along the shore to wading depth, after which depths are measured acoustically from a boat. Profiles generally extend to 1 km offshore, although recently some lines have been extended to 2 km and 5 km offshore. Surveys are compared and height differences used to detect erosion or deposition along the profile line. Heights are measured to AHD.

The Department for Environment and Heritage has tested the accuracy of profile depth soundings using rod sites and reefs as controls. Depth readings have an error range of ±15 cm. Sources of error include calibration and stability of the instrument, errors in positioning, incorrect adjustment for tides, background noise of waves and false readings due to seagrasses.

There are several ways to analyse profile data but principal among these are calculating the volume of sand down to a certain depth, calculating the width of the beach at high or low tide and, in particular, comparing these values over time.

The change in beach width measured to neap high-water mark (i.e. the distance along the profiles to –0.152 m AHD) is one way of mapping the movement of sand and effectiveness of the beach management program. Figure 4.8 clearly shows the increase in beach width from Semaphore to North Haven due to the build-up of sand from the northward littoral drift. The build-up of sand immediately south of Holdfast Shores, Adelaide Shores and the Torrens Outlet is also clearly shown while other areas of diminishing beach width corresponding to loss of sand are evident south of Point Malcolm, at the West Beach dunes and in the Somerton Park and North Brighton area. The overall slight increase in beach width at Seacliff and Brighton from 1975 to 2003 reflects the effectiveness of the beach replenishment program during that period in not only maintaining the beach width but also producing a narrow dune buffer against storms.

Measuring a beach profile line

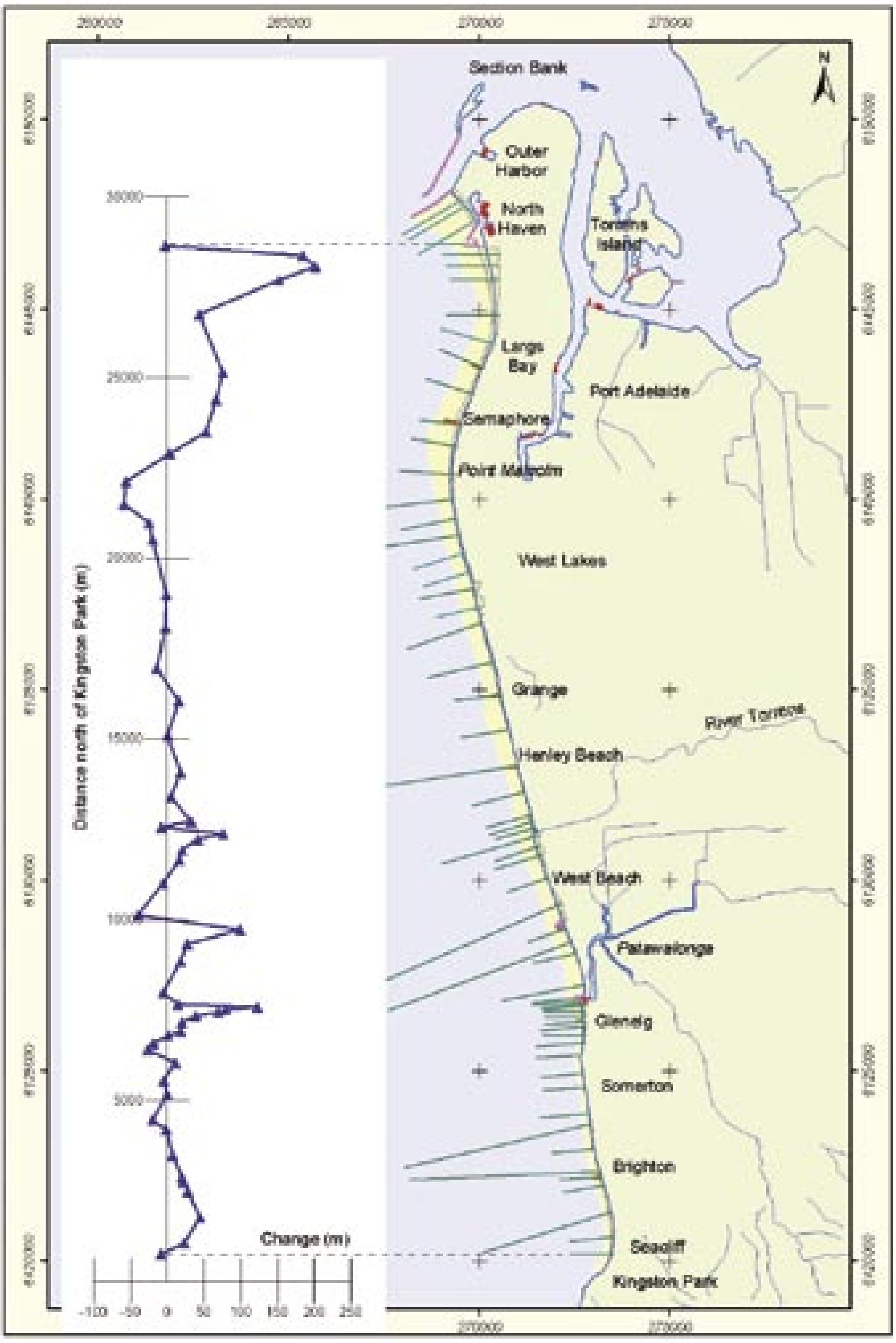


Figure 4.8 Variation in beach width along the Adelaide metropolitan coast 1975–2003

Sand level rods

Brass rods (1.6 m long) have been hammered into the seabed, to a depth of 1 m at 16 profile locations, to provide a more precise measure of seabed height change. The rod top is used as the datum and rod height measurements compared to detect changes. Rods are located 350–2000 m offshore and are generally spaced 25 m apart for the first 1000 m and 50 m apart further offshore. Most rods were placed between 1987 and 1990 and have been measured annually. The rods provide the most accurate measure of seabed erosion or deposition; with a few exceptions they are firmly embedded in clay for stability. The measuring staff has a wide flat base to prevent sinkage and is graduated in millimetres. It is rested on the bottom against the rod base, and the rod is brought squarely against the staff and its height measured. Consistent height readings within 1 cm are made during normal conditions. Occasional bottom unevenness from ripples or stones can reduce measurement accuracy by about 1 cm.

Measuring a sand level rod

Surface difference modelling

Intensive coverage of the beach and seabed by levelling and soundings has enabled mapping of erosion and deposition using surface modelling software (ArcInfo, Environment Systems Research Institute). The Adelaide coast was intensively surveyed in 1990–91 to 3 km offshore. These surveys are the baselines to which surveys that are more recent are compared. Brighton, West Beach and Semaphore Park have been regularly surveyed to varying distances offshore, and erosion and deposition changes mapped. In 2001, a swathe mapper employing side scan sonar, in addition to acoustic measurement, was used to map the Brighton and West Beach seabed, giving higher resolution mapping and also seabed texture mapping capability. Preliminary results show significant improvements in seabed mapping capability. Accuracy is similar to profile depth soundings.

4.6.2 Harbour bypass monitoring

Monitoring of sand movement at the Holdfast Shores marina and Adelaide Shores boat haven assists the sand bypassing operation and improves its efficiency. Monitoring techniques include channel surveys, surface modelling surveys and beach profiles (Deans & Smith 1999). As more data becomes available, a greater understanding of the processes is likely to lead to improved monitoring methods and a reassessment of operational needs.

5. Recent Studies and Investigations

Reviews of the coastal management strategy in 1984, 1992 and 1997 supported beach replenishment as the most cost-effective way of maintaining sandy beaches and protecting property on the foreshore. Beach replenishment relies on sustainable and economical sources of sand being available but by the late 1990s, historical sources of sand had been exhausted, and alternatives have since cost considerably more. Ongoing seagrass loss, rising sea levels and the need to bypass sand around the Holdfast Shores and Adelaide Shores developments have also contributed to an increase in sand management costs.

The 1997 reference group appointed by the then Minister for the Environment and Natural Resources, the Hon. David Wotton, MP, recommended that alternative sources of sand be investigated as a matter of urgency to supplement the existing finite amount of sand within the metropolitan beach system. The group also recommended that maintenance of beach quality for recreation and amenity should be given due regard in future coastal protection programs.

Since the 1997 review, the Coast Protection Board has investigated a range of offshore and land-based sand sources at locations including North Haven, the Section Bank, Port Stanvac, Moana, Nalpa, Mount Compass and northern Yorke Peninsula.

Coastal Engineering Solutions was commissioned to update coastal process modelling for the metropolitan coastline, taking into account future changes to seagrass meadows and sea levels.

An investigation of seagrass rehabilitation techniques in conjunction with the South Australian Research and Development Institute (SARDI) is underway and is producing encouraging results.

Studies quantifying the value of beaches to foreshore property owners and the public have aimed to update earlier studies that supported maintaining sandy beaches on economic grounds. Beach users have also been surveyed to update the Government's understanding of how the community uses the Adelaide beaches and what aspects of the beaches are valued most.

5.1 Investigation of potential sand sources

5.1.1 Ideal sand for beach replenishment

The sand required to replenish Adelaide's beaches should ideally be similar to beach sand present at the southern metropolitan beaches. Brighton and Seacliff beach sand has been used to define the specifications for beach replenishment sand (Table 5.1). It is classified as Quaternary, off-white, mainly fine grained and sub-rounded. The fines are silts, possibly with some fine organics.

Table 5.1 *Brighton beach sand sizing, 1982*

Wentworth classification (grain size description)	Sieve mesh aperture grading (grain size) (mm)	Percentage of sample passing through sieve (%)	Percentage of sample this grain size (%)
Pebbles	4.75	100	0
Granules	2.36	100	0
Very coarse sand	1.18	99.5	0.5
Coarse sand	0.60	99	0.5
Medium to coarse sand	0.425	97	2
Medium sand	0.30	83	14
Fine to medium sand	0.212	45	38
Fine sand	0.15	10	35
Very fine sand	0.075	2	8
Silt/clay	<0.075	0	2
Moisture content	**~1%**		
Fineness modulus*	**1.1**		
Cumulative % >0.2 mm	**55%**		

* Fineness modulus (FM) is a calculation based on grain-size percentage that describes sand size in a single number.

As Brighton beach consists of sand that has been supplied under the beach replenishment program, its characteristics have varied over time. The sand specifications for beach replenishment currently set by the Department for Environment and Heritage are that:

- the sand is silica
- at least 50% should be coarser than 0.2 mm
- the fines content (silt and clay) is less than 5%.

The preferred sand would be rounded or sub-rounded rather than angular (to avoid sharp grains underfoot, reduce wear of grains and reduce sand movement), off-white or pale in colour, and as clean as possible to reduce discolouration and potential environmental damage. Sands that are coarser than the existing Brighton beach sand would also be suitable as they tend to be more stable on the beach.

Sand too coarse for ready vehicular access (e.g. launching dinghies or movement of sand carting trucks) is relatively slow to move under the action of waves and therefore advantageous in countering littoral drift. Rocks within beach sands are an obstacle to walking or running on the beach, and fine materials discolour the water affecting safety for swimmers, enjoyment of the coastal landscape and health of marine environments. Coloured sand is considered by many to be unsightly, particularly when we're accustomed to Adelaide's golden-white sand. Fine sand is also more readily blown off the beach than coarse sand.

The characteristics of metropolitan Adelaide Plains coast sand are very varied. Targets for beach replenishment sand type must recognise the current local sand types but some changes would improve the capacity of the coast to provide for the range of values reliant on sand.

There is a link between sand grain size and sand distribution – since coarser-grained sands will form a steeper beach under the same wave conditions than fine sand, less sand is needed to provide a beach if the grain-size is larger. Using fine sand to replenish the beach would result in a large amount of the sand moving offshore into the sandbar part of the beach rather than building up the top part of the beach for dunes and coast protection ability. If replenishment sand were very fine-grained, it would wash offshore and smother seagrass meadows.

Most values reliant on sand would be achieved from a medium to coarse sand grain size, but not too coarse to prevent ready vehicular access or ease of walking. Mixed grain-size sand will be sorted by coastal processes. The fact that finer fractions wash seaward or blow landward means they tend to incur greater management costs (e.g. drift management, harbour management, seagrass smothering and beach replenishment).

New sand added to the coast should meet minimum acceptable requirements – a sand standard – for that area. The sand standard needs to be determined specifically for each location and would include:

- maximum level of fines (i.e. small particles that affect water clarity)
- maximum level of pollutants or impurities (e.g. heavy metal contaminants)
- maximum level of rocks, clay lumps or organic debris
- minimum density of sand (reflecting the proportion of lighter carbonate (shelly) sand)
- an optimum sand grain size grading based on existing sand and desired sand type
- an acceptable sand grain size range based on existing sand type.

5.1.2 Offshore sand investigations

Initial investigations

Offshore sediments were investigated in the late 1930s and 1940s by the Department of Marine and Harbors for two proposed boat harbours, one at Seacliff and the other at Glenelg. At Seacliff, only a thin veneer of sand or gravel, up to 0.5 m thick, covered the limestone, whereas sand thickness at Glenelg varied from 0.5 m at a water depth of 3.6 m to 2 m near the jetty. Boreholes for an investigation in 1985 inshore at Glenelg, by Coffey and Partners Pty Ltd for the proposed Jubilee Point Development, showed 1.5–2.5 m of fine to coarse shelly sand overlying a clay substrate, typical of much of the Adelaide inshore coastline.

In the early 1960s, the sediments at Port Stanvac were surveyed for construction of an oil terminal jetty. In 1961, ME Lawrie, using soundings and probes along the alignment of the proposed jetty up to 1.3 km offshore, found a sand and shell grit layer 0.6–12 m thick. Following construction of the jetty, rotary drilling by Geosurveys of Australia Ltd in 1962 intersected fine to medium grained, silty sand with shell fragments. After extensive seafloor sampling of Gulf St Vincent from 1964 to 1969 and the drilling work of 1962 near Port Stanvac, Reg Sprigg wrote to the Coastal Management Branch in 1979 advising it of a 'significant potential for submarine erosional sand supply in water depths less than about 20 m' that required further attention (Tucker & Thomas 1985).

Offshore of the Glenelg sewage treatment works was investigated for an effluent pipe in 1966, and offshore of the Port Adelaide sewage treatment works for a sludge outfall pipe in 1975. Both locations had varying sand depths from 1 m or less up to 5 km offshore to more than 2 m within 1.5 km of the shore (Engineering and Water Supply Department 1974).

In 1982, cores drilled onshore in the Outer Harbor area for the Coast Protection Board, as part of an Adelaide coastal land-level changes study, contained fine to coarse sand with organic and shelly materials. The indication of coarser sand at depth suggested deeper coring on the Section Bank would be warranted (Coast Protection Board 1982). The Department of Mines and Energy also cored sediments in the Barker Inlet area at the time to determine the shallow subsurface stratigraphy (Belperio 1985).

The Department for Environment and Heritage carried out an investigation of sand deposits on Torrens Island and found enough suitable sand for up to 10 years of beach replenishment.

An area 4–18 km offshore from Grange jetty to St Kilda was surveyed four times between 1957 and the mid-1970s in the search for suitable grade shell grit for the manufacture of cement (e.g. Adelaide Cement Co. Ltd 1975; Olliver 1963). The area was found to contain significant shelly calcarenite, with carbonate content increasing from about 70% to 90% with distance offshore.

Targeted searches

These investigations shed light on potential offshore sand deposits but did not aim to find viable sand sources for beach replenishment. The search for offshore sand sources began in earnest in 1972 with a study by Laser Electronics Pty Ltd (Brown 1972) between Henley and Marino Rocks. The study included seismic surveying and drill cores but did not assess sand suitability for beach replenishment. It did, however, note the presence of several hard layers and the possible difficulties of dredging the underlying sand. Sampling by the Department of Marine and Harbors offshore from the Brighton jetty and Seacliff followed in 1972 and 1973, respectively, as did a University of Adelaide vibrocoring study in 1977.

Between 1978 and 1980, a Coastal Management Branch vibrocoring survey examined sand deposits to a depth of 5 m in the Outer Harbor area, and further vibrocoring was undertaken in 1987. The vibrocoring results established that over 1,000,000 m^3 of sand was present but was finer grained than that on the beaches. Nevertheless, it contained enough medium-grained sand to be considered adequate for replenishment purposes, although 20–40% more sand was estimated to be needed to offset the loss of fine materials.

The Coast Protection Board then commissioned a survey by Adelaide, Flinders and Queensland Universities in 1980 that extended offshore between Port Gawler and the Onkaparinga River (Hails et al. 1982). Using an echo sounder, seismic and side-scan sonar equipment, as well as a small bucket dredge and grab sampler for seafloor samples, the study provided useful information on bathometric changes, areas of sediment erosion and accretion, and sedimentary characteristics. It isolated some possible offshore sources near the Onkaparinga estuary, O'Sullivan Beach, Marino–Hallett Cove and Wonga Shoal, but further investigations and correlation of the sediments were needed.

Construction of the North Haven marina by Gulf Point Marina Pty Ltd required sand to infill the residential development. Coring and dredging just offshore from the development and inside the haven by the Coastal Management Branch and Kinhill Stearns found clean sand of fine to medium grain size, similar to that present at Glenelg North, to a depth of –9 m AHD. Further coring by the developers identified sand suitable for beach replenishment within 500 m of the beach and adjacent to the breakwater. Gulf Point Marina Pty Ltd obtained a mining lease over an area further offshore than the area shown to be suitable for beach replenishment and dredged 400,000 m^3 in 1986.

As a follow-up to these studies, the Coast Protection Board invited registration of interest for further investigation of potential offshore sand sources in 1983. A preliminary offshore investigation by the Coastal Management Branch defined areas of significance between Maslin Beach (the limit of economically feasible sand transportation at 26 km south of Brighton) and Outer Harbor (beyond which sediments would be too fine). In the preliminary investigation divers collected hand-driven cores of 2 m or less in length (depending on their penetration or the sediment thickness) at locations fixed by either the microwave positioning system Decca or by sextant and compass on channel markers and prominent features (Tucker & Thomas 1985).

Sediment coring

Extracting a sediment core from a tube

The results indicated only six areas that warranted further investigation. In order of priority, these were:

1. immediately north of Outer Harbor where dredging in the nearby channel had shown the calcrete layer to be –9 m AHD and coring in the nearby vicinity showed coarser sand at depths greater than the 5 m tested
2. offshore from the northern end of North Haven beach in 3 m of water where 150,000 m^3 of fine to medium sand had already been proven to exist
3. an offshore bar adjacent to West Beach, although its shallow inshore location and proximity to seagrass beds would probably preclude its use
4. O'Sullivan Beach where coring indicated medium to coarse sand at depths that did not intersect any hard base, but these deposits were not expected to be extensive
5. ancient shoreline deposits off Glenelg to Outer Harbor 5–10 m below the seabed and 1–3 km offshore, except that removal of such sand and disposal of the overburden would be problematic
6. a remote possibility offshore from the Normanville area where reworked Permian sands may be present.

The subsequent full-scale survey for general sedimentological purposes by the Department of Mines and Energy in 1989 (Belperio et al. 1990) involved 15 transects over a 3-day period. An acoustic geopulse boomer was towed at 5 knots behind the Department of Marine and Harbors survey vessel to obtain continuous seismic reflection profiles, and divers took cores in water depths generally of 10–20 m at designated sites along the transects marked by buoys. The areas investigated were offshore from Largs Bay, Henley Beach, Brighton to Port Stanvac, Port Stanvac to Port Noarlunga, Port Noarlunga to Sellicks Beach, and further afield in Backstairs Passage. Only limited sand cover was recorded over much of the areas investigated, although four prospective sites were identified as having potential for metropolitan beach replenishment (Figure 5.1).

The report (Belperio et al. 1990) recommended that:

- highest priority be given to evaluating Prospect A centred on Port Stanvac as the site thought to contain up to 4,000,000 m^3 of unconsolidated sand in water depths suitable for economical dredging
- high priority also be given to further investigating Prospects C and D offshore from Moana and Maslin Beach to determine whether the two deposits were contiguous.

Prospect B was not considered a potential source as it was situated within and south-west of the Port Noarlunga reef and Onkaparinga estuary aquatic reserve, and dredging in the region would probably have a negative environmental impact.

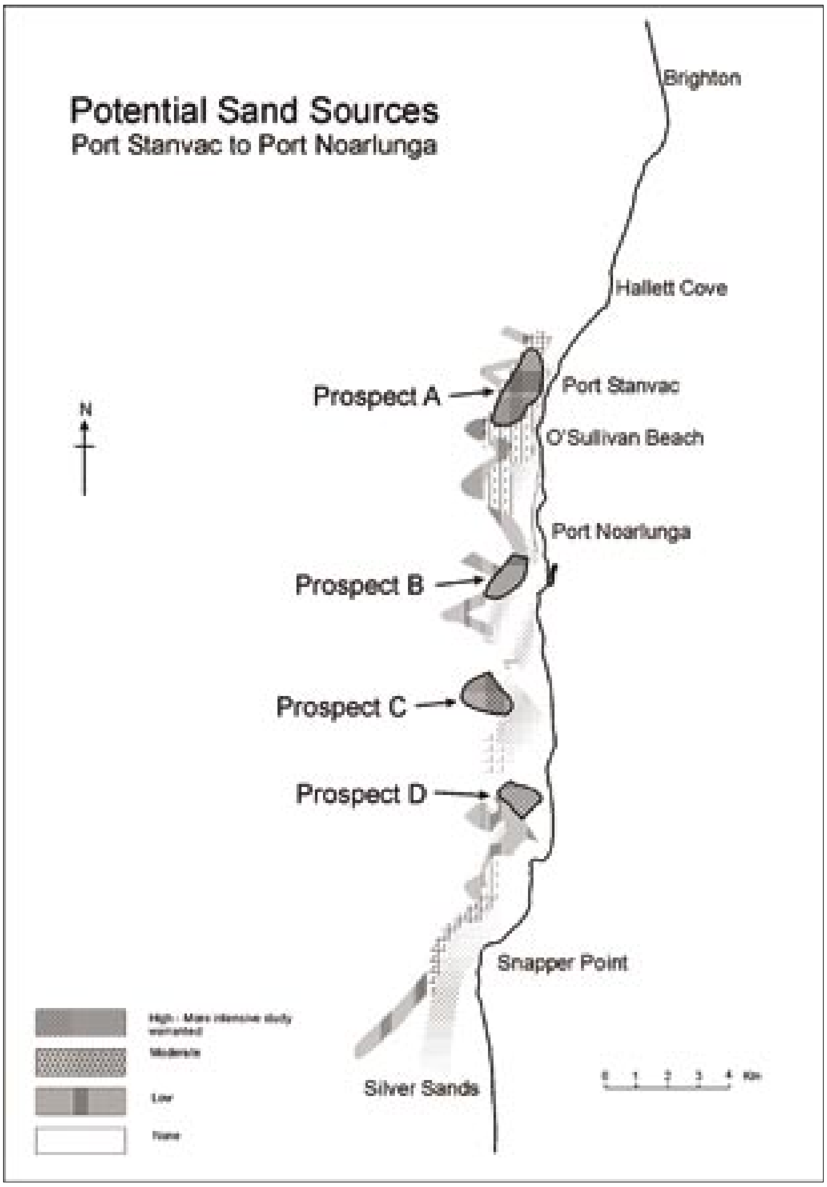


Figure 5.1 *Department for Mines and Energy sand source prospects A to D (Belperio et al. 1990)*

Port Stanvac sand source

After extensive geological investigations, a sand reserve was located offshore from Port Stanvac in 1990, which, because of its suitable sand grain size and minimal environmental considerations, was particularly valuable for metropolitan beach replenishment. The sand reserve was bounded by seagrass beds to the south and port restrictions to the north, with loading and unloading infrastructure and activities limiting the area of investigation. The sand source area, as defined for the dredging contracts, was in water depths of 12–18 m offshore from the northern boundary of the O'Sullivan Beach sewage treatment works and extended north 1.5 km to the southern boundary of the Port Stanvac oil refinery (Figure 5.2).

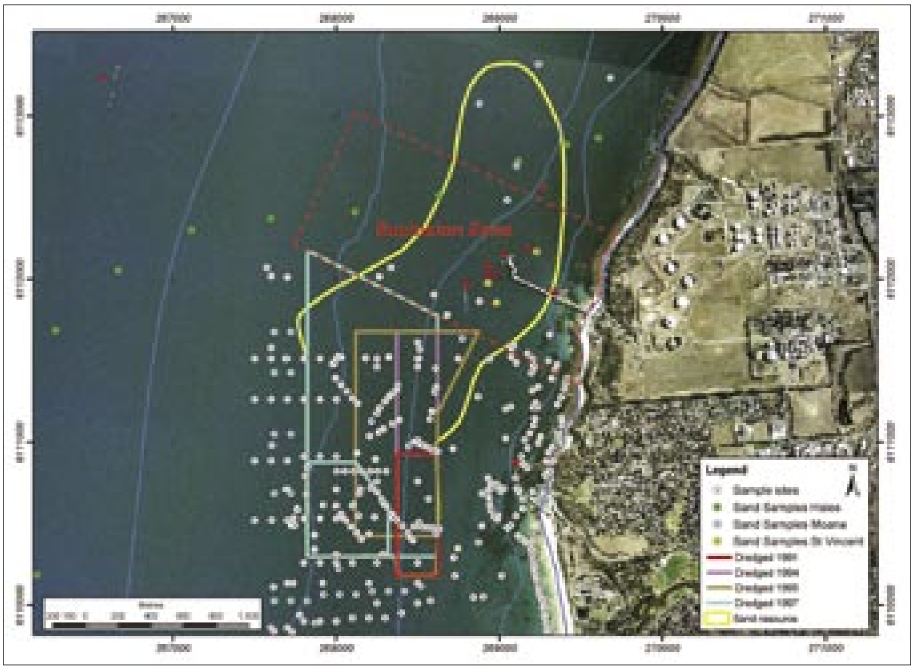


Figure 5.2 *Aerial photograph showing the Port Stanvac sand reserve*

The sand in the northern sector of this area was particularly coarse. Elsewhere, it consisted of medium to coarse-grained sand ideal for beach replenishment (Figure 5.3).

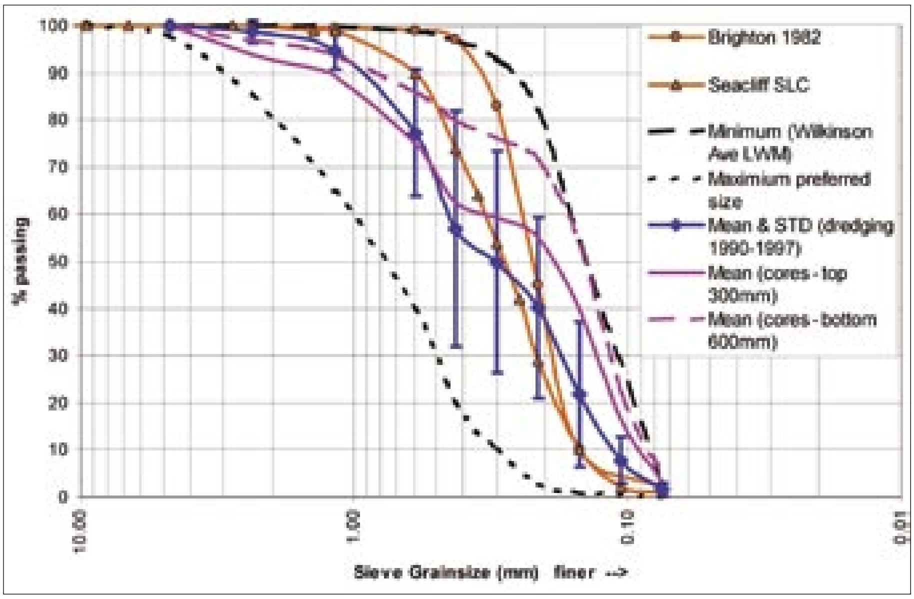


Figure 5.3 *Mean sand size analyses for Port Stanvac samples*

From 1991 to 1997, a series of dredging contracts extracted over 1,000,000 m^3 of sand from the reserve using the *Pelican* and a larger dredge, and deposited it on Brighton beach. The current good condition of this beach is due to the quantity and quality of the sand it received in the 1990s. The relatively close proximity of the supply site to Brighton was also an economic benefit.

Port Stanvac dredging and monitoring

The use of the dredges at the Port Stanvac site was monitored by the Coastal Management Branch and subjected to a variety of tests. Dredged sand from Brighton beach was also tested by the State Chemistry Laboratories for a broad range of possible contaminants, and no pollutants or contaminants were found in the analyses.

Seabed sediments from the dredge site were also analysed for the presence of possible pollutants including heavy metals, petroleum hydrocarbons and dispersants. The results indicated concentration levels well below EPA guideline limits. Water sampling of the sediment plume confirmed contaminants were not a concern. However, turbidity levels in the sediment plume were high and were monitored in 1994 and 1997 by the Coastal Management Branch.

A biological survey of the area in January and April 1992 assessed the effects of dredging (Cheshire & Kildea 1993). The dredge site was found to contain a biological community structure consistent for its alongshore and depth gradients. It appeared that despite many infaunal organisms being removed during dredging, some were able to sink back down to the substrate during the process and become re-established, while others were probably transported by tidal and wind-driven currents back into the region. Organisms such as algae, seagrasses, sponges, bryozoans, hydroids and ascidians, as well as some of the slower mobile fauna including crabs, urchins and seastars, could not avoid dredging and were therefore unable to survive it.

A significant finding was that areas to the south of the site were dominated by seagrasses and would be at risk from the dredging operations. The survey also revealed significant degradation at one of the sites presumed to result from the Christies Beach sewage treatment works effluent outfall. Monitoring of the dredging impacts between 1993 and 1995 (Cheshire et al. 1996) found a high degree of variability in the distribution and abundance of taxa in the region, which complicated any assessment of change. While significant short-term impacts were apparent, the system appeared to recover within 12 months of dredging.

Further potential at Port Stanvac

Additional dredging of the Port Stanvac site may be viable following closure of Port Stanvac in 2004, which freed up a previously restricted area. Even so, the dredge site remains constrained at its boundaries: important seagrass habitats to the south would be at risk from nearby dredging; the north and west borders have poor-quality sediments and/or shallow rock or clay; and on the eastern inshore border the Coastal Management Branch assessed that dredging in less than 10 m of water would affect inshore coastal processes.

Moana Ridge sand surveys

In 1998, sediments offshore from Kingston Park and Maslin Beach were investigated on behalf of the Coastal Management Branch (Rice & Hudson 1998). The investigation obtained continuous seismic reflection profiles using an acoustic boomer, and surface samples, video images and seabed cores. The aim was to locate an environmentally acceptable offshore sand deposit, establish a volume of suitable sand for replenishment purposes at Brighton beach, and determine the proportion of unsuitable or potentially polluting material. Ideally, the deposit would contain over 200,000 m^3 of medium- to coarse-grained sand, with no more than 3% of very fine sand and mud, and be at least 1 m thick either at or within 0.2 m of the seabed in water depths greater than 10 m. The resource also needed to be free of environmental and cultural constraints, particularly the presence of seagrass meadows and proximity to aquatic reserves or other areas of heritage significance.

Rice and Hudson (1998) reported a possible sand source suitable for beach replenishment at Moana Ridge offshore from Moana, although the bathometric and stratigraphic complexity of the area meant sand volumes could not be calculated accurately (Figure 5.4).

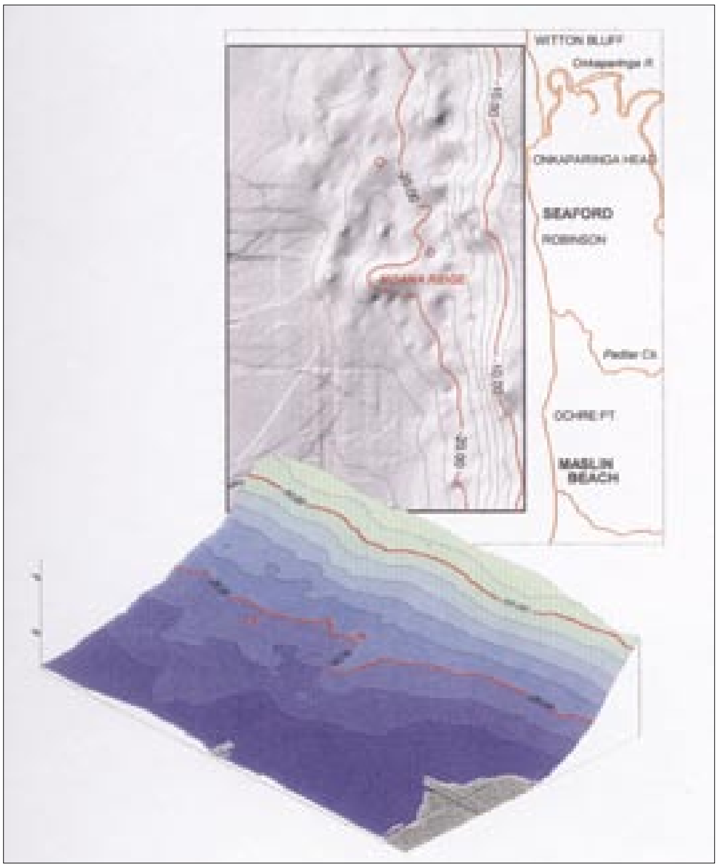


Figure 5.4 *Moana Ridge potential sand source (adapted from Rice & Hudson 1998)*

Moana Ridge as a sand source

The Coast Protection Board considered the report and, in particular, the effect that sand extraction would have on the inshore wave climate, as this could lead to significant sediment erosion. If fine sediments were found, the likely formation of a sediment plume during and after the dredging could cause unacceptable environmental impacts in the region.

The Board concluded that the deposits were too narrow to be dredged without having impacts on surrounding areas and thus did not warrant further investigation at that stage.

Section Bank sand surveys

Investigations in the 1970s and 1980s had established the Section Bank north of Outer Harbor as a potential sand source (Figure 5.5).

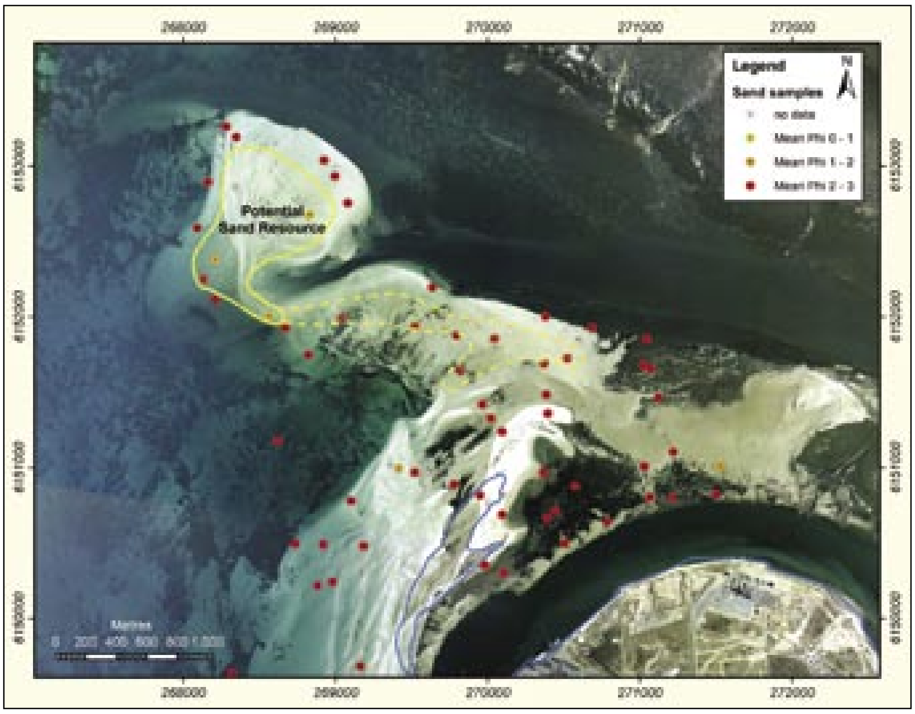


Figure 5.5 *Aerial photograph showing the Section Bank sand prospect – proposed grid drillhole locations*

By 1997 when the Port Stanvac sand reserve had mostly been depleted, another source was needed for beach replenishment beyond 2000. The 1997 *Review of the Management of Adelaide Metropolitan Beaches* recommended that known reserves at the Section Bank be reassessed as a likely offshore sand source.

Several studies have aimed to determine the suitability of the Section Bank as a sand source (e.g. Johnson 2004a). Others have aimed to determine the potential impacts of dredging on ecological communities in and around the Section Bank (e.g. Cheshire et al. 2002; Mifsud et al. 2004).

Section Bank as a sand source

Coring surveys of the Section Bank by the Coast Protection Board in 1979 and 1987 revealed fine- to medium-grained, mostly siliceous sand suitable for beach replenishment. The initial drilling program drilled 47 holes using a vibrator coupled with a 32 mm diameter, 6 m long stainless tube assisted by vacuum; the latter program drilled 19 holes using a 100 mm diameter, 6 m long aluminium pipe fitted with core catchers. Samples were collected at 1 m intervals in the 1979 cores and at specific depth intervals, often more than 1 m apart, in the 1987 cores. Only the sand size fraction of samples was recorded for 1979 cores, whereas the full range in grain size was recorded for 1987 cores (the coarse shell fraction was removed to compare results). No carbonate percentages were determined for the sand-size fraction of the 1979 drill hole samples. For 1987 samples, carbonate and organic contents were determined for the total sample but gravel and sand sizes were not differentiated. Shell contents ranged from <1% to 63% with typical results being 5–10%.

The mean grain size and standard deviations for the 1987 core samples are plotted in Figure 5.6 against grain size at Brighton and Seacliff beaches. Sand from the Section Bank plots well within the preferred size range for beach replenishment.

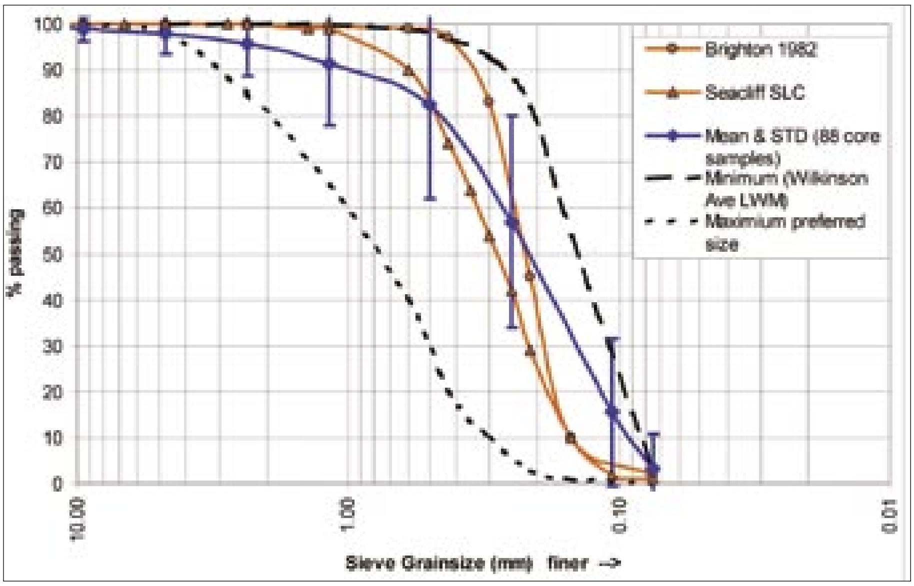


Figure 5.6 *Mean sand size analysis for Section Bank cores*

Johnson (2004a) used the Fineness Modulus (FM) system to compare grain size and determine the suitability of the Section Bank for beach replenishment. The FM describes sand size in a single number and allows for a simple comparison between different sand types. For example, very fine sand has an FM of 0.6–0.7, fine sand 1.0–1.2, medium sand 1.2–1.5 and coarse sand 1.8–2.3. Sand finer than 1 FM will not stay on the beach for long and is considered unsuitable; sand with an FM higher than 1 is coarser and will stay on the beach longer.

Western and central eastern Section Bank has sand with an FM >1.3 (Figure 5.5). The western area, defined by five drill holes, is approximately 1.1 km north–south and 600 m east–west, with a thickness of 3–4 m – about 2,200,000 m^3 of suitable sand. The central eastern area, defined by six drill holes, stretches about 2 km east–west and 250 m north–south, with a thickness close to 3 m. It could provide approximately 1,300,000 m^3 of sand.

The overall estimate of suitable Section Bank sand for beach replenishment of 3,500,000 m^3 has an average FM of 1.4. Further drilling in and around the defined region will be necessary to more accurately determine the boundary of medium to coarse sand, sand thickness and quality.

The Coast Protection Board has recently considered a pilot dredging program at the Section Bank to dredge up to 2,500,000 m^3 of sand, and then transport it by barge to be pumped onshore at different locations. Dredging at this scale would increase the bathometric depth at the Section Bank by 1.2–1.5 m over 80–190 ha and could lead to changes in wave and current conditions unless steps are taken to replenish the Section Bank itself.

State of the area

Baseline surveys to begin to assess the potential impacts on existing subtidal and intertidal communities in the region, especially seagrasses and mangroves, found significant areas of seagrass dieback, with over 50% dieback within 2 km of the Section Bank. Seagrass leaf growth rates were significantly less than at the control site, and epiphyte loads were much greater, indicating high levels of nutrient enrichment. Mangrove dieback was also found to be extensive in the region, most probably from high nutrient levels, anaerobic sediments and increases in offshore wave energy over time due to seagrass losses. The surveys clearly highlighted significant adverse impacts on the coastal ecosystem of discharges of high nutrient loads from the Bolivar wastewater treatment plant and from the Port River.

Risk assessment of dredging impacts

The main environmental risks likely to be associated with dredging the Section Bank were found to be:

- prolonged exposure of seagrasses to turbidity plumes
- nutrients releases from the sediments that would place additional stress on seagrasses
- increased frequency of waves that could erode mud flats around mangroves
- deposition of sediment in some areas that could smother mangrove pneumatophores
- loss of benthic fauna from the dredge site
- the potential of exotic species to recolonise the site and replace local species.

As real as these risks are, the greatest overall threat to the long-term health and survival of seagrass communities in the region appears to be the continued discharge of nutrients from Bolivar and the Port River. A proposed dredging program may speed up seagrass loss somewhat, although whether dredging would adversely impact the mangroves is uncertain.

Use of the Section Bank to replenish Adelaide's beaches will not take place until the environmental impacts of dredging are adequately addressed and a method of extracting the sand, and possibly replacing it with finer sand to maintain seabed levels, becomes economical.

North Haven sand source

An 18 ha sand reserve offshore from North Haven (Figure 5.7) has been known since numerous cores were drilled in the 1980s adjacent to the southern Outer Harbor breakwater in water depths to 3 m. Several cores intersected suitable beach replenishment sand, albeit with coarser shell fragments. Sand thicknesses varied from drill hole to drill hole.

Figure 5.7 *Aerial photograph showing the North Haven sand source*

In 1989, the Coast Protection Board dredged 100,000 m^3 of sand for beach replenishment, which had characteristics similar to that of the southern metropolitan beaches (Figure 5.8). Using an average thickness of 2.02 m, Johnson (2004b) estimated the sand reserve at approximately 360,000 m^3. The siliceous sand is mostly finer grained than that at the Section Bank and there is less of it. The FM numbers are also lower than those at the Section Bank, although sand with an average FM of 1.35 is located about 300 m offshore in a 100 m wide band parallel to the beach. In general, dredging of replenishment sand at North Haven would be less cost-effective than at the Section Bank.

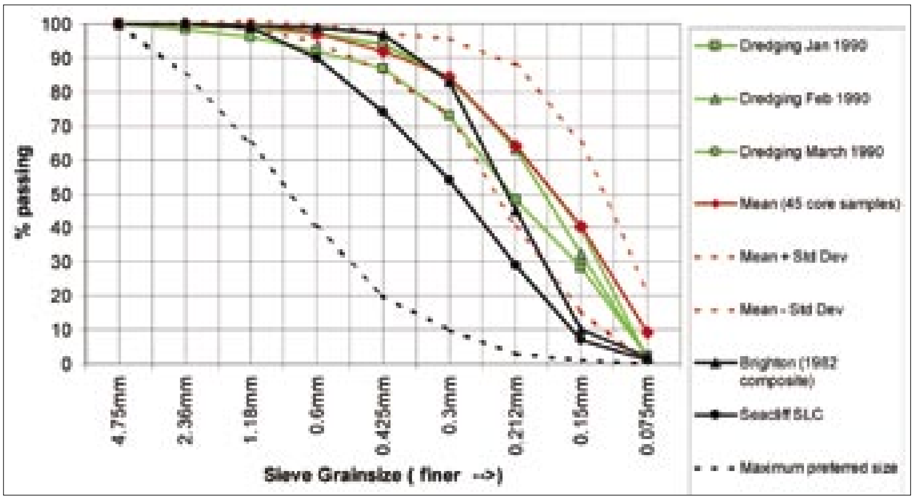


Figure 5.8 *Mean sand size analysis for North Haven cores*

5.1.3 Land-based sand investigations

The silica sand present within several Quaternary, Tertiary and Permian deposits near Adelaide varies between locations but has some general similarities.

Silica sand from the Quaternary era (last two million years) is typically unconsolidated coastal and inland dune sand, coastal beach sand or alluvial valley sand. It can be found in coastal areas, the northern Adelaide Plains, Lake Alexandrina, and Tailem Bend to Coomandook regions although these deposits are relatively small. Where it has a low silt content, it is suitable for beach replenishment. Plants extracting this sand type operate at Reeves Plains, McLaren Flat and Nalpa near Wellington. Most Quaternary sand along the southern and western coastline of South Australia is carbonate sand and hence unsuitable.

Sand from the Tertiary period (43 to 2 million years ago) has been deposited in numerous embayments along the western side of the Mount Lofty Ranges. This sand type is slightly consolidated, sub-rounded to sub-angular, often stained by iron oxide, and on average contains around 15% silt and clay. These sands are generally used in the construction industry. To meet beach replenishment specifications they would require washing. Tertiary sands have also been found on the eastern side of northern Yorke Peninsula from Ardrossan to Bute. Pits in this area supply much of Adelaide's concrete needs, and some of the sand would be clean enough to be used for beach replenishment once it was dry-screened to remove the gravel. Tertiary sand pits with washing plants operate at Rowland Flat, Sandy Creek, Golden Grove and Noarlunga–Maslin Beach; dry-screened sand pits operate at Kulpara, Clinton and Price.

Fluvio-glacial silica sands from the Permian era (270–300 million years ago) occur within several areas of the Fleurieu Peninsula, around Mount Compass and along the Inman Valley. Much of the sand is slightly consolidated, fine to medium grained and rounded but would require washing to be useful. However, some local deposits of coarse sand with low fines are potentially suitable without washing.

Operating Permian sand pits are located at Mount Compass and east of Mount Compass where sand is processed for glass or foundry use and for concrete, respectively.

Suitability of land deposits

Suitable deposits of silica sand for beach replenishment, based on sizing, retention on the beach, colour, grain shape and price, exist at Nalpa near Wellington and Glenshera near Mount Compass. The Nalpa and Glenshera sands are rounded to sub-rounded, and have low fines content and hence good retention properties. When washed they are coarser than the existing sand on Brighton and Seacliff beaches (Figures 5.9a and 5.9b). Sand from Price on the Yorke Peninsula is also suitable, falling within the optimal sand-size range (Figure 5.9c), but it is mostly sub-angular and requires further haulage than that from the closer sources.

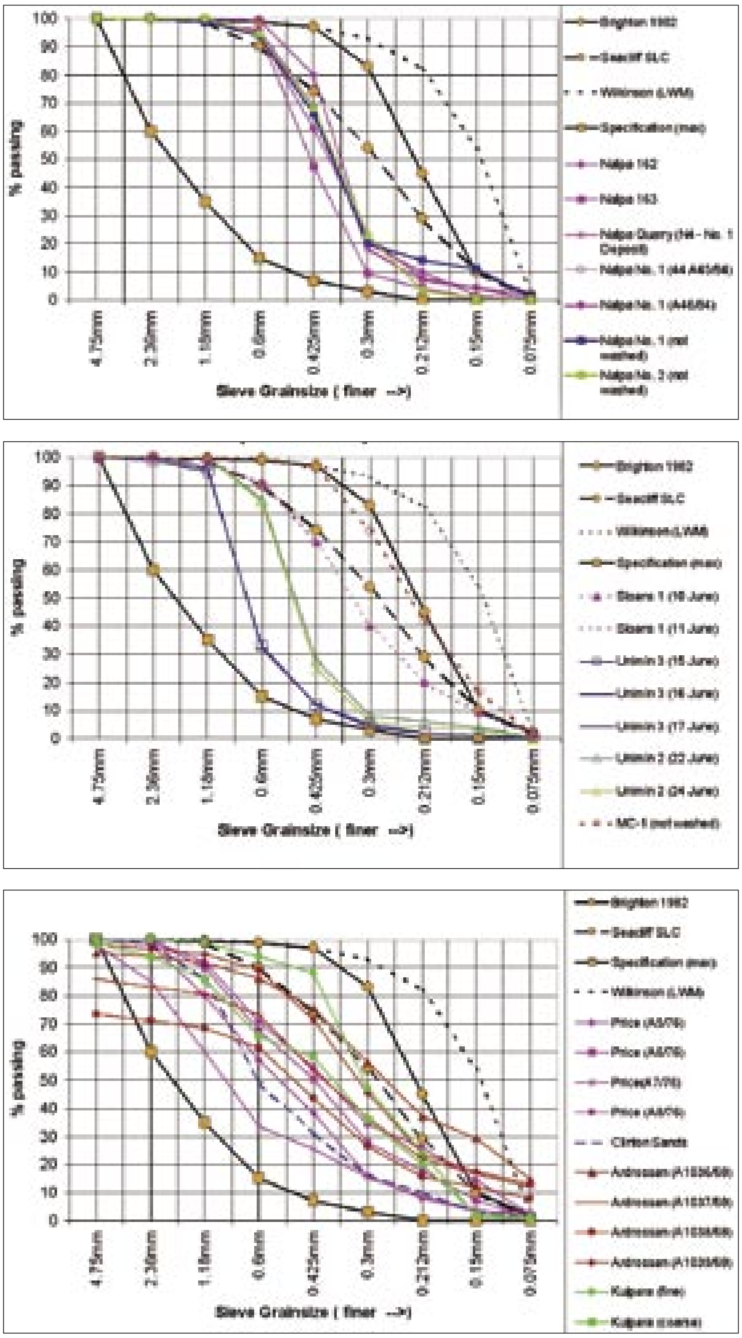
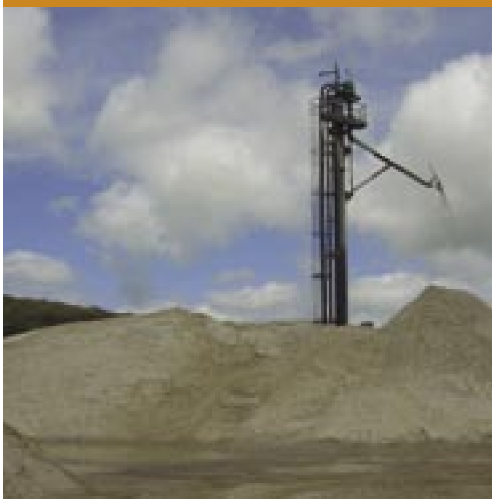


Figure 5.9 *Grain size analyses for suitable land-based sand deposits (a) Nalpa (b) Mount Compass (c) northern Yorke Peninsula*

Sand pit at Unimin Sand Plant (Glenshera, Mount Compass)



Sand used for beach replenishment at Unimin Sand Plant (Glenshera, Mount Compass)

Sand dumping platform at Edwards Street, Brighton – view from the Esplanade

Sand dumping platform at Edwards Street, Brighton – view from the beach below the platform

Sand dumping platform at Edwards Street, Brighton – trucks dumping sand on the platform

Other sand sources that meet beach replenishment specifications include those at Kulpara, Clinton, Rowland Flat, Sandy Creek, Gawler, Christies Beach, Rocla, Maslin Beach, Highbury, Noarlunga, Mount Compass, Tooperang, Ashville and Coomandook.

Murray Mouth sand

The Coast and Marine Section of the Department for Environment and Heritage investigated the suitability of sand from the Murray Mouth for replenishment purposes in 1999 (Fotheringham et al. 1999). Several cores up to 1.4 m deep were collected by Lexan tube from the northern tip of Younghusband Peninsula, the sand banks inside the mouth and the intertidal shore of Bird Island. Grain-size analyses between these and Brighton/Seacliff deposits are shown in Figure 5.10.

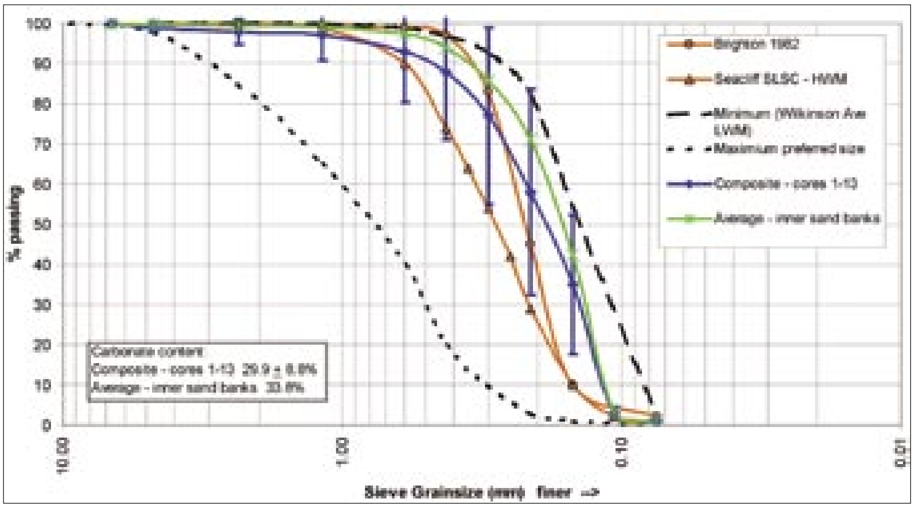


Figure 5.10 *Grain size analyses for sand samples at the Murray Mouth*

Grain size at the mouth varied considerably within a short distance and several samples are considered too fine-grained for beach replenishment use (i.e. overfill ratios >3.5). Importantly, the carbonate content of samples was quite high at 18–50%. Given the greater mobility of carbonate sand than silica, this would increase the overfill ratio to at least four in some cases.

The cost to transport 1,000,000 m^3 of sand from the Murray Mouth by truck was estimated at the time to be approximately \$23/m^3 and by dredge \$18/m^3. When an overfill ratio of four is applied, the cost becomes \$92 and \$74/m^3, respectively.

Apart from the unsuitably high carbonate content and prohibitive costs, the area forms part of the Coorong, Lower Lakes Ramsar Wetland and Younghusband Peninsula and is part of the Coorong National Park. As such, it is generally unavailable as a sand source. Moreover, recent significant erosion to the north-west of the mouth on Sir Richard Peninsula, combined with reduced river flows, has trapped sediment previously supplying the region inside the mouth. Management of the area would therefore require any sand dredged from the flood deltas to be returned to the littoral system on the ocean beach side of Sir Richard Peninsula rather than to replenish beaches elsewhere.

Indicative prices for onshore sand sources

Total prices for beach replenishment sand include several costs: supply, loading, hauling, dumping and spreading sand on the required beach or beaches. Supply costs are greatly influenced by extraction methods and whether the sand needs to be washed or dry-screened. Haulage costs are also highly variable depending on road freight costs and petrol prices, or sea freight costs if sand is barged to its destination. Estimates of spreading sand on the beach can also vary greatly, as can the cost of pumping slurried sand to shore from an offshore barge or along the coast.

Pricing rates are usually given as either cost per tonne ($/t) or per cubic metre ($/m^3). Operating pits are required by law to sell sand on a tonnage basis verified over their weighbridges, and bulk freight movements work on a tonnage basis from weighbridge dockets. To convert tonnage to cubic metres, the bulk density of sand must be known but the range is generally 1.55–1.6 tonnes per cubic metre. Therefore, a multiplication factor of 1.55 is used to obtain the cost per cubic metre.

The broad range of costs for land-based sand sources has been estimated (Table 5.2) based on recent beach replenishment to Brighton, several registrations of interest and a questionnaire sent to sand suppliers. Barge supplied costs reduce with increased tonnage and may become competitive especially if truck traffic in the beachside suburbs is reduced.

Table 5.2 *Cost estimates based on 2001–04 data for beach replenishment from suitable onshore sand sources*

Sand source	Mass (tonnes)	Total cost	
		$/t	$/m^3
		Road haulage	
Mount Compass		20–24	31–37
Price		25–29	39–45
Nalpa		21–23	32–36
Other known sources		18–33	27–52
		By barge	
Price	25,000	37–39	57–61
Price	100,000	27–29	41–45

The relatively high costs of beach replenishment sand from quarries – from $27/m^3 to $52/m^3, with several alternatives around the $40/m^3 mark – indicate that sand recycling from within Adelaide's littoral cell remains the most cost-effective method for managing Adelaide's beaches. However, the cheaper sand has to be topped up with external high-quality, coarse sand to counter the ongoing loss of dune volume and beach width caused by sea level rise and other factors. Suitable land-based sources are therefore utilised when required or when they become available on an opportunistic basis.

5.2 Modelling of coastal processes

5.2.1 Littoral zone sand transport

Sand moves along the coast in the littoral zone – the area bounded by the seaward extent of wave breaking and the landward limit of wave action on the coast. The width of this zone varies along the coast, depending on the steepness of the beach, the extent of nearshore sandbars and the wave climate – each one of which influences the other. In practical terms, the littoral zone is generally 200–500 m wide along Adelaide's beaches.

Waves move sand by transferring wave energy to the sand grains within the littoral zone. Along with turbulent dissipation, this completely dissipates the energy in a wave on the beach. (An exception is in situations with a steep beachface, where part of the wave's energy is reflected back out to sea.)

The rate of alongshore sand transport is related to the energy in a wave and the angle at which the wave breaks on the beach. The greater the angle between the beach and the line of the wave's crest, the greater the potential for the wave to move sand along the coast. For example, if a wave approached and broke on a beach parallel to that beach, sand would be suspended and moved up and down the beachface across the shore but not along the beach.

Different wave conditions move the sand in different directions. The overall (net) movement of sand along the Adelaide coast is to the north, because of the constant swell, and prevailing wind and waves from the south-west. However, northerly and north-westerly winds, common in winter and spring, generate waves that push sand from north to south. Thus, there are two measures of alongshore sand transport used: the gross, or amount of sand moved in both directions; and the net, or overall amount. On the Adelaide coast, net transport – the total volume moved northward minus the total volume moved southward – is northward.

Sand is also moved across-shore by waves, mainly during winter storms. The high water levels during a storm surge allow storm waves to reach and erode the dunes, dune buffers and upper beaches along the coast. Sand eroded from these areas is moved offshore into the sandbar system. The classical model of beach change suggests that during summer calm conditions, the sand moves from the bars back onto the beach, from where it is blown back into dunes behind the beach. However, on the Adelaide coast, the sand in the bars tends to be moved alongshore by littoral transport in summer. The summer sea breezes generate waves that are often too rough for onshore movement to occur. Onshore sand movement is more common in Adelaide's typically calm autumn and occasionally calm winter periods.

5.2.2 Predictive sand transport modelling

The rate of sand movement along the Adelaide coast has been estimated since the 1960s. Rates can be calculated by modelling the waves and their breaking action, or by measuring changes on the beach. The calculations actually provide estimates of sand transport *potential* (how much sand would be moved if there were always sand to be moved (i.e. a sandy beach)). Along parts of the Adelaide coast where the sea regularly reaches a seawall behind the beach, or where the sand is not covering a hard layer, these calculations do not therefore represent actual sand movement but rather the sand movement that would occur if there was a beach.

Early calculations estimated an average net northward sand transport potential at Grange in the order of 11,500–19,000 m^3/year, and a comparison of Outer Harbor survey data from 1875, 1946 and 1966 determined annual drift in the order of 28,300 ± 11,500 m^3/year, assuming that half the accumulating volume was seagrass wrack (Culver 1970). The 1984 review reported that excavations had determined only about 20% of the volume accumulated was wrack, and revised the sand drift calculations to 40,000–50,000 m^3/year. Furthermore, based on beach replenishment activity to 1983, an average alongshore drift rate of approximately 30,000 m^3/year was deduced. Modelled calculations of sand drift in 1984 estimated an average rate in the order of 30,000 m^3/year.

Since the 1980s, mathematical models for calculating alongshore sediment transport have become considerably more sophisticated, taking into account more of the numerous factors that influence alongshore sand transport. These improvements include consideration of the separate contributions of sea and swell waves, beach slope, sand grain size, sand density and porosity of the beach. These factors, along with improvements in the ability to model wave generation and propagation onto the Adelaide beaches, have helped give better, though still approximate, calculations of sand movement potential along the coast.

5.2.3 Coastal processes study

In April 2003 the Coast Protection Board commissioned Coastal Engineering Solutions Pty Ltd to update coastal process modelling for the metropolitan coastline from Kingston Park to Outer Harbor, to provide technical support for the latest review of Adelaide beach management.

The study took into account possible future changes to seagrass meadows and sea levels (as a consequence of climate change), as these have the ability to alter nearshore wave conditions and thus the amount of sand being transported along the coast. The coastal reach in the vicinity of Hallett Cove was also included in the study area to investigate a possible strategy of exploiting the predominant northerly sand transport processes to naturally supply sand to the downdrift metropolitan beaches while improving beach amenity at Hallett Cove. As well as addressing the existing situation, the study included modelling of the processes affecting the beaches as they might have been 100 years ago and are likely to be in 20, 50 and 100 years time. The last three scenarios have obviously made progressively larger assumptions about how the coast and climate will change. Sea level rise scenarios used are the mid-range of the current predictions of the Intergovernmental Panel on Climate Change (2001).

Figure 5.11 shows the estimated sand drift rates along the coast from Kingston Park to Outer Harbor for 100 years ago, the present and 50 years in the future. The average rate for conditions before offshore seagrass was lost was approximately 40,000 m^3/year between Glenelg and Semaphore Park. Now the rate is in the order of 70,000–50,000 m^3/year along much of the coast, with a noticeable change to the lower rate from West Beach to the north.

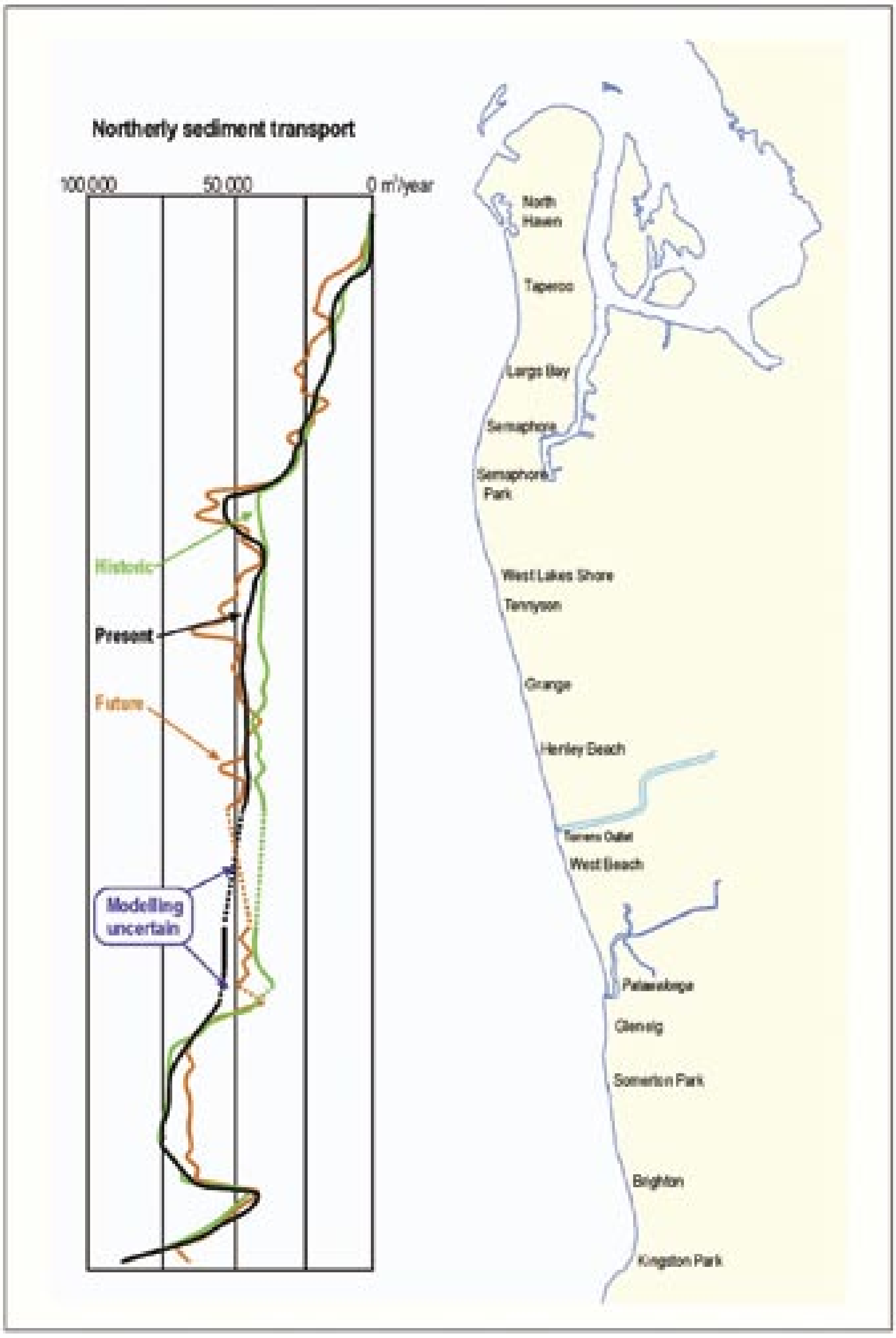


Figure 5.11 *Sediment transport rates for 100 years ago, present conditions and plus 50 years*

The general picture of sand drift in the future is not intuitive. The refraction of waves and thus their concentration on certain parts of the coast varies with changes in sea level. Of major importance is the outcome that there will be much more variation in alongshore drift in the future and that rates might differ markedly within a short distance along the coast. The increase in sand transport at Semaphore Park, a critical erosion area since the 1980s, is quite apparent from the modelling results (Figure 5.11).

Further modelling, aimed to predict across-shore sand transport, relates to the amount of sand removed from protective beaches and dunes during storms. Beach profiles from 1999 were used to represent the shape of the beach before the effect of storms was modelled. Storm cuts were modelled at Brighton South, Brighton, the Minda dunes, Glenelg, the West Beach dunes, the Torrens Outlet (south of Breakout Creek), Tennyson, the Tennyson dunes, Semaphore Park and the

Semaphore jetty. The sand dune buffer volumes required for protection are discussed in section 4.5.1.

A sensitivity analysis of the modelling results investigated the effects of different scenarios than the ones considered most likely. Changed variables included increased wave heights during storms to reflect predictions of increased storminess because of climate change, continuing seagrass loss, and coarser sand on the beach from new beach replenishment sources.

Alongshore sand transport could be reduced by up to 30% using coarser sand to replenish the beaches, while maintaining their amenity and recreational value. The main benefit of coarser sand is that it is much more resistant to across-shore transport, and so provides a more stable buffer against storm erosion. Storm-induced erosion of the dune buffer was reduced by up to 80% if 0.5 mm sand replaced the current 0.22 mm sand. However, the effects of increased storm wave height and sea level rise of 0.5 m predicted for 2100 nearly doubles the storm-induced erosion for a given sand size. Overall, coarser sand can more than compensate for stormier weather and consequently the current emphasis is on providing coarser sand from Mount Compass to adjust for existing sand losses of around 25,000 m^3/year due to relative sea level rise.

The modelling exercise also predicted that the increase in alongshore sand transport due to larger waves would be approximately proportional to the wave height increase.

The Coastal Engineering Solutions (2004) study had many important features:

- 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.
- The modelling considered both swell waves generated by distant weather systems in the oceans south of the Australian continent and sea waves generated by local winds blowing across the open water fetches of Gulf St Vincent.
- Wave hindcasting for swell waves and for sea waves covered the period 1993 to 2002 (inclusive), thereby creating a 10-year wave database for consideration by the modelling. Severe storm events, dating back to 1948, were also identified and modelled. Hindcast wave data was combined with measured ocean levels so that real water levels were included in the various datasets used for all subsequent modelling.
- The largest offshore swell waves in the 10 years of the hindcast period occurred in May 1994 and were estimated to have a significant wave height of greater than 11 m. 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 significant wave height was about 4.5 m in the deep waters of the Gulf.
- 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 (a suite of mathematical models) was applied to replicate these processes.
- Seabed friction is an important phenomenon in the wave transformation process and the results of the transformation modelling are quite sensitive to how it is formulated. A complete 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. A sandy seabed may be either rippled or flat, and the roughness of a rippled seabed is considerably greater than 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.

- The foreshore between Kingston Park in the south and the Outer Harbor breakwater in the north was investigated at some 94 nearshore locations, each selected to be in approximately 3.0–3.5 m depth of water at mid-tide, at approximately 300 m intervals along the shoreline.
- Application of the wave transformation module determined the swell and sea wave characteristics at 3-hourly time intervals over the 10 year long wave database for each nearshore site and thus produced a comprehensive temporal and spatial representation of the nearshore wave climate affecting the metropolitan beaches.
- These 10 year wave datasets at each location were then put into a sediment transport module to determine the rates of longshore sediment movement at each of the 94 nearshore sites. Longshore sediment transport rates were determined for each site at 3-hourly intervals over the 10 years.
- The wave transformation module and the sediment transport module were applied for each of the 94 nearshore locations and for each of five nominated scenarios:
  1. present day conditions
  2. those which may have occurred 100 years ago
  3. those possibly occurring in 20 years time
  4. those possibly occurring in 50 years time
  5. those possibly occurring in 100 years time.
- Sediment is moved offshore during severe storms by the waves generated within Gulf St Vincent; swell waves do not contribute. The most severe storms in recent times, identified by considering wave hindcast data, were determined to have occurred in April 1948, April 1956, May 1960, April 1985, November 1994, September 1996 and June 1999.

Present day scenario

- The seabed was schematised using all of the latest available survey data, supplemented with recent aerial photos to define the extent of seagrass coverage.
- The contribution of sea waves and swell to net northerly longshore transport potential varies along the coast:
  1. South of West Beach, the contribution by swell is generally 10–20% greater than the contribution by sea waves.
  2. From West Beach to Semaphore Park, the contribution by sea waves is about 10% greater than by swell.
  3. From Semaphore Park to Largs Bay, the contribution by each is about equal.
  4. Between Largs Bay and North Haven, the contribution by swell waves dominates.
- The longshore sediment transport potential is about 70,000 m^3/year and is largest off Brighton, mainly due to its exposure to swell waves. This predicted rate of sediment movement out of the Brighton area is confirmed by measured changes of the beach replenishment volumes.
- Sand is recycled within the Brighton area by trucking, which allows the larger sediment transport potential to be satisfied without initiating erosion processes.

- The lowest longshore sediment transport potential occurs off West Beach where a local offshore shoal 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.
- The longshore sediment transport potential is about 60,000 m^3/year at Semaphore Park, whereas the potential to supply sand from Tennyson is only about 40,000 m^3/year. This is consistent with present-day erosion at Semaphore Park.
- Longshore sediment transport potential between the Torrens Outlet and Tennyson is fairly constant at 40,000–50,000 m^3/year.
- 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

- The distinguishing feature of the minus 100 year schematisation was the extent of seagrass coverage assumed. Given the lack of precise records, seagrass meadows were assumed to extend inshore as far as the RL –3 m (to CD) depth contour. It was also assumed that the seabed level was some 0.5–1 m higher in those areas where seagrass was then found but is not at present.
- The extent of seagrass south of Glenelg jetty was assumed to have not changed over the past 100 years.
- Other physical features that were different and included in the schematisation were:
    1. The Patawalonga was not trained.
    2. The Torrens Outlet did not exist.
    3. North Haven did not exist and the shoreline in this area was about 500 m further to the east.
    4. The Semaphore shoreline did not have a wide low dune as it does today.
- For those foreshores that had seagrass into the RL –3 m contour (that is between Glenelg North and Semaphore Park) the estimated sediment transport potential was 10–15% lower than for present day conditions.
- The presence of seagrass over the shoal and adjacent areas off West Beach ‘smoothed’ the local decrease in longshore sediment transport potential as is the case today in this area.
- 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 suspended sediments.
- Average sediment transport potential was 40,000 m^3/year for most of the coast from the Patawalonga to Semaphore Park.
- Sediment transport potential south of Glenelg would have been much the same as it is today (i.e. about 70,000 m^3/year).

Future scenarios

- 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 bypassed at Holdfast Shores and West Beach at present-day rates. The shoreline position and seabed contours were schematised to accommodate expected accretion north of Semaphore Park. It was assumed that there would be no further seagrass losses but recently depleted seabed areas inshore of the seagrass meadows would drop by up to 0.5 m over the next 100 years.
- Increases in the ocean water level (due to the greenhouse effect) were selected at 0.1 m (plus 20 years), 0.2 m (plus 50 years) and 0.5 m (plus 100 years). Sensitivity modelling was carried out in relation to increased 'storminess' that might accompany climate change.
- The increase in water level and decrease in seabed level (in those areas of former seagrass meadows) will have a significant effect on wave refraction for the longer period swell waves. Nearshore seabed contours are generally not parallel to the beach and so the angles at which swell waves arrive on the beach vary between scenarios. The variation is not steady over the time scales of future scenarios.
- Plus 20 year scenario predictions:
  1. Longshore sediment transport potential will decrease from Brighton to West Beach and from Grange to Tennyson.
  2. From West Beach to Henley Beach the longshore sediment transport potential is unchanged.
  3. Longshore sediment transport potential will increase from Tennyson to Semaphore Park and from the Semaphore jetty to North Haven.
- Plus 50 year scenario predictions:
  1. Longshore transport potentials will be similar to the Plus 20 year scenario for Brighton to West Beach.
  2. North of West Beach the sediment transport potential becomes more erratic with localised increases. The inference is that 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.
- For the Plus 100 year scenario, the modelling predicts a more erratic sediment transport potential for southern metropolitan beaches as well as for northern beaches.
- These predicted changes in sediment transport potential are due to swell waves moving sand northward and the sensitivity of nearshore wave height and direction to seabed features that lie immediately off the beach.
- Overall, average longshore sediment transport potentials do not increase for future scenarios over existing conditions – provided the extent of seagrass meadows does not change significantly.

Replenishment at Hallett Cove

- Longshore sediment transport potential at Hallett Cove is well in excess of 100,000 m^3/year.
- Assuming that the prime purpose of replenishment at Hallett Cove is to provide a sediment feed to the metropolitan beaches, while also adding the benefit of a sandy beach at Hallett Cove, the average annual replenishment rate would be 60,000 m^3. The sand would be transported northward at a rate of over 100,000 m^3/year, so 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.
- The steep nearshore seabed slopes and the deep water close to the shoreline present a significant risk of sand losses into deep water between Hallett Cove and Kingston Park.

Offshore sand movement during storms

- A model called SBEACH was used to determine the extent of offshore sediment transport during the seven severe storms since 1948. It was run for 10 locations along the shoreline between Brighton and the Semaphore jetty and found that the most severe storms occurred in April 1948, April 1956 and November 1994.
- 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 made the highest cut in the dunes at each location but the eroded sand stayed in the active beach zone because of the short duration of the storm.
- 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.
- The volume of sand eroded from the beach and dune system was generally greater for southern beaches than for northern beaches. At Brighton, the maximum predicted erosion was 40 m^3/m length of beach above 1.0 m AHD.
- At Semaphore Park the erosion volume reduced to 18 m^3/m length of beach above 1.0 m AHD; at the Semaphore jetty the predicted erosion during these severe storms was only 13 m^3/m above 1.0 m AHD.
- 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.
- For the northern beaches, the seabed approach slopes are flatter with 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

- The predominant northerly current induced by winds blowing from the south-west cannot initiate sediment movement alone but will move sand that may have been lifted into suspension by waves.
- Waves with a period of 4–5 seconds and a wave height of 1 m will cause seabed sediments to lift into suspension. A 10 knot wind can generate such waves from the south-west.
- The net quantity of sand moving northward due to tidal and wind-generated currents is estimated to be 25,000 m^3/year between Glenelg and Semaphore Park, where the loss of seagrass meadows has been significant.

Equilibrium beach angles

- *Equilibrium beach alignment* is defined as the plan alignment of the beach for which net longshore transport is zero.
- The existing beaches are not at an equilibrium alignment with the prevailing wave conditions. The difference between the existing beach alignment and equilibrium beach alignment varies from 3° to 29° over the length of the metropolitan beaches.
- 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° between Brighton and Tennyson.
- North of Tennyson, the difference increases steadily to 29° at Largs Bay. This change is attributable to the more acute angle at which breaking swell waves arrive on the foreshore.
- 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

- The sensitivity of longshore transport potential to varying sand size (median sizes of 0.5 mm and 0.8 mm) was investigated by the sediment transport module. Given the same wave conditions, approximately 20% less of 0.5 mm sized sand will be moved than 0.22 mm sand (the median grain size of naturally occurring Adelaide beach sand) and 30% less of 0.8 mm than 0.22 mm sand.
- 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 of 0.5 mm sand is only 20% of that removed from a beach of 0.22 mm sand.

Sensitivity to climate change

- Increased storminess as a consequence of climate change will have a relatively small impact on longshore sediment transport potential. The modelling suggests an increase of 10–15% for the Plus 100 year scenario (based on the assumption that storm waves increase in height by 10%).
- Increased storminess accompanied by sea level rise will have a significant effect on offshore sand motion during storms. Increasing the still-water level by 0.5 m and the storm wave heights by 10% will approximately double the quantity of sand moved offshore during a storm.

The key findings of the coastal processes study (Coastal Engineering Solutions 2004) are summarised in Figure 5.12.

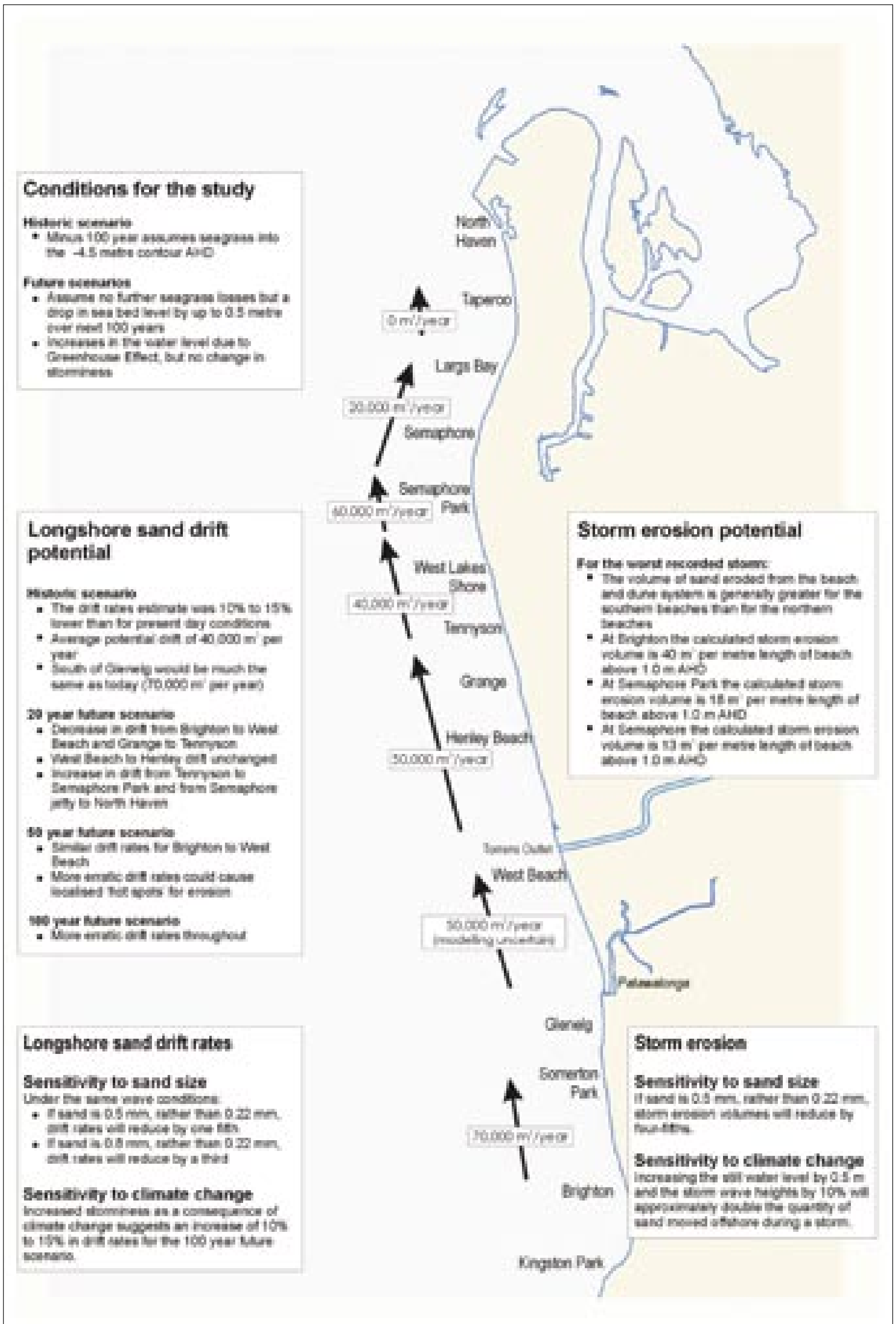
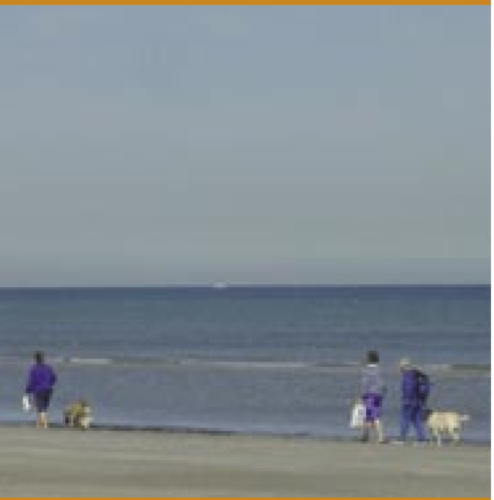


Figure 5.12 *Key findings from the coastal processes study*

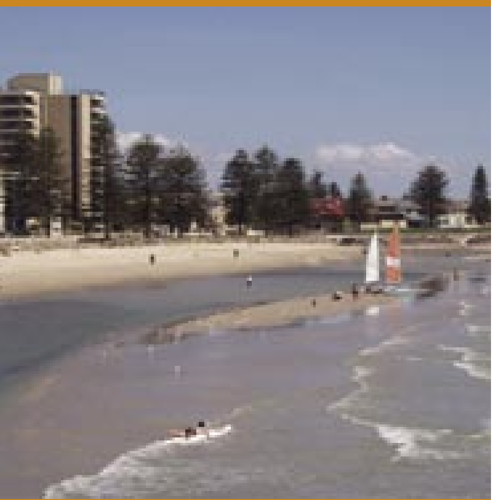
5.3 Seagrass rehabilitation studies

The Department for Environment and Heritage has initiated investigations into seagrass rehabilitation. In 2002, a workshop considered issues for seagrass rehabilitation along the Adelaide coast. Its main objectives were to explore the potential for seagrass restoration and find out how natural regeneration could be assisted as a means to ameliorate coastal erosion and restore seagrass habitat. To date, most seagrass restoration efforts worldwide have been concentrated in the USA and Western Australia, while southern Australia (South Australia, Victoria and Tasmania) have yet to test restoration despite having significant areas of seagrass loss (Seddon 2002).

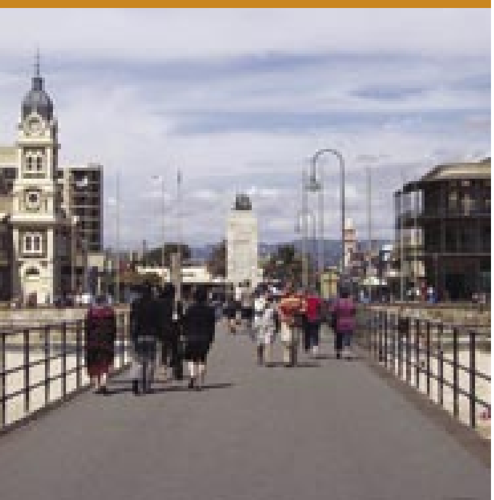
The primary factor in successful restoration is improvement of coastal water quality (see section 2.4).



Largs North



Glenelg



Glenelg jetty

Currently, laboratory and field studies on rehabilitation techniques in conjunction with the South Australian Research and Development Institute (SARDI) are in their second year and producing encouraging results. Most successful is the use of hessian material to boost natural recruitment of *Amphibolis antarctica* juveniles. Trial sites are located at Henley Beach and Tennyson. Seedlings are being monitored for survival and growth. If the trials prove successful, then artificial stabilisation of the seabed to assist seagrass regrowth could be contemplated.

New seagrass meadows would provide habitat and protect marine life, which could restore a substantial ecology that has been lost off the Adelaide coast. However, it would be many centuries before seabed levels are restored by this means. Therefore, the exacerbated foreshore erosion due to seagrass loss will only partially be reduced. This reduction would be due solely to the increase in seabed friction on wave energy from the seagrass meadows.

Where seagrass cover has been lost, tidal plus wind-generated currents can move a net 6000–30,000 m^3 of sand per year northward (in water depths of less than 6 m). This is in addition to wave-generated longshore drift.

5.4 Economic value of Adelaide's beaches

5.4.1 Property and beach amenity value

Studies have quantified the value of beaches to foreshore property owners and the public (Table 5.3; Evans & Burgan 1993; Burgan 2003). Records of historic storm damage give an indication of the value of beaches to protect not only houses but also foreshore infrastructure including roads, services and public amenities. These values would be lost or significantly reduced where beaches are not prevented from drifting away.

Table 5.3 *Results of beach value study (Burgan 2003)*

Value of beaches to properties with beach access	$5 million per year
Value of beaches to properties in walking distance	$16 million per year
Value of beaches to day visitors	$23 million per year
Value of beaches to public finance (higher levels of council rates, stamp duty on property transfers and emergency services levy)	$2 million per year
Total value of beaches to properties and general public	**$46 million per year**

A 2003 survey by McGregor Tan Research put beach visitation at around 9 million visits per year, of which half are from the population outside of Adelaide's coastal suburbs. In comparison, around 1 million people visit the Adelaide Botanic Gardens each year and around 3 million people visit national parks in South Australia each year. Based on annual operating costs of $6.2 million for the existing management strategy (see section 7.1.2), the cost of providing beach amenity is estimated at less than $1 per visit. In comparison, based on annual operating costs of $2.5 million for the Adelaide Botanic Gardens, the cost of providing garden amenity is estimated at $2.50 per visit.

5.4.2 Storm protection value

The value of beaches for storm protection is difficult to quantify but can be estimated from the reduction in damage costs incurred.

The present-day value of storm damage costs pre-1973 has been estimated as $85 million or approximately $1.8 million per year since 1930 when most of the coast became developed. The present-day value of storm damage since 1973 has been estimated as $1.5 million, or about $100,000/year since beach replenishment began. Therefore, long-term average benefits of the beach in terms of protection of foreshore infrastructure are in the order of $1.7 million/year.

Another measure of storm protection value is the assets along the coast at risk within 10 m of the dune or seawall, such as footpaths, roads and services. These have been valued at $66 million (based on an assessment of $28 million in 1983 dollars from Kinhill Stearns and Reidel and Byrne (1983) and increased by twice CPI, as these type of assets have increased at a far greater rate than CPI). These assets could be lost within a 50-year period without intervention (i.e. a damage cost of $1.3 million/year). This estimate excludes private properties in vulnerable locations and other foreshore structures, such as ramps, surf life saving clubrooms, kiosks and cafes, located within the likely damage zone; it also excludes the inconvenience caused to foreshore residents and businesses when access to properties is not available.

5.5 Activities and views of beach users

In 2003, the Department for Environment and Heritage commissioned a study (McGregor Tan Research 2003) to determine:

- how the community uses the beach
- the value of particular beach attributes
- attitudes towards different beach management strategies.

Data was collected from focus groups, telephone surveys and face-to-face interviews.

Focus groups

Between 17 and 20 February 2003, eight focus groups were held, each comprising 8–10 participants who were:

- beach users involved in less organised activities, e.g. swimming and walking
- beach users involved in more organised activities, e.g. windsurfing and sailing
- members of the public not necessarily current beach users as such, but having an opinion on the preservation of Adelaide beaches as a public amenity
- beachside residents
- traders and businesses dependent on beach traffic, including two beach activity operators (windsurfing and adventure activities), two accommodation establishments (a caravan park and a motor inn with restaurant), and a boat charter operator
- members of beachside councils (included representatives from the Cities of Onkaparinga, Port Adelaide Enfield, Holdfast Bay, Charles Sturt and West Torrens)
- members of environmental and community groups.

Telephone surveys

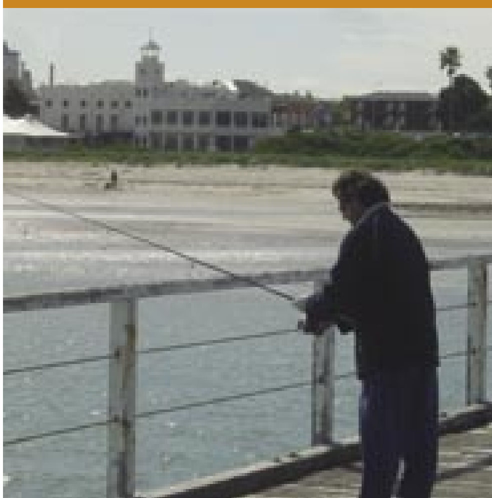
Between 5 and 11 March 2003, 501 telephone surveys were conducted with a random sample of metropolitan Adelaide residents.

Face-to-face interviews

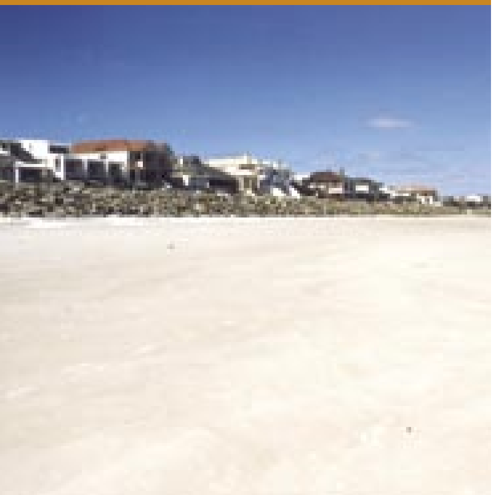
Between 12 and 16 March 2003, 502 face-to-face interviews were conducted with beach users at metropolitan Adelaide beaches.

Mother and daughter playing near Brighton jetty

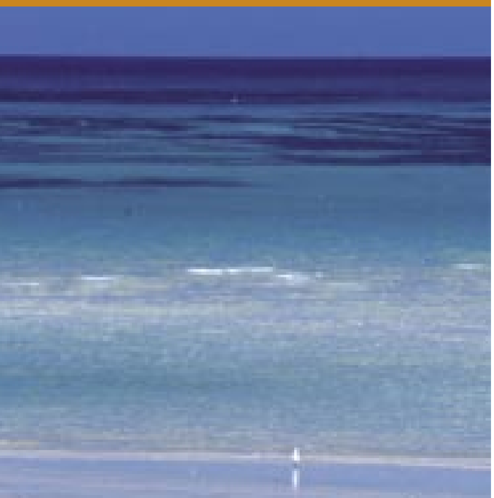
Broadway kiosk



Semaphore jetty



Henley Beach



Brighton

Largs Bay

5.5.1 Types of beach use

Adelaide residents make an average of 5.1 visits to the beach during the three months of summer and 7.4 visits during the rest of the year. Allowing for some unavoidable sampling bias towards those who visit more frequently, total beach visitation over the year is approximately 9.2 million visits.

Participants articulated a variety of beach uses including (in order of priority):

- walking
- swimming
- relaxing/sitting
- walking on the jetty
- going to restaurants and cafes
- taking the kids to play
- walking the dog
- fishing.

Participants with an environmental interest were more likely to be examining aspects such as storm damage, wave action, state of the sand dunes and level of vegetation.

5.5.2 Valued beach attributes

All respondents to the telephone (general community) and face-to-face (beach user) surveys were asked what they wanted at metropolitan beaches in terms of the natural state of the beach and/or facilities (Table 5.4).

Table 5.4 *Valued beach attributes*

What do you want at metropolitan beaches in terms of the natural state of the beach and/or facilities?	Percentage of respondents (%)	
	General community	Beach users
Clean beach/litter free	43	41
Sand: Total Sandy beach Good quality sand Sand dunes	37 23 15 10	27 17 10 6
Toilets	28	33
Shops/kiosk	22	11
Clean ocean	20	19
Shade	13	15
Family place/safety/lifesavers	12	8
Car parking	11	8
Showers	8	10
Grassed area(s)	7	7
Not crowded	7	6
Seating	5	3
Direct access	4	5
Nice view	5	3
Drinking water taps	4	6
Natural vegetation	4	3
Dog walking allowed	4	6
Keep as natural as possible	4	8
Dog free zone/dog control/dogs on leashes	3	5

All respondents were also read a list of aspects of metropolitan Adelaide beaches and asked to indicate which were important to them.

As Figure 5.13 shows, a clean beach, a clean ocean and having sandy beaches were considered valuable by a large proportion of respondents.

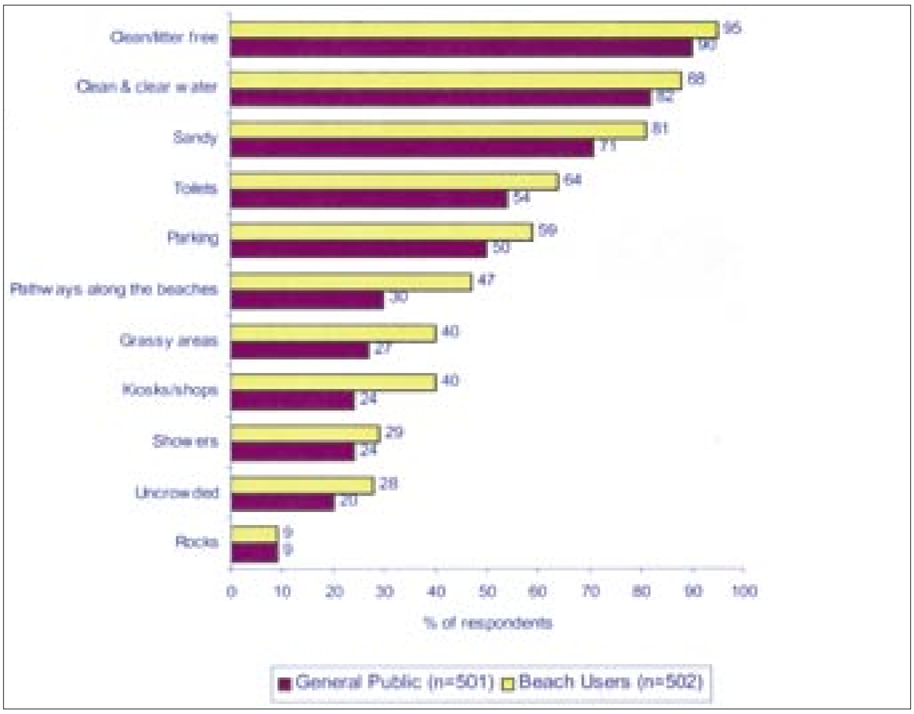


Figure 5.13 *Beach attributes considered valuable by the general public and beach users*

5.5.3 Level of support for beach management methods

Most study participants who visited the beach frequently were aware that there was some form of management of Adelaide's metropolitan beaches. Those with less affinity for the beach were less aware, with some unsure of what 'beach management' actually meant. Some participants interpreted 'beach management' as rubbish and litter control or revegetation programs, and did not spontaneously mention any beach management practices concerning sand. Knowledge of who manages metropolitan beaches was generally low, as was understanding of the history of beach management. Most community group participants seemed to have particularly poor knowledge of the history of beach management.

Figure 5.14 represents the level of support or opposition for different beach management methods, based on the results of the telephone survey.

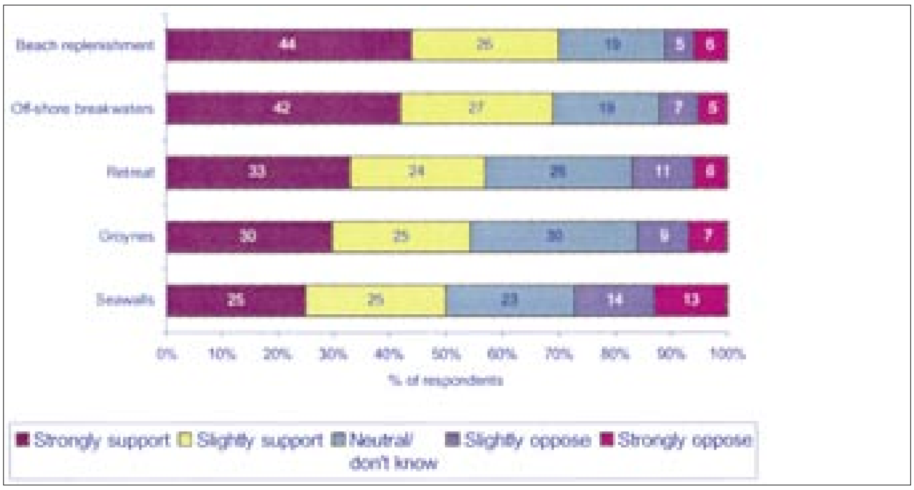
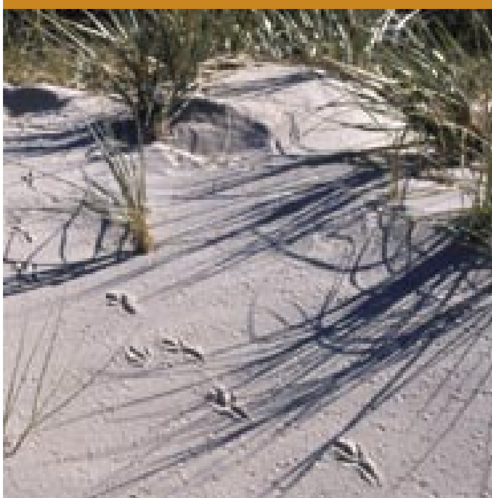


Figure 5.14 *Level of support/opposition for various beach management methods (Retreat: removing houses or other structures and services immediately threatened by beach erosion)*

See section 8.6 for a summary of the community's views on beach management.

Semaphore

Largs North



Tennyson

6. The Future Management Strategy

The Coast Protection Board has been managing Adelaide's beaches for over 30 years in response to sand eroding and moving north along the coast. The main management actions under the current strategy have been to replenish beaches with sand taken from offshore, other metropolitan beaches or elsewhere, and to build seawalls as a last line of defence (see chapter 4). Had this strategy not been implemented, many of Adelaide's southern metropolitan beaches would now be devoid of sand.

Even so, the Coast Protection Board recognises the need to improve sand recycling methods, particularly to reduce the number of trucks carting sand along the beach. Moreover, following a major program of offshore dredging at Port Stanvac in the 1990s, local sand supplies have diminished and the cost of importing sand from elsewhere has escalated to the point that other management options have had to be initiated. A trial breakwater has been built at Semaphore South to slow sand movement and protect the coastline to its south. So far, this has proved to be successful for managing localised beach erosion.

Another recent development affecting beach management is the construction of Holdfast Shores at Glenelg and Adelaide Shores at West Beach (referred to generally as the Glenelg and West Beach harbours), which have markedly changed the metropolitan coastline and interrupted much of the alongshore movement of sand. Bypassing of significant quantities of sand at these locations is now required.

In 2000, on behalf of the Coast Protection Board, the Department for Environment and Heritage initiated a review of the management of Adelaide's metropolitan beaches to address these issues. *Adelaide's Living Beaches: A Strategy for 2005–2025* is the culmination of that review, which examined a range of alternative approaches, and a series of modelling and feasibility studies (chapter 5), and has had input from the community (chapter 7).

6.1 Coast protection alternatives

Approaches to sand management on the Adelaide coast are inherently linked to coast protection alternatives. A range of them has been examined in previous studies (see chapter 3). Such alternatives are reconsidered here in light of the recent changes to the coast and the results of updated coastal process modelling data commissioned by the Board during the review. Fusion approaches are also considered.

Alternative management strategies

Match sand movement

1. ***Maintain current strategy:*** **Maintain the current sand management activities, i.e. beach replenishment and harbour bypassing (including carting and dredging of sand), to not only match the rate of littoral drift but also slowly build up dune buffers in critical areas.**
2. ***Reduced level of beach replenishment:*** **Maintain sand management activities, but reduce the level of beach replenishment to 'just match' the rate of littoral drift.**
3. ***Major replenishment:*** **Undertake a large replenishment program that will make further replenishment unnecessary for 20 years.**
4. ***Recycle sand:*** **Install pipelines and pumping systems to pump sand that accumulates on northern beaches back to southern beaches.**

Retreat or no replenishment

5. ***Retreat:*** **Relocate, 'buy back' or rezone foreshore development allowing the shoreline to recede as a result of erosion, i.e. no replenishment, no new seawalls, and gradual removal of existing seawalls as they are undermined by erosion.**

Slow sand movement

6. ***Groynes with replenishment:*** **Construct a groyne field along the coast to minimise net littoral drift, and replenish the beaches between groynes as required.**
7. ***Offshore breakwaters with replenishment:*** **Construct a field of offshore breakwaters along the coast to minimise net littoral drift, and replenish the beaches in the lee of the breakwaters as required.**
8. ***Hybrid field of structures:*** **Construct a field of groynes and offshore breakwaters, tailored to local coastal values and uses, and replenish the beaches along the field as required.**
9. ***Use coarser sand:*** **Replenish the beach with coarser sand, which drifts less under Adelaide's wave conditions.**

Fusion approaches

10. ***Sand recycling and/or replenishment combined with structures:*** **A combination of approaches, managing sections of the coast with sand recycling and/or minor replenishment and sections of the coast with structures.**
11. ***Sand recycling combined with structures and replenishment with coarse sand:*** **A combination of approaches, managing sections of the coast with sand recycling and sections of the coast with structures, but also adding coarse sand from external sources.**

Other approaches

12. ***Seawalls:*** **Protect foreshore development from erosion when and as needed by constructing seawalls.**
13. ***Do nothing:*** **No further sand management or coast protection works. Remove seawalls, roads, pipelines, other infrastructure and houses when damaged by erosion.**

6.1.1 Evaluation of alternative strategies

During the review, the Department for Environment and Heritage evaluated the alternative strategies as follows:

1. *Maintain current strategy:* This alternative is practical, maintains sand on the beaches, builds up dune buffers and provides additional sand to compensate for sand loss as a result of relative sea level rise. However, the cost of coastal management under the existing strategy is continually increasing.
2. *Reduced level of beach replenishment:* This alternative would not build up dune buffers nor provide additional sand to compensate for sand loss as a result of relative sea level rise. Consequently, there would gradually be less and less sand on beaches affected by erosion. Maintaining sand on the beaches is important to the community for both social and economic reasons, so this alternative is unacceptable.
3. *Major replenishment:* The environmental and social impacts of this alternative are unacceptable. Nearshore seagrass would be buried under replenishment sand, stormwater outfalls would become clogged with sand, and beaches would initially be very wide and subject to high levels of sand drift. Furthermore, the replenishment rates necessary to undertake such a major replenishment could only be achieved by dredge, and no suitable offshore sand sources have been identified that are economically viable at present.
4. *Recycle sand:* This alternative is not feasible on its own, because sand accumulating on the beaches north of Semaphore is mostly fine and calcareous and therefore unsuitable for replenishment of the southern beaches. Nevertheless, the concept of a pipeline to recycle sand is valid and is considered under alternative 11.
5. *Retreat:* This alternative would unlock impounded sand within the dunes and maintain beach amenity. However, the cost for purchasing properties alone would be prohibitive, let alone the cost of replacing and modifying public infrastructure such as roads, water and sewerage systems. Assessment of the cost of properties and equating this to the volume of sand released indicates a cost in the order of $400 per cubic metre, which is more than 10 times the current cost of sourcing all sand from Mount Compass. In some areas, sub-surface clay could be exposed, thus reducing beach amenity. In addition, it would be very difficult for retreat to be achieved in a manner that was fair to coastal residents. This alternative is therefore not feasible.
6. *Groynes with replenishment:* This alternative would require an extra 2 million m^3 of sand from external sources than would a beach without structures, and is therefore very expensive. Once constructed, a groyne field could not be adjusted to cater for ongoing sea level changes or managed for seasonal or longer-term variations in wave conditions, other than by adding or removing sand. A groyne field would also interfere with the coastal landscape and limit pedestrian access along sections of the beach. This alternative was costed during the review but has been dismissed because of the social impacts and high ongoing capital cost involved.
7. *Offshore breakwaters with replenishment:* This alternative is similar to alternative 6, but with higher construction costs offsetting a relative advantage in terms of continued pedestrian access along the coast. This alternative has been dismissed for similar reasons as alternative 6.
8. *Hybrid field of structures:* This alternative has been dismissed for similar reasons as alternative 6.
9. *Use coarser sand:* This alternative could not by itself prevent erosion of Adelaide's beaches. The large-scale replacement of the vast quantity of sand on the beaches is not feasible, even were a sand source of this size available. Furthermore, littoral drift would continue to occur at substantial levels, requiring ongoing recycling and replenishment. The use of coarse sand is therefore best combined with other methods, as considered under alternative 11.

10. *Sand recycling and/or replenishment combined with structures:* This alternative is a combination of the best aspects of alternatives 4 and 8. While this alternative is feasible, it is less effective than alternative 11, and of a similar or slightly greater cost.

11. *Sand recycling combined with structures and replenishment with coarse sand:* This alternative draws on the best aspects of alternatives 4, 8 and 9. It is more effective than alternative 10 because it incorporates the use of external sand sources to counter the ongoing loss of dune volume and beach width caused by sea level rise and other factors. This alternative forms the basis of the strategy for 2005–2025.

12. *Seawalls:* This alternative would quickly result in the loss of sand from beaches if not combined with beach replenishment. Maintaining sand on Adelaide's beaches is important to the community for both social and economic reasons, so this alternative is unacceptable on its own. However, seawalls are important as the last line of defence against storms, so their continued maintenance has been included in the strategy for 2005–2025.

13. *Do nothing:* This alternative would quickly result in the loss of sand from beaches and progressive damage to foreshore infrastructure and buildings. The cost due to loss of beach value alone would be very high, with further costs incurred for the management of subsequent debris and pollution. This alternative is therefore not feasible.

6.2 Components of the future management strategy

Adelaide's Living Beaches: A Strategy for 2005–2025 (summarised in Figure 6.1) is based on alternative 11 (see above). When compared to the other alternatives (see this chapter and section 7.1), the strategy clearly provides a more efficient and cost-effective method of managing the Adelaide beach system, including harbour management. In addition, it can be adapted to meet changing climatic conditions and will reduce the impact of beach replenishment activities on beach users and coastal residents.

Adelaide's Living Beaches: A Strategy for 2005–2025

1. ***Continue beach replenishment* – Continue the existing program of beach replenishment, placing 160,000 m^3 of sand each year at strategic locations on southern and central beaches to maintain the sandy foreshore, build up dune buffers, and protect coastal infrastructure.**

2. ***Recycle sand more effectively using sand slurry pumping and pipelines* – Existing sand supplies will be recycled more effectively using sand slurry pumping and pipelines, which will minimise the need for trucks to cart sand along beaches and suburban roads.**

3. ***Add coarse sand from external sources* – Coarser, more stable sand will be added to the system from external sources such as Mount Compass to tackle the ongoing loss of dune volume and beach width caused by sea level rise and other factors.**

4. ***Build coastal structures in critical locations* – Structures such as groynes and offshore breakwaters may be used in a few critical locations to slow the northerly drift of sand.**

5. ***Integrate sand bypassing at harbours with beach management* – Integrating sand bypassing requirements at harbours with the beach replenishment program will result in more effective recycling of sand and reduced harbour management costs.**

Semaphore Park, 1999

Semaphore Park, 2004

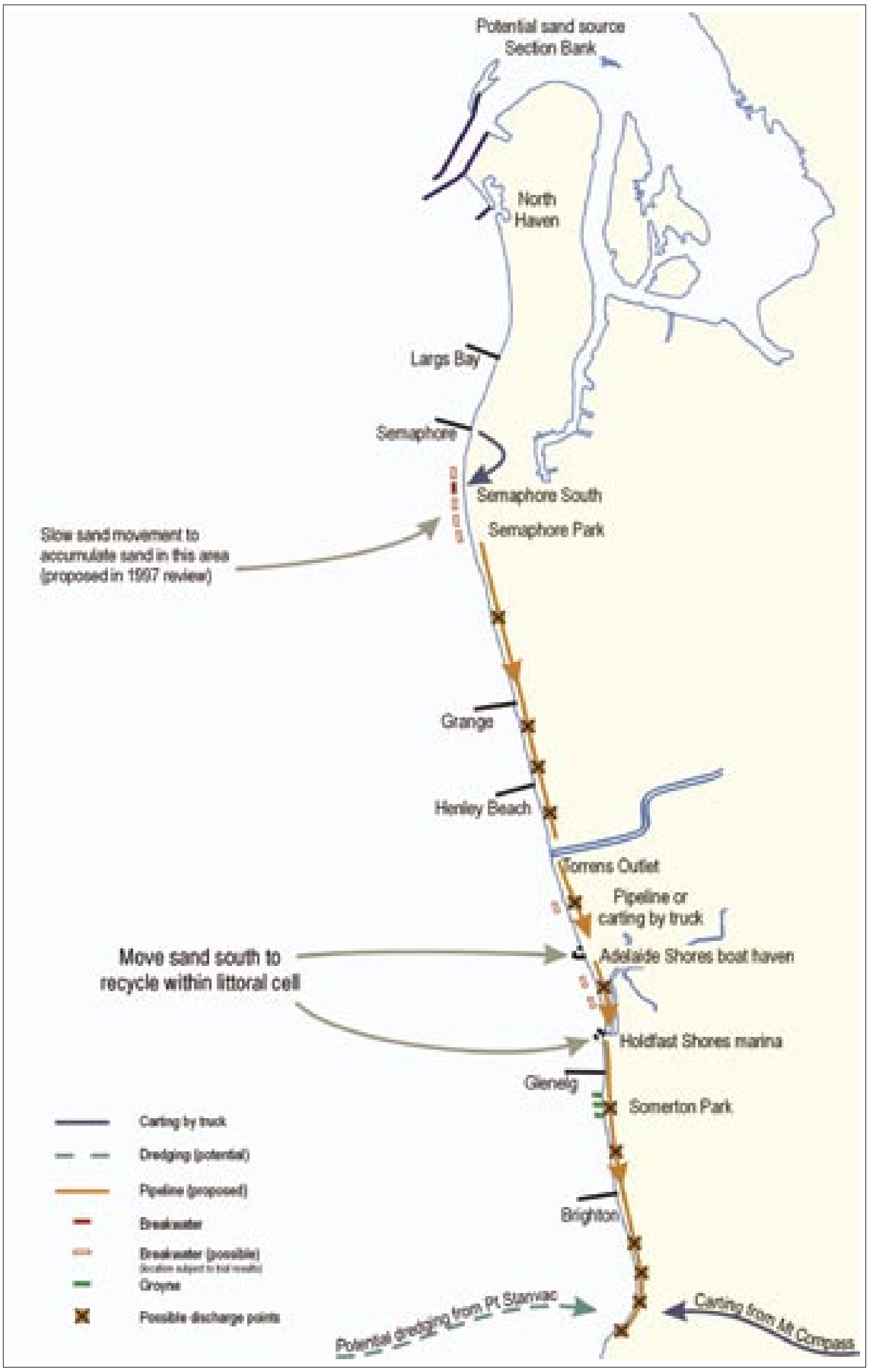


Figure 6.1 *Summary of Adelaide's Living Beaches: A Strategy for 2005–2025*

6.3 Continue beach replenishment

6.3.1 The importance of beach replenishment

Littoral drift along the eastern shores of Gulf St Vincent has moved sand over thousands of years in a net northward direction from southern beaches to northern beaches. Since the 1970s, the Coast Protection Board has replenished Adelaide's southern beaches on an ongoing basis to counter natural sand loss, while sand has built up at the Torrens Outlet, Semaphore, Largs Bay and North Haven. Beaches centrally located along Adelaide's coastline, including Glenelg North, Tennyson and Semaphore Park, have also periodically required replenishment following storms.

It is worth imagining how Adelaide's beaches would have looked if it were not for beach replenishment. The southern beaches would have little to no sand but instead would have eroded down to underlying calcrete, clay and cobblestones. Numerous developments along the coast would have been damaged or destroyed by larger waves reaching the shoreline. The coastline would have many more seawalls or groynes disrupting the mainly continuous beaches we have at present.

Along some of the northern beaches, wider, shallower beaches would have locked up sand in extensive low-lying dunes with coastal infrastructure some distance away.

Such dune systems are already present along Adelaide's northern beaches. In less than a century, over 100 m of sand dunes have formed around the Semaphore jetty (mostly since 1970). Sufficient sand has been deposited along the Lefevre Peninsula and Largs Bay seabed to establish the Gulf Point marina and North Haven residential area.

Had the sand dunes not been built on and erosion allowed to occur unimpeded, the coast would have slowly adjusted itself towards the prevailing wave direction. Consequently, over thousands of years, the coast would have receded in the south towards Brighton Road and accreted in the north near Wonga Shoal. Evidence of the dunes in the southern areas having been much further seaward of their present position is seen in the mangrove roots and mud occasionally exposed at the Broadway, Glenelg, dated about 4000 years ago, which probably were an estuarine backwater behind the coastal dunes.

6.3.2 Future sand recycling sources

Semaphore, the Torrens Outlet and Glenelg are locations within the metropolitan littoral cell where sand reserves with suitable grain size have been accessed to replenish eroding sections of the coast further south (Figure 4.1; Table 4.2).

Groynes and seawall in Sheringham, UK (Bedford High School)

Groynes and seawall in Florida, USA (US Geological Survey)

Build-up of dunes at Largs Bay

Build-up of dunes at Taperoo

Required sand dune buffers

Sand dune buffers are required to protect coastal infrastructure from damage during severe storms. The Department for Environment and Heritage currently seeks to maintain 80 m^3 of sand per metre of shoreline above a level of 1.0 m AHD. This quantity, known as a design dune buffer, was established as twice the largest measured amount of storm erosion on the Adelaide coast (Coastal Management Section 1995).

As part of the current review, a modelling study was commissioned to assess the suitability of this design dune buffer for likely future conditions along the coast. The study, by Coastal Engineering Solutions Pty Ltd (Coastal Engineering Solutions 2004), simulated how a number of local beaches between Brighton and Semaphore would respond to eight of the more severe storms that have occurred since 1948 (see section 5.2.3). For the purposes of modelling beach response, the beach profile surveyed at each site in 1999 was selected to represent the beach before the onset of each storm. The results of this modelling study (Table 6.1) show the maximum storm erosion above 1.0 m AHD that could be expected at each location as a result of these historic storms. In the majority of cases, the 1956 storm was expected to cause the greatest volume of sand to be eroded.

Table 6.1 *Summary of modelled maximum storm erosion above 1.0 m AHD expected at each location as a result of eight of the more severe storms that have occurred since 1948*

Location	Maximum erosion per metre of shoreline
Brighton South	28 m^3/m
Brighton	40 m^3/m
Minda dunes	33 m^3/m
Glenelg	33 m^3/m
West Beach dunes	35 m^3/m
Tennyson	23 m^3/m
Tennyson dunes	20 m^3/m
Semaphore Park	18 m^3/m
Semaphore jetty	13 m^3/m

The modelling showed the erosion potential for all locations to be substantially less than the design dune buffer volume of 80 m^3/m. This indicates that the design dune buffer volume remains an acceptable target and does not require modification.

It is noted that about half the metropolitan coastline is protected by seawalls, and dune buffers for these locations are not as critical as for unprotected stretches of the coast. As sea level rises relative to land levels, additional sand will be needed to build up the beach and maintain dune buffers. It has been estimated that 25,000 m^3 of sand will be needed annually to achieve this.

Semaphore–Largs Bay sand dunes

The wave climate and thus the longshore drift rate decline progressively in Largs Bay (the water body between Point Malcolm and Outer Harbor) from south to north (see Figure 1.6). This has the effect of sorting the sand that drifts in from the south, with the coarser sand dropping out of suspension in the water at the southern parts of the bay, and the finer material continuing north until the waves are too small to carry it further. The end result is that the coarser fraction of the sand, which is suitable for replenishment purposes, collects on the beach at Semaphore (Figure 6.2a), whereas the remaining sand, which is too fine and carbonate-rich for beach replenishment purposes, drifts north to Largs Bay, Largs North, Taperoo and North Haven.

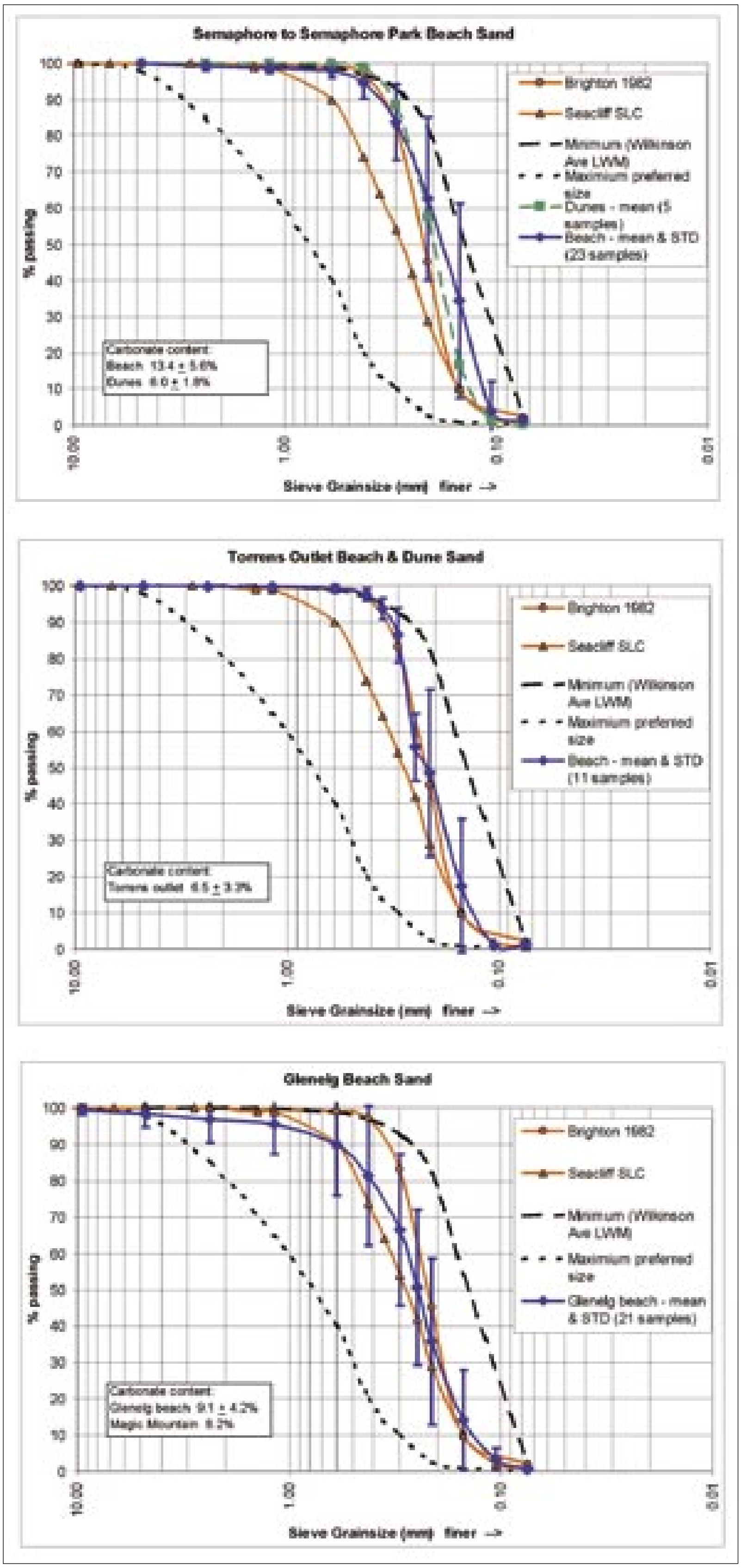


Figure 6.2 *Grain size analyses for recycled sand sources (a) Semaphore (b) Torrens Outlet (c) Glenelg (Holdfast Shores)*

Build-up of sand at the Semaphore jetty

Build-up of sand north of the Semaphore jetty

Build-up of sand at the Torrens Outlet, 1994

In the past 30 years, over 700,000 m^3 of sand has been taken from Semaphore beach, from both south and north of the Semaphore jetty. This sand has been trucked along local and major roads to beaches such as Brighton and Seacliff. In recent years, the sand has been carted along the beach to replenish the eroding foreshore at nearby Semaphore Park.

In 2004, 120,000 m^3 of sand was carted from Semaphore beach to pre-fill the salient at the trial breakwater site at Semaphore South. This was expected to cause a dune recession of 30–50 m, or approximately the volume of sand that had built up in the area over the last 10 years. In the 12 months since the work was completed, dune recession has been measured at only 3–5 m, possibly due to the relatively mild winter, with sand being moved inshore rather than from the dune to readjust the beach shape.

While Semaphore beach continues to build and impound sand in the dune system, this area will, by necessity, be considered as a source for replenishment sand, as long as sufficient dune volume and width is maintained to provide for protection against two 1-in-100-year average return interval storms.

The Torrens Outlet

Sand trapped by the Torrens Outlet is regularly bypassed to replenish beaches to the north. This sand was used solely to replenish Henley Beach South from 1991 to 2002, but recent carting programs have also taken it to West Beach, Brighton and Seacliff. This will continue in the near future. Sand from the Torrens Outlet is similar to sand on the southern beaches (Figure 6.2b).

As part of the strategy for 2005–2025, the dunes at the Torrens Outlet will be drawn down to allow approximately 250,000 m^3 of sand to be redistributed while maintaining a dune volume and width that provides for protection against two 1-in-100-year average return interval storms (Figure 6.3).

Glenelg (Holdfast Shores)

The sand from the beach in front of Holdfast Shores is similar to sand at Brighton and Seacliff (Figure 6.2c). For a discussion of future sand recycling from Holdfast Shores, see section 6.7.

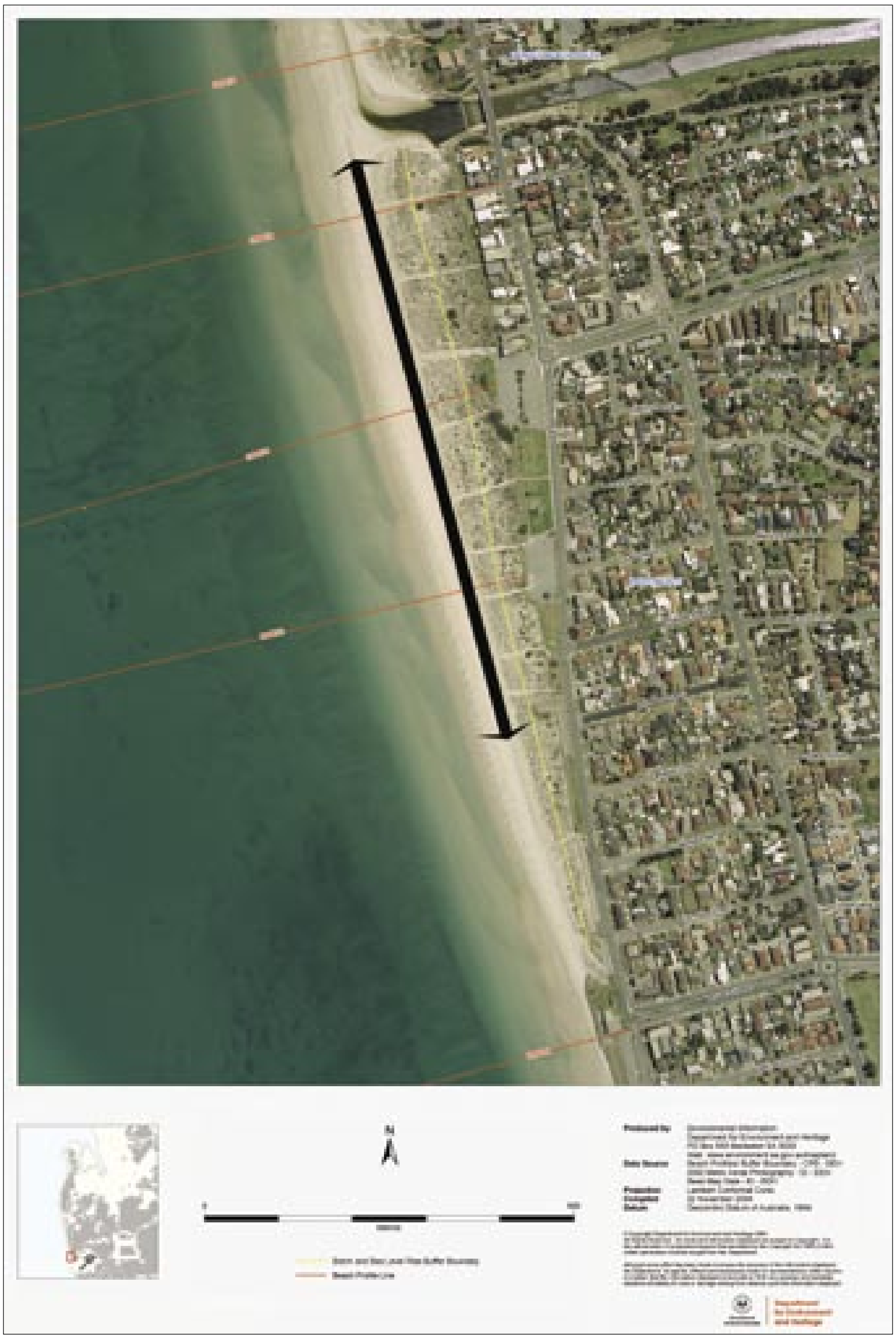


***Figure 6.3** Expected residual dune width near the Torrens Outlet as a result of the five-year sand recycling program (2004–05 to 2008–09). The black line indicates the length of the beach from which sand may be removed during the five-year program. The yellow line indicates the extent of the dunes that may be progressively eroded by subsequent storms.*

Pipeline booster station operating at Noosa, Queensland (SlurrySystems)

6.4 Recycle sand more effectively using sand slurry pumping and pipelines

6.4.1 Pipeline transfer system

Sand slurry pipelines are an effective way to move granular material, such as beach sand, long distances with minimal operational costs. Pipelines are already being used at a number of areas around Australia to recycle beach sand and to bypass harbours. The most notable of these locations are the Tweed River (New South Wales), the Nerang River (Queensland), the Dawesville and Mandurah inlets (Western Australia), Lakes Entrance (Victoria) and the Port of Portland (Victoria).

Adelaide's Living Beaches: A Strategy for 2005–2025 involves dividing the Adelaide metropolitan coastline into a series of management cells and using pipeline transfer systems to recycle or backpass sand from north to south within some of these cells. The following pipelines could be constructed:

- a 6.5 km pipeline from south of the Glenelg harbour to Kingston Park
- a 1.5 km pipeline from south of the West Beach harbour to Glenelg North
- a 1.5 km pipeline from south of the Torrens Outlet to the West Beach dunes
- a 9.5 km pipeline from West Lakes Shore to Henley Beach South.

Each pipeline system would consist of a sand acquisition system, a polyethylene pipe of about 300 mm diameter and a number of slurry booster pumping stations, one for each 2.2 km length of pipeline. The stations are typically housed in a shipping container insulated to reduce noise emissions. A series of outlets would allow sand to be discharged to where it is most needed.

The capacity of the pumping and pipeline system must be sufficient to move larger than average annual sand drifts to take into account variations in weather between seasons and years. The systems considered in the strategy have sufficient capacity to easily achieve this, with an average operating time of around 50 to 80 days per year.

Placement of the pipelines and booster stations would be designed to fit with the level of development along the coast. In the areas of existing dune systems the pipeline and booster stations would be installed along the rear of the dunes; in areas of seawalls and no dunes the pipeline and booster stations would be installed into the existing seawall protection.

The medium- or high-density polyethylene pipe would typically have a life of at least 20 years. In areas where installations are difficult to replace, a sleeve pipe, culvert or steel pipe with a polyurethane lining could be used.

The sand acquisition system removes sand from the beach, mixes it with seawater to form a slurry mixture and pumps this slurry into the pipelines. Two options for trials of sand acquisition systems have been identified, the Sand Shifter and the Slurrytrak.

Both systems have the advantage over conventional dredging techniques of controlling the pumped sand slurry to a more consistent density, and separating seagrass and other material through a screening process. This allows the discharge to be placed directly onto the beach, and is anticipated to result in less nuisance odours, deleterious matter and turbidity than conventional dredging. In addition, the sand volume can be more reliably measured by devices such as magnetic flow and nuclear density metering than it can with conventional dredging.

Each system has advantages over the other, with the Sand Shifter having better noise control while the Slurrytrak has better manoeuvrability.

While these proprietary systems have been identified for trials and used for costing purposes, the Department for Environment and Heritage will ensure open tendering for any permanent installations.

6.4.2 Sand acquisition systems

Sand Shifter system

The Sand Shifter system is currently being used to dredge and move sand along beaches and across inlets at the Port of Portland and Lakes Entrance, Victoria, and Noosa, Queensland.

The innovative system, developed and patented by SlurrySystems Pty Ltd, operates underneath the beach and moves sand by fluidising the bed and pumping out the slurry mixture. Figure 6.4 provides a conceptual view of how the system operates.

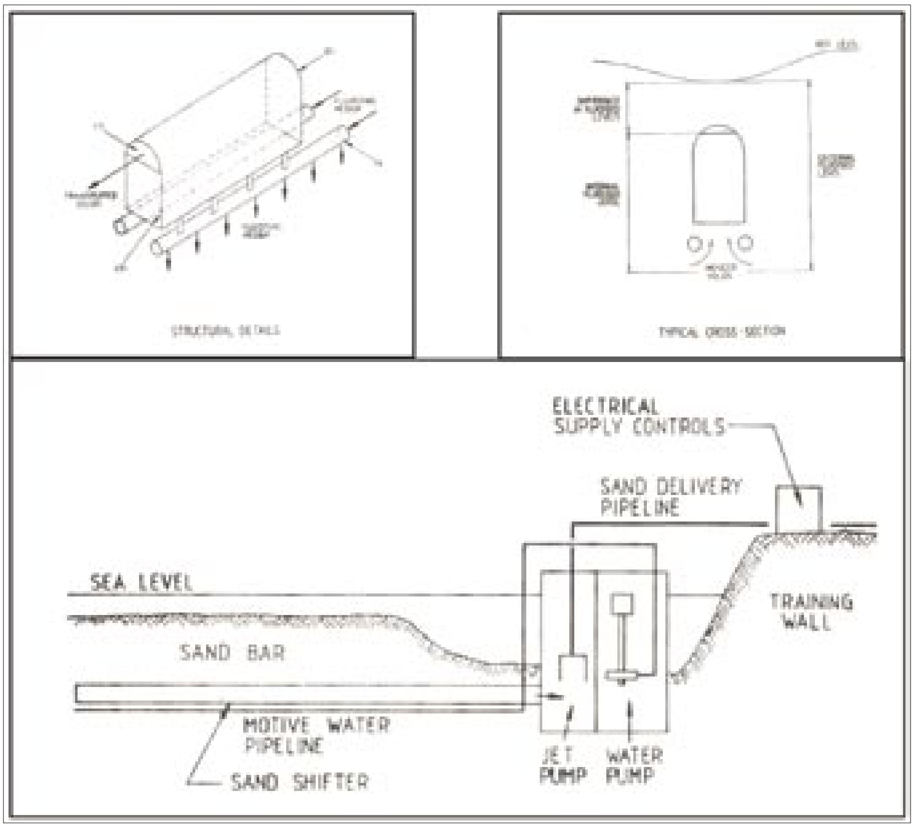


Figure 6.4 *Conceptual view of the Sand Shifter system (Patterson, Britton & Partners 1996)*

Sand Shifter system prior to burial (SlurrySystems)

Slurrytrak system in operation at the Dawesville and Mandurah Inlets, Western Australia (CGC Dredging)

Sand Shifter units comprise an inverted U steel shell typically 500 mm deep, 100 mm wide and 18 m long. Directly underneath the upturned U-section, a diffuser pipe has downward facing water jets placed at regular intervals. High-pressure water emitted from these jets fluidises the bed and allows the sand to flow like a liquid. Pressure is lower inside the U-section than outside, which causes the fluidised sand to flow into the Sand Shifter under gravity. A pump removes sand from one end of the sand system and transfers it to the screening and pipeline transfer system.

By removing sand under the beach, the unit causes a depression or a hole approximately 20 m x 40 m x 6 m to be formed on the surface of the sand directly above it. Sand moving along the coast is trapped and collected within this depression. Each time the depression is re-filled with sand, pumping would restart.

The Sand Shifter can be deployed from a barge to be operated in much the same way as a dredge. It does have an advantage over a dredge used in this manner: it can be used in higher wave environments because the suction unit is not rigidly connected to the floating plant.

Slurrytrak system

The Slurrytrak system is a mobile land-based screening and pumping plant designed and constructed by the Cooper Group of Companies. The system is currently being used to bypass sand at Dawesville and Mandurah in Western Australia.

Beach sand is loaded into the top of the Slurrytrak using an excavator and then screened, mixed with water to form a sand slurry mixture, and transferred to a pipeline by an on-board pumping plant. The system is highly mobile and can be moved along the beach to areas where access to the sand is required. To transfer the sand along the coast, the system is attached to the pipeline transfer system (see section 6.4.1).

It is anticipated that only one Slurrytrak system would be hired and moved to different areas along the metropolitan coast as needed.

6.5 Add coarse sand from external sources

There remains some sand offshore from Port Stanvac, and the Section Bank holds a large reserve of sand. However, due to practical constraints and the uncertainty of environmental impacts, these sources are unsuitable in the near future (see section 5.1.2). The Coast Protection Board has therefore been reassessing sand within the littoral cell (see section 6.3.2) and inland sources (see section 5.1.3) for future beach replenishment.

The Mineral Resources group of PIRSA has identified large potential resources of Permian sand in the Mount Compass area (Figure 6.5), some of which have been estimated from drill hole intersections to be several million cubic metres in volume, or enough for hundreds of years' supply at current beach replenishment rates. The sand in selected deposits is slightly coarser than existing beach sand and light brown to white in colour, with a variable but generally low fines content. These characteristics make it desirable beach replenishment sand.

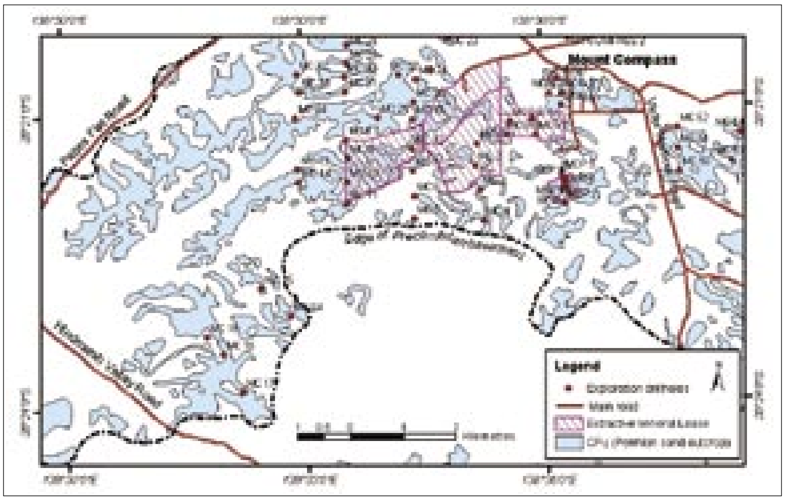


Figure 6.5 *Mount Compass Permian sand resources*

Not all Permian sand in the Mount Compass region is suitable for beach replenishment and many areas have not been tested. Some regional exploration may be necessary to test areas that could provide suitable sand sources.

The Coastal Engineering Solutions report (2004) demonstrated that alongshore sand transport could be reduced by up to 30% using coarser sand to replenish the beaches. The main benefit of coarser sand is that it is much more resistant to across-shore transport, and so provides a more stable buffer against storm erosion. Coarser sand can more than compensate for stormier weather and, consequently, the strategy for 2005–2025 includes the provision of coarser sand from Mount Compass or other sources to adjust for existing sand losses of around 25,000 m^3/year from relative sea level rise. To date, small quantities of suitable sand have been purchased from commercial operations at Mount Compass, including the Unimin Sand Plant at Glenshera, to supplement Brighton and Seacliff. The Department for Environment and Heritage will be investigating a potential long-term supply of sand from non-commercial operations in the Mount Compass area.

6.6 Build coastal structures in critical locations

To retain beaches in some critical locations, and improve the cost-effectiveness of pumping and pipeline systems, the strategy for 2005–2025 includes the investigation of appropriate ways to slow sand movement along Adelaide's coast. The Semaphore South breakwater trial is an important step in determining whether shore-parallel, 'least intrusive' structures are effective in slowing sand movement. The Coast Protection Board prefers using shore-parallel structures rather than perpendicular structures because the latter would interrupt the mostly continuous beaches we are so fortunate to have today.

Groynes and offshore breakwaters are commonly used in coastal engineering. Examples of groynes on the Adelaide coast are the low rock-groyne at the Broadway, Glenelg, and the rock walls that define the harbours at Glenelg, West Beach, North Haven and Outer Harbor (the southern structure). The last three are often called training walls because they control or 'train' the location of the entrance to a harbour. Examples of offshore breakwaters are the breakwater at Glenelg, just south of the harbour entrance, the trial breakwater offshore from Bower Road at Semaphore South, and the northern breakwater at Outer Harbor.

6.6.1 Groynes

Groynes are structures built across the coast usually from dry land out into the water. They act to interrupt the alongshore movement of sand by being a physical barrier across the beach, collecting sand on the updrift side in what is called a *fillet*. They can only trap sand if there is significant alongshore drift to bring sand into the fillet. To completely stop alongshore transport, a groyne needs to extend out far enough to allow the build-up of sand to reach an equilibrium angle (the angle of the beach (as viewed from above) at which the breaking wave crests are parallel to it). A groyne also needs to be long enough to extend beyond the seaward limit of the littoral zone to prevent sand washed offshore by storms from then being transported alongshore. For the Adelaide coast, this length would be around 300 m for groynes spaced about 600 m apart.

A groyne should be of sufficient height to prevent alongshore sand transport by overtopping. For both now and in the future on the Adelaide coast with its large tidal range, that would mean heights of about 1 m lower than the height of seawalls backing the beach. Such a large structure would probably result in a lowering and recession of the beach to the north (downdrift) of it. There would be significant difficulty in walking along a beach interrupted by such a large structure, since there would be a drop of several metres between the beach on the updrift and downdrift sides of it.

A complete groyne field would be both publicly unacceptable and very costly in Adelaide. As an alternative, smaller groynes can be useful for raising beach levels on a very small scale and their height can be adjusted to trap enough sand to aid use of the beach without being obstructive. An example is the small, geotextile groyne at Somerton Park built in 2001. At approximately 1.5 m high and 25 m long, the structure has collected enough sand to raise the beach level to the south of it above normal high-tide level on a beach that was previously submerged at high tide. Because of its size, the fillet was filled quickly and sand now bypasses and washes over the groyne. There is no observable adverse effect on the beach downdrift of it.

In mid 2005, several similar small groynes were constructed at Somerton Park, with the aim of raising beach levels along that part of the coast to provide beach access over longer periods of the day.

6.6.2 Breakwaters

Breakwaters are structures usually built in the water, often parallel to the coast. They act by blocking wave energy from an area between the breakwater and the beach. As sand is transported along the coast by waves, it enters a calm area where there is not enough energy to keep the sand suspended and it settles to the sea floor. A breakwater thus traps sand and builds the beach up in what is called a *salient*. If a salient grows to the extent that it reaches the breakwater, it is called a *tombolo*.

Because breakwaters do not physically obstruct sand movement along a beach but raise the beach level and width, they maintain pedestrian or vehicular access along the beach. However, because they are built out at sea rather than on the beach and at a height of about 1 m above mean sea level, they are highly visible and can obstruct sea views.

The trial breakwater at Semaphore South was designed to be occasionally overtopped by tides and waves. It is less obstructive, both as an inhibitor of sand movement and visually, than a structure designed to completely stop sand transport along the coast.

The degree to which a breakwater traps sand can be 'tuned' by adjusting its height, length and distance offshore. Whether a tombolo will form depends on the ratio of breakwater length to distance offshore. If the breakwater is further offshore than it is long, only a salient will form. If it is as far offshore as it is long, a tombolo might barely form. Any closer and a tombolo will form. This rule assumes that the breakwater is high enough not to be overtopped. The Semaphore South breakwater is 200 m long and 200 m offshore but is not high enough for tombolo formation.

The trial breakwater has several purposes. As Stage 1 of the Semaphore Park Coast Protection Strategy, it collects sand that is used to replenish the eroding foreshore. It is also useful as a trial for the possible breakwaters elsewhere along the Adelaide coast to provide protection, slow sand movement and/or collect sand for replenishment. The length of the trial period is four to five years, although there will be sufficient data within a year or two to improve the design of possible future structures. Even so, detailed design would be necessary for each future structure, because of differences in beach shape and wave climate along the Adelaide coast.

6.6.3 Hybrid fields

The size of a structure, its location and local conditions govern how much sand is needed to provide a stable fillet of sand or fill a salient or tombolo. This is a critical factor in making decisions for sustainably managing Adelaide's coast. If beach sand volumes are not to be significantly reduced in providing for sand for fillets and salients, sand must be imported from outside the beach system. This is expensive compared with moving sand about within the beach system and has been carefully considered.

Given the pre-existence of both groynes and breakwaters on the Adelaide coast, it is sensible that the management strategy for the future encompasses a hybrid alternative, consisting of structures, both old and new, in addition to beach replenishment. For example, between the groynes that define the beach from Glenelg North to the West Beach boat harbour, a small field of breakwaters may help stabilise the beach at the southern end where it is often devoid of sand. This would reduce the need to replenish this part of the coast by trapping sand in this vulnerable area. The strategy for 2005–2025 allows for this possibility.

Clearly, actions on one part of the coast influence the management of an adjacent part. With bypassing no longer required to maintain the Glenelg North beach, the sand collected by the southern Glenelg groyne and the offshore breakwater can be transported back to Brighton, Seacliff or Kingston Park to match the sand drift out of the area.

To implement the sand slurry pumping and pipeline method described in section 6.4 in an efficient manner, accumulations of sand are required at the sand acquisition locations. This is aided by sand trapped at structures. The existing breakwaters at Glenelg and West Beach would be used for this purpose. The strategy for 2005–2025 includes using the Semaphore Park proposed breakwater field and the sand accumulation at the Torrens Outlet in a similar manner.

The use of some structures to slow sand is important in effectively managing Adelaide's beaches. However, the strategy will limit the number of large structures on the coast due to the cost and visually intrusive nature of these structures.

6.7 Integrate sand bypassing at harbours with beach management

Under the existing strategy, the harbours at Glenelg and West Beach require ongoing sand and seagrass bypassing and channel maintenance at a cost of $1.9 million/year (in 2004–05), which is about the same as the current cost of metropolitan beach replenishment.

At Glenelg, sand is dredged from the Patawalonga channel and from the leeward side of the offshore breakwater (between breakwater and beach) and pumped offshore at Glenelg North. At West Beach, sand is dredged from the harbour channel and pumped offshore immediately to the north, while sand south of the breakwater is removed by excavator and truck and carted north to the West Beach dunes.

In 2004, because harbour management operations could not bypass sufficient sand at Glenelg, 80,000 m^3 of sand was removed by excavator and truck from the beach in front of Holdfast Shores. It was carted south to Brighton and Seacliff as part of the replenishment program for the metropolitan beaches.

Furthermore, the West Beach dunes have eroded back to a position that existed before construction of the West Beach harbour. This is a critical retreat position for the West Beach dunes in terms of protecting development and maintaining a viable dune system. The erosion is primarily the result of insufficient sand bypassing at the Glenelg and West Beach harbours over recent years. In 2004, an extra 30,000 m^3 of sand was carted from the Torrens Outlet to the West Beach dunes to make up the shortfall, again as part of the metropolitan beach replenishment program.

The responsibility for sand management at the Glenelg and West Beach harbours, and therefore the dredging contract, are being transferred from Transport SA to the Department for Environment and Heritage in 2005.

As part of the strategy for 2005–2025, the sand bypassing at the harbours will be integrated with the maintenance of the metropolitan beaches to manage the whole sandy beach system more effectively. Sand building up at the harbours will be used to replenish beaches to the south, and sand will be recycled from further up the coast to avoid erosion north of the harbours (see section 6.8.1).

Sand bypassing at Holdfast Shores

Sand bypassing at Adelaide Shores

6.8 Implementation plan

Adelaide's Living Beaches: A Strategy for 2005–2025 will be implemented in a phased manner to:

- trial the Semaphore breakwater over three years to ensure an adequate assessment of design features
- trial sand pumping methods and equipment
- investigate how pipelines can be installed unobtrusively behind dunes and at the top of seawalls
- ensure that designs are prepared in a manner that takes into account existing development and land use
- allow time for public consultation in conjunction with development applications
- allow time for the necessary infrastructure to be put in place
- allow dune reserves to erode gradually over time.

6.8.1 Coastal management cells

The Adelaide metropolitan coast will effectively be divided into seven management cells, with some interconnectivity between them (see Figure 6.6).

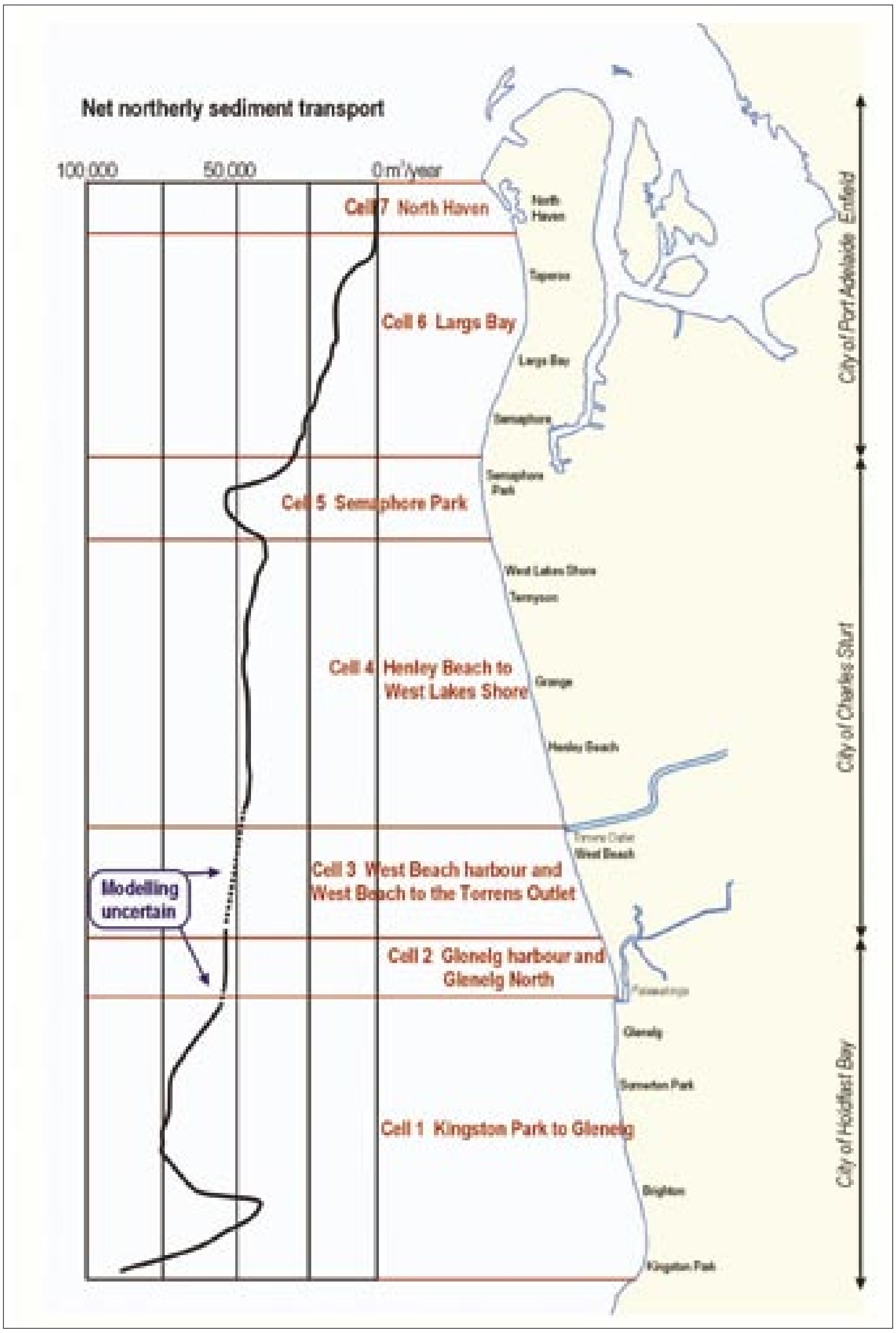


Figure 6.6 *Proposed coastal management cells in the strategy for 2005–2025*

The actions proposed for each coastal management cell are outlined in Table 6.2.

Table 6.2 *Management actions based on sediment transport rates within each coastal cell*

Coastal management cell	Proposed actions
1: Kingston Park to Glenelg Average annual net northward drift of sand is 70,000 m^3	• Add 25,000 m^3 of sand each year to the dunes at Brighton/Seacliff to counter the ongoing loss of dune volume and beach width along the metropolitan coast caused by sea level rise and other factors. From 2005–06 to 2008–09 this sand will be backpassed from the Torrens Outlet, with coarse sand added from trials of onshore sources. • In 2006–07 backpass 40,000 m^3 of sand from Glenelg to Brighton/Seacliff by truck and commence construction of the pipeline between Glenelg and Kingston Park. In 2007–08 start pumping 50,000 m^3 of sand each year from Glenelg to Kingston Park.
2: Glenelg harbour and Glenelg North Expected annual net northward drift of sand is 50,000 m^3 at Glenelg North	• Dredging of the Glenelg harbour will be managed by the Department for Environment and Heritage from 2005–06 onwards (it was previously managed by Transport SA). In 2005–06 bypass approximately 100,000 m^3 of sand from channel and tombolo maintenance around the Glenelg harbour to Glenelg North. Thereafter, bypass only 20,000 to 30,000 m^3 of sand each year. Continue using a dredge to bypass seagrass from the channel and tombolo to offshore Glenelg North. • In 2006–07 undertake a sand pumping trial to backpass 30,000 m^3 of sand from the West Beach harbour to Glenelg North and commence construction of the pipeline between the West Beach harbour and Glenelg North. In 2007–08 start pumping 30,000 m^3 of sand each year from the West Beach harbour to Glenelg North. • Consider construction of two breakwaters between Glenelg North and the West Beach harbour as an alternative to backpassing.
3: West Beach harbour and West Beach to the Torrens Outlet Expected annual net northward drift of sand is 50,000 m^3 from West Beach to Torrens Outlet	• Dredging of the West Beach harbour will be managed by the Department for Environment and Heritage from 2005–06 onwards (it was previously managed by Transport SA). From 2005–06 bypass approximately 30,000 m^3 of sand and seagrass around the West Beach harbour each year. • From 2005–06 to 2008–09 draw down the sand reserves at the Torrens Outlet by 50,000 m^3 each year, with 25,000 m^3 of sand backpassed to Brighton and 25,000 m^3 bypassed to Henley Beach South. • In 2005–06 undertake a sand pumping trial to backpass 40,000 m^3 of sand from south of the Torrens Outlet to the West Beach dunes. In 2006–07 backpass 40,000 m^3 by truck/scraper and commence construction of the pipeline from the Torrens Outlet to the West Beach dunes. In 2007–08 start pumping 40,000 m^3 of sand each year from the Torrens Outlet to the West Beach dunes. This assumes that, of the dredged bypass sand, at least 10,000 m^3 each year can be fed onto West Beach and that, under current conditions, an average of around 16,000 m^3 of sand accumulates each year at the Torrens Outlet despite annual mechanical bypassing of 25,000 m^3. • Construct a breakwater north of the West Beach Surf Life Saving Club if erosion there cannot be contained. Consider a breakwater south of the West Beach Surf Life Saving Club to further stabilise dunes if necessary.
4: Henley Beach to West Lakes Shore Expected annual net northward drift of sand is 50,000 m^3	• Until the Semaphore Park breakwater field is completed, this area will depend on mechanical bypassing of 25,000 m^3 of sand each year from the Torrens Outlet plus natural northerly drift. • From 2009–10 onwards, backpassing of 50,000 m^3 of sand by pipeline from south of the breakwater field will be necessary.
5: Semaphore Park Expected annual net northward drift of sand to breakwater is 60,000 m^3	• In 2005–06 backpass 40,000 m^3 of sand from the trial breakwater at Semaphore South to Semaphore Park. • The trial breakwater is currently operating until 2006–07. In 2007–08, subject to successful completion of the trial, armour the trial breakwater and construct a new rock breakwater. In 2008–09 construct two further breakwaters (subject to the results of the trial) and commence construction of the pipeline from south of the breakwater field to the Torrens Outlet. In 2009–10 construct a final breakwater (subject to the results of the trial) and start pumping 50,000 m^3 of sand each year from south of the breakwater field to the Torrens Outlet.
6: Largs Bay Expected annual net northward drift of sand is 30,000 m^3	• During the breakwater trial, backpass up to 10,000 m^3 of sand each year from Semaphore to the north of the trial breakwater using trucks or scrapers. This assumes around 33,000 m^3 of sand drifts north past the breakwater each year. • Subject to successful completion of the breakwater trial, draw down the Semaphore dunes to fill the salients of the breakwater field, using a temporary pipeline to pump the sand to Semaphore South.
7: North Haven No expected annual net northward drift of sand except for accumulation south of, and in the channel of, North Haven	• Dredge the channel at North Haven (conducted by the Department for Transport, Energy and Infrastructure). Consider using the reserve of fine sand at North Haven, and further south towards Largs Bay, to backfill the Section Bank if dredging of beach replenishment sand from the Section Bank is found to be economically and environmentally sound in the future.

6.8.2 Schedule of capital and operating costs

For the purposes of this implementation plan, the schedule of costs for the strategy has been based on current capital and operating costs using the Sand Shifter (Table 6.3).

Table 6.3 *Schedule of current capital and operating costs using the Sand Shifter*

Items	Current costs	Notes
2005–06 OPERATING COSTS		
Glenelg and West Beach harbours	$3,320,000	Current contract for harbour bypassing
General coastal management	$1,901,000	Current cost estimate for business as usual
Sand input from Mount Compass	$988,000	External coarser sand input to Brighton
Subtotal	**$6,209,000**	
2005–06 CAPITAL COSTS		
None scheduled	$0	
Subtotal	**$0**	
2006–07 OPERATING COSTS		
Glenelg and West Beach harbours	$3,320,000	Current contract for harbour bypassing
General coastal management	$1,901,000	Current cost estimate for business as usual
Sand input from Mount Compass	$988,000	External coarser sand input to Brighton
Subtotal	**$6,209,000**	
2006–07 CAPITAL COSTS		
Glenelg to Brighton–Kingston Park pipeline	$1,542,000	Pipeline cost to be offset over 2 years
Subtotal	**$1,542,000**	
2007–08 OPERATING COSTS		
Glenelg and West Beach harbours	$1,606,000	Harbour channel maintenance, no bypassing
General coastal management	$2,462,000	New management plan implemented using trucks in the interim
Sand input from Mount Compass	$988,000	External coarser sand input to Brighton
Subtotal	**$5,056,000**	
2007–08 CAPITAL COSTS		
Glenelg to Brighton–Kingston Park pipeline	$2,293,000	Pipeline cost to be offset over 2 years
West Beach to Glenelg North pipeline	$562,000	Pipeline cost to be offset over 2 years
Armour trial Semaphore Park breakwater	$470,000	Finalise design of trial breakwater and armour geotextile
Subtotal	**$3,325,000**	
2008–09 OPERATING COSTS		
Glenelg and West Beach harbours	$1,606,000	Harbour channel maintenance, no bypassing
General coastal management	$2,462,000	New management plan implemented using trucks in the interim
Sand input from Mount Compass	$988,000	External coarser sand input to Brighton
Subtotal	**$5,056,000**	
2008–09 CAPITAL COSTS		
West Beach to Glenelg North pipeline	$944,000	Pipeline cost to be offset over 2 years
Torrens Outlet to West Beach pipeline	$1,506,000	Total pipeline cost
West Lakes Shore to Henley pipeline	$1,958,000	Pipeline cost to be offset over 2 years
Breakwater construction	$2,730,000	Construct second and third Semaphore Park breakwaters
Subtotal	**$7,138,000**	
2009–10 OPERATING COSTS		
Glenelg and West Beach harbours	$1,606,000	Harbour channel maintenance, no bypassing
General coastal management	$531,000	New management plan implemented using constructed pipelines
Sand input from Mount Compass	$988,000	External coarser sand input to Brighton
Subtotal	**$3,125,000**	
2009–10 CAPITAL COSTS		
West Lakes Shore to Henley pipeline	$3,733,000	Pipeline cost to be offset over 2 years
Breakwater construction	$2,730,000	Construct fourth and fifth Semaphore Park breakwaters
Subtotal	**$6,463,000**	
2010–11 OPERATING COSTS		
Glenelg and West Beach harbours	$1,606,000	Harbour channel maintenance, no bypassing
General coastal management	$531,000	New management plan implemented using constructed pipelines
Sand input from Mount Compass	$988,000	External coarser sand input to Brighton
Subtotal	**$3,125,000**	
2010–11 CAPITAL COSTS		
None scheduled	$0	
Subtotal	**$0**	

7. Economic, Social and Environmental Considerations

During development of *Adelaide's Living Beaches: A Strategy for 2005–2025*, due consideration has been given to economic, social and environmental aspects. In summary, the estimated cost of the future strategy is less than that of continuing the existing strategy, the social impacts of beach replenishment will be reduced, and environmental impacts will be similar to current operations.

7.1 Economic evaluation

7.1.1 Evaluation of the alternatives presented in the 1992 review

The 1992 *Review of Alternatives for the Adelaide Metropolitan Beach Replenishment Strategy*, which was undertaken by the Coastal Management Branch, Department of Environment and Planning, discussed and estimated the cost of six approaches to protect and/or preserve Adelaide's metropolitan coastline.

These alternatives were:

- maintain the status quo
- abandon replenishment and construct seawalls when and where necessary
- major replenishment by dredge
- major replenishment using a pipeline from North Haven
- progressive construction of groynes
- increase replenishment.

These approaches fit within and are representative of the full range of alternatives identified in section 6.1.

To reassess the costs of each of the 1992 alternatives is not feasible, as several of the alternatives have proved to be unacceptable in the years since. The exception is the progressive construction of a groyne field along the coast to slow sand movement. However, each of the 1992 alternatives will be discussed in this section to determine their economic feasibility as a future management strategy.

Note that the first two approaches in the 1992 review have been excluded from serious consideration as they fail to provide adequate beaches either now (abandon replenishment approach) or in the future (status quo approach). The reasons for this are discussed below.

Maintain the status quo

This alternative proposed to carry on the status quo as it stood in 1992 with no improvement to beach amenity or foreshore protection and no account taken of sea level rise. The alternative was based on a biennial dredging program of some 200,000 m^3 to replenish the beach system, and recycling of approximately 50,000 m^3 of sand by trucking. The dredged material was to be sourced initially from Port Stanvac and then from North Haven.

This alternative is no longer valid for the following reasons:

- Since 1992, a great deal of effort has been undertaken to improve Adelaide's beaches in terms of both beach amenity and foreshore protection. To go back to a 1992 state would be both impractical and unpopular, because beach amenity has been found to be of overwhelming economic and social value.
- The Port Stanvac sand source has been largely depleted by subsequent dredging episodes. Hence, this resource no longer exists as a long-term solution.

- The North Haven sand source has been dismissed as a viable option for beach replenishment due to its calcareous nature and fine grain size. If this sand were placed on the southern beaches, it has been predicted that it would accelerate the northerly drift of sand in this area, which in turn would require more sand to be imported into the southern beaches.
- Use of the Section Bank to replenish Adelaide's beaches will not take place until the environmental impacts of dredging are adequately addressed and a method of extracting the sand, and possibly replacing it with finer sand to maintain seabed levels, becomes economical.

Abandon replenishment and construct seawalls when necessary

This alternative only considered the protection of coastal property and infrastructure using seawalls, with the abandonment of beach replenishment. There was no allowance in this alternative to maintain or improve beach amenity.

Seawalls are an important aspect of the current strategy as a final line of defence and allowances have been made in the future costing of alternatives to maintain the existing seawalls along the coast. However, to allow the amenity of the metropolitan beaches to degrade would be publicly unpopular and would undo the considerable effort that has been undertaken to improve the beach resource since 1970. Hence this option is no longer valid and is not costed.

Major replenishment by dredge

This alternative suggested a major one-off dredging program that would place 3 million m^3 of sand on the southern beaches with a top-up replenishment dredging of 200,000 m^3 of sand every three years thereafter. The sand would be sourced from Port Stanvac, North Haven and possibly the Section Bank.

This alternative is no longer feasible because there are no suitable offshore sand sources that can be dredged at present.

Major replenishment from an onshore source such as Mount Compass would be prohibitively expensive (approximately $110 million for 3 million m^3, plus $7.35 million every three years thereafter).

Major replenishment using pipeline from North Haven

This alternative proposes that a large diameter pipeline be constructed from North Haven to the southern beaches to transport North Haven sand south. However, as described above, the North Haven sand source has been dismissed as a viable option for beach replenishment due to its calcareous nature and fine grain size (see section 3.3.4). Furthermore, this alternative does not take into consideration the additional sand that would be required to counteract rising sea level. This option as it stands in the 1992 report is not costed separately. However, the concept of a pipeline to recycle sand is valid and this will be costed in the next section.

Progressive construction of groynes

The construction of a groyne field requires not only the construction of the groynes themselves but also the filling of the embayments formed between each of the groynes.

The cost of constructing the groynes has been determined by applying the consumer price index to the estimates provided in the 1992 review.

The cost of filling the embayments formed between each of the groynes is much higher than anticipated in 1992 because the sand sources suggested at the time are now either unavailable (Port Stanvac) or unsuitable (North Haven). Instead, sand from an external source such as Mount Compass would have to be used to fill the embayments. Sand from Mount Compass currently costs approximately $\$38/m^3$, whereas in 1992 sand from Port Stanvac was estimated to cost $\$8/m^3$ and sand from North Haven was estimated to cost $\$11/m^3$.

Other additional costs not included in the 1992 assessment are the cost of managing the harbours at Glenelg and West Beach and the need to import coarse sand from an onshore source to counteract the effects of climate change.

The costing of this option will be discussed further in the next section.

Increase replenishment

Essentially this alternative represents the existing beach management strategy, but proposes an increase in beach replenishment to first maintain then increase beach amenity over a 20-year period. Increasing the volume of sand on the beaches increases the protection the beach and associated dunes provide to coastal properties and infrastructure and takes into account rising sea level.

The existing management of Adelaide's beaches is included in the comparison of costs provided in the next section.

7.1.2 Comparison of capital and operating costs for practical alternatives

Practical alternatives for managing Adelaide's beaches are costed in this section, including three potential ways of implementing the future management strategy – using trucks and excavators, using a Slurrytrak and pipelines, and using Sand Shifters and pipelines.

The Slurrytrak and Sand Shifter options have been costed because they are the established proprietary systems likely to be used during initial sand slurry pumping trials. The cost-effectiveness of alternative systems will be considered during the open tender process that will take place prior to installation of a permanent system.

Completion of the Semaphore Park Coast Protection Strategy, involving the possible construction of a field of breakwaters at Semaphore Park, is assumed in each scenario except the progressive construction of a groyne field. An increased supply of externally sourced sand is also assumed in each scenario, with the cost based on supply from Mount Compass.

The cost estimates provided do not take into account the expected planning, policy, research and monitoring costs over the next 20 years. These costs are similar for each scenario.

Progressive construction of a groyne field

The 1992 assessment of this option was based on the construction of one groyne per year over a 20-year period and a biennial replenishment program of 200,000 m^3 to fill the embayments between groynes. The current assessment is based on constructing one groyne per year with an annual replenishment program of 100,000 m^3. The schedule of costs for this assessment is presented in Figure 7.1.

The cost of a conventional groyne in 1992 was estimated as $0.9 million. Applying the consumer price index to this figure provides a current capital cost of approximately $1.2 million/year.

Operating costs for this alternative have been assessed as follows:

- In 1992, maintenance costs of $0.1 million/year were included in the assessment. This equates to a current operating cost of $0.13 million/year.
- The management of the harbours at Glenelg and West Beach, including sand bypassing until these parts of the coast were stabilised by groynes in 2010–11, would cost approximately $3.3 million/year. After 2010–11, ongoing channel maintenance would cost approximately $1.6 million/year.
- The cost of importing sand from external sources is based on using the Mount Compass source. 25,000 m^3/year would be needed to counteract the effects of climate change, and 100,000 m^3/year would be required to fill the embayments between groynes. Based on a price of $38/m^3, the cost of importing sand from Mount Compass would be $4.75 million/year.

The total operating cost has therefore been determined as $8.18 million/year up to 2010–11 and $6.48 million/year after 2010–11.

The net present value of the progressive construction of a groyne field is discussed in section 7.1.3.

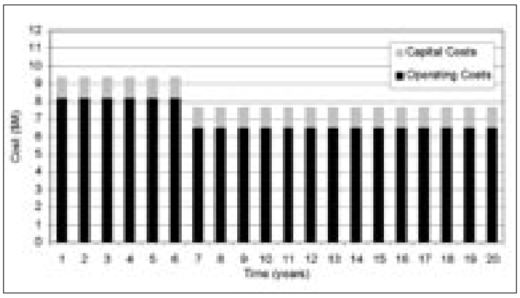


Figure 7.1 *Schedule of costs for the progressive construction of a groyne field*

Continue the existing beach management strategy

The current cost of the existing beach management strategy is $1.7 million/year, which includes a beach replenishment program of 160,000 m^3/year and a seawall upgrading and sand drift control expenditure of $250,000/year. This allows for additional sand from external sources to meet the requirements of sea level rise plus land subsidence. The current cost of sand bypassing at the Glenelg and West Beach harbours, which is essential to the overall management of Adelaide's beaches, is $1.9 million/year. However, on new tendered rates the cost is expected to increase to $3.3 million/year.

An estimate of the future capital and operating costs for the existing management activities is provided in Table 7.1. Under this option, excavators and trucks would be used to recycle sand along the coast and the same volume of sand as is currently moved would be bypassed around the Glenelg and West Beach harbours using a dredge. The harbours are not incorporated into the overall management strategy of the coast so remain a separate management issue. This option has a low capital expenditure, but high ongoing operating costs.

The schedule of costs for this option over the next 20-year period is presented in Figure 7.2. The construction of the breakwater field at Semaphore Park is scheduled to commence in 2007–08 and will take three years to complete.

Table 7.1 *Capital and annual operating costs to continue existing management activities*

Existing management activities	Cost
Capital costs	
Semaphore Park breakwaters (over three years)	$5,930,000
Total	**$5,930,000**
Operating costs	
Mount Compass – sand input of 25,000 m^3/year	$988,000
Torrens Outlet to Brighton – sand backpassing 18,000 m^3/year	$316,000
Semaphore to Brighton – sand backpassing 32,000 m^3/year	$763,000
Glenelg and West Beach harbours – maintenance	$3,320,000
West Beach to Henley South – sand bypassing 20,000 m^3/year	$139,000
Semaphore to Semaphore Park – sand backpassing 40,000 m^3/year	$114,000
Estcourt House to Tennyson – sand backpassing 10,000 m^3/year	$77,000
Semaphore to breakwater – sand backpassing 15,000 m^3/year	$115,000
Seawall upgrading and sand drift control	$377,000
Total	**$6,209,000**

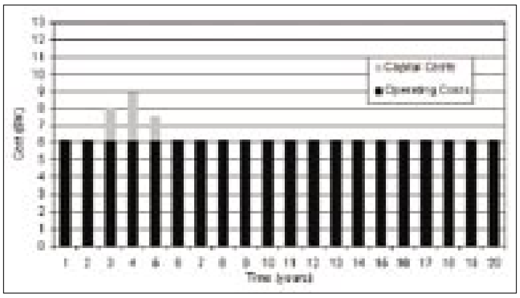


Figure 7.2 *Schedule of costs based on continuing existing management activities*

Implement the future strategy using predominantly excavators and trucks

This option is similar to the previous option but integrates the management of the Glenelg and West Beach harbours into the overall management of the coastline. The estimated capital and operating costs to recycle sand using trucks and excavators are presented in Table 7.2. As with the previous alternative, this option has a low capital expenditure but a high ongoing operating cost. The capital expenditure for this option is again limited to the construction of the breakwater field at Semaphore Park. The reduction in operating costs compared to the previous alternative is due to a reduction in dredging required at the Glenelg and West Beach harbours. Dredging would still take place under this option, but the majority of sand would be recycled within each coastal management cell by truck instead of being bypassed around the harbours by dredge.

Figure 7.3 presents the schedule of costs under this option over the next 20 years. As with the previous alternative, the construction of the breakwater field at Semaphore Park is scheduled to commence in 2007–08 and will take three years to complete. The high operating cost in the first two years represents the current harbour management contract.

Table 7.2 *Capital and annual operating costs of future management activities using excavators and trucks*

Future management activities using excavators and trucks	Cost
Capital costs	
Semaphore Park breakwaters (over 3 years)	$5,930,000
Total	**$5,930,000**
Operating costs	
Mount Compass – sand input of 25,000 m³/year	$988,000
Glenelg to Brighton – sand backpassing 50,000 m³/year	$738,000
Glenelg harbour – maintenance	$935,000
West Beach to North Glenelg – sand backpassing 30,000 m³/year	$227,000
West Beach harbour – maintenance	$671,000
Torrens Outlet to West Beach – sand backpassing 40,000 m³/year	$327,000
Torrens Outlet – maintenance	$2,000
West Lakes Shore to Henley – sand backpassing 50,000 m³/year	$791,000
Seawall upgrading and sand drift control	$377,000
Total	**$5,056,000**

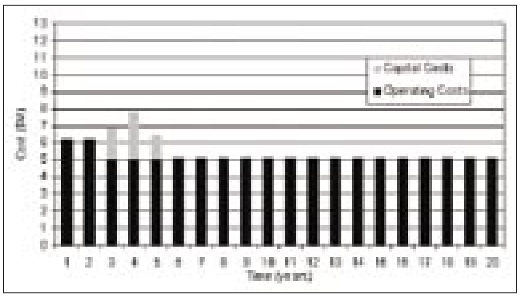


Figure 7.3 *Schedule of costs based on using predominantly excavators and trucks*

Implement the future strategy using a Slurrytrak and pipelines

Table 7.3 presents the capital and operating costs for the option of using a Slurrytrak and pipelines to recycle sand. As with the excavator and trucks alternative, this option integrates the management of the Glenelg and West Beach harbours into the overall coastal management strategy. The Slurrytrak plant would not be purchased under this option. Instead, one Slurrytrak unit and an excavator would be hired on a contract basis and relocated along the coast as needed. This option has a high capital expenditure but a lower ongoing operating cost compared to the previous two alternatives.

Figure 7.4 presents the schedule of costs over the next 20 years under this option. Four pipelines are proposed, with the construction of the pipelines broken into two stages. Stage 1 is scheduled to commence in 2006–07, while Stage 2 is scheduled to commence in 2008–09. The operating costs will stay high until the Stage 1 pipelines are completed.

Table 7.3 *Capital and annual operating costs of future management activities using a Slurrytrak and pipelines*

Future management activities using a Slurrytrak and pipelines	Cost
Capital costs	
Glenelg to Kingston Park – 6.5 km pipeline (over 2 years)	$3,599,000
West Beach to North Glenelg – 1.5 km pipeline (over 2 years)	$849,000
Torrens Outlet to West Beach – 1.5 km pipeline (over 2 years)	$849,000
West Lakes Shore to Henley – 9.0 km pipeline (over 2 years)	$5,035,000
Semaphore Park breakwaters (over 3 years)	$5,930,000
Total	**$16,262,000**
Operating costs	
Mount Compass – sand input of 25,000 m³/year	$988,000
Glenelg to Brighton – sand backpassing 50,000 m³/year	$342,000
Glenelg harbour – maintenance	$935,000
West Beach to North Glenelg – sand backpassing 30,000 m³/year	$185,000
West Beach harbour – maintenance	$671,000
Torrens Outlet to West Beach – sand backpassing 40,000 m³/year	$245,000
Torrens Outlet – maintenance	$2,000
West Lakes Shore to Henley – sand backpassing 50,000 m³/year	$358,000
Seawall upgrading and sand drift control	$377,000
Total	**$4,103,000**

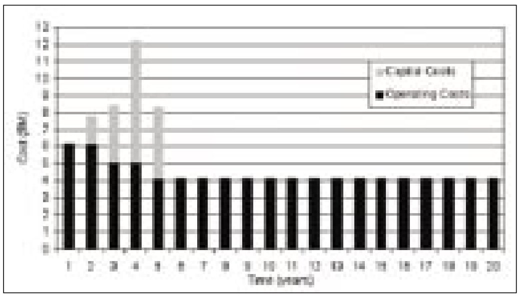


Figure 7.4 *Schedule of costs based on using a Slurrytrak and pipelines*

Implement the future strategy using Sand Shifters and pipelines

This option uses a number of Sand Shifters and pipelines to recycle sand within each coastal management cell as well as incorporating the management of the Glenelg and West Beach harbours into the overall management of the coastline. Table 7.4 presents the capital and operating costs for the Sand Shifter and pipelines option. This option has the highest capital expenditure and the lowest ongoing operating cost. The extra capital expenditure is required to purchase the Sand Shifter units (and required headworks), while the savings in operating costs come about by use of electrical power and running the largely automated system in-house.

The schedule of costs for this option is shown in Figure 7.5. As with the previous option, operating costs will stay high until the Stage 1 pipelines are completed.

Table 7.4 *Capital and annual operating costs of future management activities using Sand Shifters and pipelines*

Future management activities using Sand Shifters and pipelines	Cost
Capital costs (note 4 Sand Shifter units are deployed)	
Glenelg to Kingston Park – 6.5 km pipeline and Sand Shifter (over 2 years)	$3,834,000
West Beach to North Glenelg – 1.5 km pipeline and Sand Shifter (over 2 years)	$1,506,000
Torrens Outlet to West Beach – 1.5 km pipeline and Sand Shifter (over 2 years)	$1,506,000
West Lakes Shore to Henley – 9.0 km pipeline and Sand Shifter (over 2 years)	$5,691,000
Semaphore Park breakwaters (over 3 years)	$5,930,000
Total	**$18,467,000**
Operating costs	
Mount Compass – sand input of 25,000 m^3/year	$988,000
Glenelg to Brighton – sand back passing 50,000 m^3/year	$54,000
Glenelg harbour – maintenance	$935,000
West Beach to North Glenelg – sand back passing 30,000 m^3/year	$13,000
West Beach harbour – maintenance	$671,000
Torrens Outlet to West Beach – sand back passing 40,000 m^3/year	$17,000
Torrens Outlet – maintenance	$2,000
West Lakes Shore to Henley – sand back passing 50,000 m^3/year	$68,000
Seawall upgrading and sand drift control	$377,000
Total	**$3,125,000**

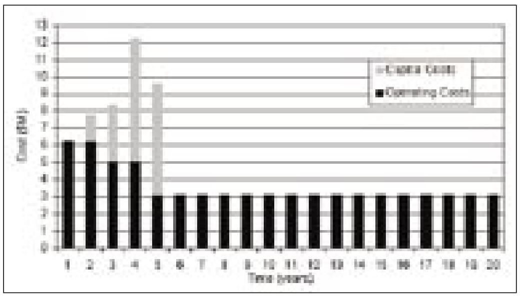


Figure 7.5 *Schedule of costs based on using Sand Shifters and pipelines*

7.1.3 Net present value of practical alternatives

It is not particularly useful to make a direct comparison of the costs of the four scenarios presented above, because the costs accrue over different periods and the value of money changes over time. This is a result of the existence of real interest rates – that is, the difference between actual interest rates and inflation – and is reflected in the community's preference to receive benefits as soon as possible, and pay costs as late as possible.

A commonly used method for eliminating this variable is to convert all costs to an equivalent dollar value at a particular point in time. It is usual to convert the costs to today's dollars and call the result the net present value (NPV). To achieve this, a discount rate is applied to future costs. The discount rate is the rate, per year, at which future costs are diminished to make them more comparable to values in the present. The Department of Treasury and Finance currently recommends that a discount rate of 7% be applied to public sector projects, but that sensitivity checks are made using rates of 4% and 10%.

Table 7.5 shows the net present value of the five options discussed in section 7.1.2. In simple terms, the NPV of each scenario depends not only on the overall costs but also on how the costs are scheduled over the 20-year forecast period. Negative values indicate a cost, whereas positive values indicate a benefit.

Note that the following analysis only takes into consideration the tangible costs of each option – not intangible costs such as the cost of greenhouse gas emissions or trucks on roads. The cost of the progressive construction of a groyne field has been included in Table 7.5 to demonstrate its prohibitive cost.

Table 7.5 *Net present value ($million) of practical alternatives*

Option	NPV ($million) at different discount rates		
	4%	7%	10%
Progressive construction of a groyne field	–113	–89	–73
Existing management strategy	–89	–70	–57
Future strategy using excavators and trucks	–76	–60	–49
Future strategy using a Slurrytrak and pipelines	–75	–61	–51
Future strategy using Sand Shifters and pipelines	–67	–56	–47

The overall cost of the Sand Shifters and pipelines scenario using a discount rate of 7% is approximately $56 million over 20 years, whereas the overall cost of continuing the existing management activities is approximately $70 million over the same period. In other words, the cost of the Sand Shifters and pipelines scenario is 20% less than the cost of continuing the existing management activities. The Sand Shifters and pipelines scenario is the cheapest across all discount rates.

7.1.4 Economic benefits of beach management and coast protection

As discussed in section 5.4, benefits of beaches accrue to foreshore residents and businesses and the greater population and have been conservatively valued as being at least $46 million/year, with approximately half this value benefiting the general public. The benefit of wide sandy beaches and dunes to provide storm protection has been estimated as $1.7 million/year.

The net present value of having sandy beaches over a 20-year period is provided in Table 7.6. As shown, the estimated net present value of the benefits of keeping sand on the beaches is in the order of $500 million dollars over the next 20 years.

Table 7.6 *Net present value of the benefit of having sandy beaches over a 20-year time frame*

Benefit	NPV ($million) for different discount rates		
	4%	7%	10%
Beach value	671	533	438
Storm protection	25	20	16
Total	**696**	**553**	**454**

7.1.5 Benefit–cost analysis

On the basis of the net present value of the cost of each of the five options presented in Table 7.5 and the net present value of quantifiable benefits presented in Table 7.6, the benefit–cost ratio can be calculated for each option over the 20-year evaluation period. Table 7.7 presents the benefit–cost ratio for all five practical options.

Table 7.7 *Benefit–cost ratio of practical options over a 20-year period*

Option	Benefit–cost ratio for different discount rates		
	4%	7%	10%
Progressive construction of a groyne field	6.2	6.2	6.2
Existing management strategy	7.8	7.9	8.0
Future strategy using excavators and trucks	9.2	9.2	9.2
Future strategy using a Slurrytrak and pipelines	9.2	9.0	8.9
Future strategy using Sand Shifters and pipelines	10.3	9.9	9.6

Table 7.7 shows that the benefits far outweigh the costs associated with keeping sand on Adelaide's metropolitan beaches for all options presented. The cheapest option, using a Sand Shifter and pipelines, has a benefit that is 10 times the cost associated with constructing and operating the system over the next 20 years.

The above table realistically reflects the benefit–cost ratio of the beach replenishment options (i.e. the final four options), because the benefits have been determined based on beaches that are clear of structures. The groyne option does not fulfil this requirement, so the true benefit–cost ratios for this option may be somewhat less than those presented in Table 7.7.

7.1.6 Risk assessment

Two aspects of risk assessment are considered here:

1. the risk that the capital costs of the new strategy will be different from those estimated
2. the risk that the operating costs of the new strategy will be different from those estimated.

Variations in capital costs

The net present value of capital costs could vary from those estimated if a different arrangement of pumps, pipelines and structures is needed now or in the future, the unit cost of built items is different, or the construction schedule is different.

The technical performance of pumps, pipelines and structures relating to the strategy is well understood and there is a low risk that the overall configuration of the strategy would be found to need alteration. This is principally due to the flexibility that the strategy offers. This is in contrast to alternatives that use mainly fixed structures, as these cannot be adapted to changing conditions without further large capital costs.

Strategy flexibility

The existing beach management strategy is to replenish beaches by trucking sand, which maintains beach amenity and provides protection to development, with seawalls constructed as the last line of defence against storms. This strategy is flexible because management activities can be adapted readily to adjust beach levels without costly changes to capital infrastructure. Harbour management is currently carried out by contract carting and dredging. It is therefore adaptable to the volume of sand that needs to be bypassed and is not constrained by a commitment to capital investment in infrastructure. However, current beach replenishment and harbour management methods result in disruption to the public enjoyment of the beach, disruption to coastal residents, and inefficient movement of sand.

The future strategy is also flexible in operation. The pipeline component has been well tested in practice and poses minimal risk apart from the risk of storm damage to pipelines, which can be managed through the design of the pipeline location. The risk that the sand drift rate, storm intensity or rate of sea level rise may increase (or decrease) beyond anticipated forecasts can be readily managed by adjusting the duration of sand slurry pumping and the amount of sand discharged through various outlets. While this strategy is adaptable to seasonal, annual and longer-term changes in sand movement, there is an associated variation in operating costs (discussed below).

The alternative management options of extensive structural solutions such as groynes and breakwaters present much higher risks, needing a high level of capital investment in fixed infrastructure that is not readily adaptable to unforeseen or changing management requirements. In particular, the fixed spacing of structures means that changes in sand drift conditions may result in the beaches between structures becoming inadequately protected, requiring additional structures or sand, alterations to structures or additional seawall construction. Similarly, these approaches are less able to maintain good quality beaches under the variations in weather conditions that occur from year to year.

The capital costs of the future strategy are principally those of the pumping stations and pipelines. The majority of structures in the strategy already exist, or in the case of the field of breakwaters at Semaphore Park, the costs are well-defined through experience. The greatest scope for variation from the cost estimates is with pumping equipment. First, the sand acquisition equipment is reliant on sufficient sand being washed or moved into the sand collection area, and on how well the equipment handles or avoids dead seagrass accumulations. Both of these aspects have the potential to necessitate equipment or site alterations. Second, the location, noise emission levels and visual impacts of the sand pumping stations are socially sensitive, and the cost of construction will be dependent on how effectively these social impacts can be managed. For example, pump stations may need to be installed underground, which would be more costly than the estimates used for net present value assessment.

The greatest risk in the use of sand slurry pumping equipment is its ability to access sand accumulations effectively. The risk of this affecting the preferred long-term strategy or increasing costs considerably will be avoided by undertaking a sufficient trial period to evaluate the currently available equipment before committing to a plan of action. The trial will also help evaluate social response to the pump stations, assisting with design of the future permanent pumping stations.

The significant capital works required for the Semaphore breakwater field and the pipelines could be delayed due to the planning approval process. To determine how sensitive the four newer options are to delays in construction, a separate net present value analysis has been undertaken based on the construction works being delayed by four years. Table 7.8 shows the results of this analysis. The three options for the future strategy have the management of the harbours included into the overall management of the coastline. Prior to the pipelines being built, the yearly operational cost of these options will be the same as the excavator and truck option, i.e. $5.056 million/year (see Table 7.2).

Table 7.8 *Net present value of the four newer options based on a four-year delay in the construction schedule*

Option	NPV ($million) for different discount rates		
	4%	7%	10%
Existing management activities	–89	–69	–56
Future strategy using excavators and trucks	–75	–59	–48
Future strategy using a Slurrytrak and pipelines	–76	–61	–50
Future strategy using Sand Shifters and pipelines	–71	–57	–48

As shown in Table 7.8, the overall rank of the four newer options does not change due to a delay in construction. The most expensive option across all discount rates is still the existing management strategy, while the least expensive option is the future strategy using Sand Shifters and pipelines. Even if continuing the existing management activities was not associated with any delays (refer to Table 7.5), but the Sand Shifters and pipelines option was associated with delays, the latter option would still be less expensive.

Variations in operating costs

The operating costs of the proposed strategy could vary from those estimated under the following circumstances:

- if the requirement for sand supply from external sources increases
- if the unit cost of sand supplied from external sources becomes more expensive
- if energy costs increase
- if sand collection is more problematic or less efficient than expected
- if operating costs are evaluated over a short time-frame.

Additional sand from external sources would be needed if sea level rise occurs at a greater rate than that anticipated, or if larger dune buffers than adopted in the strategy are required. The most likely change in this regard is social pressure against the gradual draw-down of existing dune areas that are significantly larger than needed for coast protection purposes. The dune areas identified for gradual draw-down are the Torrens Outlet and, in the longer term, Semaphore. The total estimated volume of sand identified for draw-down at each of these locations is 250,000 m^3. The current value of 500,000 m^3 of sand is approximately $17 million. Consequently, strategy costs are highly sensitive to the quantity of sand needed from external sources. This favours the future strategy, because sand requirements are minimised as a result of the proposed recycling of as much sand as possible and the distribution of the limited sand quantities in the most equitable way.

The supply of sand from external sources has been based on the current cost of trucking sand from Mount Compass to Brighton beach. These costs would increase if energy costs increase or if funding is needed for road repair due to the increased truck traffic. Investigation of alternatives to trucking in residential areas will be considered and may involve an incremental increase in the cost of sand from this source. Alternatively, sand may be sourced from elsewhere and barged, thus reducing traffic impacts. However, current indications are that this would be more expensive and these additional costs would need to be weighed against the ongoing social impacts of truck traffic.

An increase in energy costs will increase unit operating costs for sand slurry pumping equipment and pumping stations, as well as increasing the cost of transporting sand from external sources onto Brighton beach. While the operating costs of sand transport and pumping are dependent on energy costs, the sensitivity of these derivative costs is difficult to define due to the variations in energy use for different equipment. Generally, however, energy costs for trucking are a small proportion of the total cost. Therefore, options with less trucking but more pumping would be more sensitive to energy cost increases.

Sand collection efficiency is critical to the financial viability of coast protection approaches that depend on sand bypassing at harbours or sand recycling. While the sand collection efficiency of most techniques (dredging, excavation, Sand Shifter and Slurrytrak) is well known under ideal situations, variations from these can result in significantly reduced efficiency and hence increased costs. The most significant risks to sand collection efficiency at Adelaide are:

- the accumulation of dead seagrass (seagrass wrack) on and within the sand
- water conditions, including sea water level and waves
- a low rate of sand collection compared with sand transport capacity.

Management of seagrass wrack at the Glenelg and West Beach harbours costs about as much as annual sand management. However, management costs are highly variable because seagrass wrack occurs in a sporadic and unpredictable manner. The future strategy plans to avoid the current extent of seagrass management costs and impacts. This will be achieved either by working around periods and locations of high seagrass wrack accumulation (for the Slurrytrak) or through the means of sand collection (for the Sand Shifters). The possibility of additional costs for the removal of surface seagrass wrack will be one of the aspects under investigation in the trials. The planned higher frequency of sand pumping will reduce the need to handle sand in which seagrass wrack has been entrained for some time. This is anticipated to reduce the exposure of black odorous decomposing seagrass that has been an offensive aspect of dredging operations at Adelaide's harbours.

Water conditions, such as sea water levels (high tides and storm surges) and high waves, tend to limit the efficiency and operating hours possible for floating dredges, resulting in non-productive standby costs. The Sand Shifter equipment is not affected by wave climate, so down-time from this cause is not a concern. Trucking on beaches is limited to times when high water levels do not occur, and work is therefore not undertaken in winter. Similar, although reduced, limitations apply to the use of the Slurrytrak. Consequently, water conditions pose less of a financial risk under the future strategy than under existing operations.

To maintain efficient sand management, the uplift of sand needs to be well matched to the transfer of sand. Currently this is achieved by ensuring an adequate number of sand carting trucks are available to work with a loader on the beach. However, dredge efficiency is less easily obtained, because the dredge needs to move location (a time-consuming activity) to keep within sections of the beach where the sand layer is deep enough to maintain efficient dredging. Similarly, the maintenance of sufficiently deep sand deposits for a Sand Shifter device may be problematic. This operational aspect can be managed by more intermittent operation of the Sand Shifter, allowing more time for sand to reach the collection point. The trials of the sand slurry pumping equipment will establish the efficiency of this approach. The Slurrytrak system has been developed to avoid rate of sand supply problems, as sand is fed by machinery to a hopper, which ensures efficient sand pumping.

Operating costs are based on annual averages of sand movements required, but the coastal environment is highly variable and therefore the actual operating costs in a given year can vary substantially. Annual net northward drift of sand on the Adelaide coast tends to be similar from year to year, but variations of up to 40% can occur in some years. The effect on operating cost would be less than 40%, as a proportion of the operating cost is fixed, i.e. independent of weather. The variation can be further minimised by maintaining dune buffers greater than necessary for coast protection, and accepting larger year-to-year variations in beach condition along the coast. However, this is associated with higher long-term costs due to extra sand requirements to build the buffers, or greater social impacts as beach loss occurs more frequently. On balance, it is more cost-effective in the long term to limit the quantity of externally sourced sand and maintain a high level of operational flexibility. Maintaining the operational flexibility inherent in the future strategy does require financial flexibility in annual operating budgets. It is estimated that variations in annual operating costs could be covered by an allowance of between 15% and 10% (depending on the selection of sand acquisition equipment) of the average operating cost.

Depending on how the coast reacts to further seagrass loss, seabed deepening and sea level rise, it has been anticipated that longshore drift rates will change over time. These will generally increase, but also vary along the coast. The future strategy is flexible enough to manage these changes. However, long-term operating costs may vary, and the sand volumes moved to maintain beaches need to monitored and compared with computer models of expected sand drift (based on weather conditions experienced). This will assist in determining whether sand management requirements, and hence operating costs, are increasing over time or whether variations are due to normal inter-annual weather variability.

7.1.7 Summary of economic assessment

This report has costed a number of options for managing Adelaide's metropolitan beaches. The preferred management option based on financial considerations is to recycle sand within each coastal management cell using a Sand Shifter and associated pipelines (or a similar system based on the same method). This option is the cheapest based on a 20-year time frame and is relatively flexible in terms of sand volumes. Considerable savings are achievable using this option compared to the existing management strategy.

Glenelg

7.2 Social impacts

For the purpose of this discussion, social impacts are defined as relating to recreation, amenity, visual aspects and machinery/noise interruptions or effects. The views of the community on the social impacts of coastal management activities are discussed in section 8.6.

7.2.1 Social impacts of beach replenishment

Over the last 30 years, beach replenishment has been carried out by excavating a layer of sand from the intertidal beach zone up to the toe of the sand dunes and carting it by truck to the beaches requiring replenishment. In the 1990s, dredging has also been undertaken.

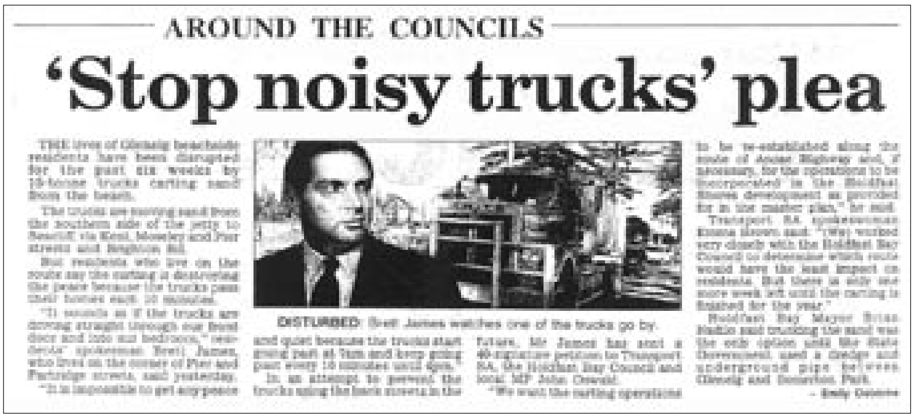
Trucks used are tandems of 11 m^3, or with trailers, 21 m^3, capacity, or semi-trailers of 23 m^3 capacity. Tandems are most suited to operation on the beach as semis are prone to bogging. In some cases, a rubble track on filter cloth has to be used for operations on the beach. Where truck movements can be confined solely to the beach, specialised articulated 6-wheel drive vehicles have been used. In a few cases, scrapers have been used for short land distances. Operations on beaches have to be limited to daytime hours, generaly from 7.00 am to 7.00 pm.

Generally, spreading and levelling of sand on the beach means the presence of trucks and machinery such as excavators and bulldozers. This restricts beach access and creates the possibility of injury. Earthmoving equipment is loud, especially when reverse warning alarms are in use, and nearby residents must endure their constant and unpleasant noise. The activities are often restricted to months when the number of people on the beach is at a minimum, but they still pose a risk, disturb beachside residents and deter visitors from using the beach.

Recent sand carting programs have focused on minimising beach use interference where possible by carting locally from neighbouring beaches and/or during autumn and spring when the beaches are used less. Winter periods are unsuitable because the more frequent higher tides limit access to a firm beach.

One of the concerns about trucking sand to Adelaide's beaches is the amount of disturbance and traffic congestion created along the beachside suburbs (see Figure 7.6), much of it in the Brighton and Seacliff areas. Rail crossings and roundabouts are common in these suburbs, and trucks need to slow or stop regularly, thus generating noise from braking and acceleration and air pollution from exhaust fumes.

To replenish sand at Brighton beach in the order of 75,000 m^3 annually, it is estimated that around 3300 semitrailer truckloads (with an average capacity of 23 m^3) would be needed – that is one truck every half-hour for 10 hours per day, five days each week over the six months of beach replenishment.



AROUND THE COUNCILS

'Stop noisy trucks' plea

THE lives of Glenelg beachside residents have been disrupted for the past six weeks by 10-tonne trucks carting sand from the beach.

The trucks are moving sand from the southern side of the jetty to Seacliff via Kent, Moseley and Pier streets and Brighton Rd.

But residents who live on the route say the carting is destroying the peace because the trucks pass their homes each 10 minutes.

"It sounds as if the trucks are driving straight through our front door and into our bedroom," residents' spokesman Brett James, who lives on the corner of Pier and Partridge streets, said yesterday.

"It is impossible to get any peace and quiet because the trucks start going past at 7am and keep going past every 10 minutes until 4pm."

In an attempt to prevent the trucks using the back streets in the future, Mr James has sent a 40-signature petition to Transport SA, the Holdfast Bay Council and local MP John Oswald.

"We want the carting operations to be re-established along the route of Anzac Highway and, if necessary, for the operations to be incorporated in the Holdfast Shores development as provided for in the master plan," he said.

Transport SA spokeswoman Emma Brown said: "(We) worked very closely with the Holdfast Bay Council to determine which route would have the least impact on residents. But there is only one more week left until the carting is finished for the year."

Holdfast Bay Mayor Brian Nadilo said trucking the sand was the only option until the State Government used a dredge and underground pipe between Glenelg and Somerton Park.

– Emily Osborne

DISTURBED: Brett James watches one of the trucks go by.

Figure 7.6 *Truck traffic at Glenelg (The Advertiser 2001)*

Henley Beach South

Clearly, if trucking sand is to continue, changes would be required to minimise the impacts on beachside residents. Depending on which beaches are to be replenished, designated routes or a variety of different routes would need to be established over times of least inconvenience to the community. Removal of humps and roundabouts (such as the roundabout at the junction of Edwards Street and the Esplanade, Brighton) or construction of a beach access ramp opposite Edwards Street have been suggested as ways to ease some of the noise, air pollution and disruption to traffic flow. The Department for Transport, Energy and Infrastructure, local councils and the community would need to be consulted about details of intended routes before changes could be made.

A dumping platform recently created opposite Edwards Street to facilitate beach replenishment is not adequate to handle large volumes of sand. Alternatives are needed. Other arrangements being investigated include a holding depot somewhere near Brighton Road with a pipe to transport sand to Seacliff and Brighton. Each alternative would require substantial funding for works programs or infrastructure.

To maintain Adelaide's beaches into the future, it will be necessary to continue recycling sand from areas of net gain, including Semaphore and the Torrens Outlet, even though some parts of the community wish to retain the current width of the beach and dunes in these areas.

7.2.2 Social impacts of using sand slurry pumping and pipelines

A major benefit of the future management strategy is that sand slurry pumping and pipelines would minimise the ongoing need for earthmoving machinery and trucks to cart sand along beaches and suburban roads.

A significant but short-term matter is the effect on beach amenity and public safety during construction of sand slurry pumping stations and pipelines. It is planned to fence off some beach areas, foreshore esplanades and footpaths during construction. All efforts will be made to maintain a safe route along the coast for pedestrians, as has been past practice for coastal works.

The Sand Shifter unit causes a depression or a hole approximately 20 m x 40 m x 6 m to be formed on the surface of the sand directly above the unit. The hole is covered by water, and signs are used to warn the public of this hazard. It is anticipated that the system would be fully automated and would operate at night under off-peak electrical power, thereby reducing operating costs and the effect on local residents and beach users.

The Slurrytrak system would operate during the day and its noise levels and low visual amenity would cause some slight inconvenience to beach goers, although this would be slight compared with trucking. In any case, the system can transfer sand at a much higher rate than traditional methods of excavating and trucking so the impact to any given area of the coast would not be ongoing. Being mobile, this system could not as easily be electrically powered and therefore noise levels in certain locations would be higher. The trials will include testing of noise minimisation equipment. The Slurrytrak requires an excavator to be on the beach during its operation to feed sand into the hopper.

Booster stations, which are required for each 2.2 km length of pipeline, are typically housed in buildings about the size of a shipping container that are insulated to reduce noise emissions. Both systems would pump sand only intermittently, thus minimising the time of discharge, which in general could be limited to night-time operation, particularly for electrically powered facilities. Electrically powered installations are quieter in operation but require a high-capacity power supply of around 1000 KVA.

A number of sand outlets are required at strategic locations along the coastline in areas of active erosion. Because seagrass and other material is separated through a screening process before entering the pipelines, discharged sand can be placed directly onto the beach with reduced nuisance odours and deleterious matter being present compared with dredging sand. A warning system will be installed at sand outlets to advise the public when sand pumping is taking place.

7.2.3 Social impacts of adding sand from external sources

The strategy makes allowance for the need to provide additional sand on metropolitan beaches, preferably coarser in grain size, to counteract land subsidence, sand loss and sea level rise. An estimated 25,000 m^3 of sand sourced from external supplies such as those at Mount Compass would be required each year for this purpose.

The Department for Transport, Energy and Infrastructure already receives a considerable number of complaints about the numbers of trucks travelling through Mount Compass (Hollister, pers. comm., 2005). If 25,000 m^3 of sand were sourced each year from Mount Compass in the future, the level of heavy traffic through the area would increase. This is likely to lead to an increased number of complaints from the public. The extra traffic would also increase wear on local roads and may increase congestion at the intersection of Victor Harbor Road and Main South Road. The Department for Transport, Energy and Infrastructure, local councils and the public would need to be consulted about intended routes. Safety issues and secondary costs such as increased wear on roads will be considered as alternative sand sources and methods of sand transport are evaluated.

If sand is imported from Mount Compass or another external source, the level of traffic through suburban streets near the coast would also increase. Methods such as a pipeline to the beach from the main arterial roads are being investigated to reduce this impact.

A further alternative is the use of sea freight to transport sand to Adelaide's beaches, most possibly from Yorke Peninsula. While the cost of sea freight is much higher for transporting smaller quantities of sand, it becomes comparable to road freight for quantities over 100,000 tonnes. Sand could be pumped directly onshore from the barges but spreading and levelling would still have to be undertaken on the beach. This would require sand moving equipment and may involve closure of sections of the beach.

7.2.4 Social impacts of using structures to slow sand

The use of structures to slow sand will be limited to a few critical locations because of their visually intrusive nature and potential interference to beach users and coastal residents. The trial breakwater at Semaphore is an important step in determining whether shore-parallel, 'least intrusive' structures can be effective in managing sand movement along Adelaide's coast.

Beach amenity and fencing off areas during construction

A significant but short-term impact is the effect of construction activities on beach amenity. The presence of machinery and construction activity on the coast always presents a public safety risk. Over many years of work on the coast, the Coast Protection Board has developed strict contract conditions to manage this risk. It is envisaged that sections of the beach will be closed to the public during construction work. During beach closures, which will be kept to a minimum, all efforts will be made to maintain a safe route along the coast for pedestrians, as has been past practice for coastal works.

Visual amenity

A major disadvantage of structures is their visual impact. To be effective, groynes and breakwaters have to be high enough to be exposed during most tidal conditions. However, careful design can minimise this impact by carefully choosing the height for the structure's purpose. There may also be scope for locating the structures where visual intrusion would be less important, but the criteria that influence location are varied and many. Structures would be located primarily to maximise their effectiveness for sand management.

Beach heights

An ongoing impact of the construction of large groynes would be the interruption of level and continuous access along the beach. Groynes work by building up sand on one side of the structure, meaning some erosion on the other side is unavoidable. This results in a step in the beach, potentially in the order of 2 m high. Such impacts of groynes are carefully considered by the Coast Protection Board and, in part, influenced its decision to adopt a breakwater strategy rather than using groynes at Semaphore Park. Breakwaters do not have such a hard effect on the coast and maintain easy alongshore access. Smaller groynes, such as those constructed at Somerton Park, have a lesser effect. Furthermore, where the groyne is built with a gap from the existing seawall, walking access along the beach is maintained.

Changes in currents

Groynes and breakwaters also influence nearshore waves and currents. A groyne, because of its cross-beach alignment, will redirect nearshore currents offshore to some degree. A series of breakwaters can also generate offshore currents between individual structures as the water set up on the coast by breaking waves runs back out to sea. The scale of these effects is related to the size and spacing of structures and becomes greater as wave conditions increase. The effects can be modelled and predictions would be made as part of the design process to minimise these impacts as a matter of public safety.

7.2.5 Social impacts of integrating sand bypassing at harbours with beach management

The rationalisation of sand bypassing requirements at Holdfast Shores and Adelaide Shores will reduce the impact of beach replenishment activities on beach users and local residents. Sand building up south of the harbours will be backpassed to the south using a beach-based slurry pumping system and pipelines. This more efficient system will minimise the need for trucks and earthmoving equipment on the beach. Changes in how dead seagrass is handled are likely to reduce the current odour impacts of accumulated rotting seagrass.

7.2.6 Summary of social impact assessment

One of the major benefits of the strategy for 2005–2025 is that it will reduce the impact of beach replenishment and harbour management activities on the community. There will be some periodic inconvenience associated with using pipeline transfer systems to recycle sand and adding sand from external sources, but the impact of this on the community will be less than that of the existing sand carting program. The use of structures to slow sand will be limited to a few critical locations because of their visually intrusive nature and potential interference to beach users and coastal residents.

Greater levels of artificial sand management, such as harbour bypassing, draw-down of dune reserves and reliance on importing sand, tend to result in greater variations in day-to-day beach condition. The social implications of this are:

- the need for access steps and ramps to go deeper into the beach to allow for lower beach levels
- the higher frequency of scarping of the dunes by storms as beaches adjust to varying levels. This may result in potentially dangerous sand 'cliffs', which could collapse causing injury.

As sand on the Adelaide coast is already highly managed and these risks already exist, these matters are managed by State and local government under beach access and storm response programs.

7.3 Environmental impacts

For the purposes of this discussion, environmental impacts are defined as relating to influences on biodiversity and ecosystem integrity, greenhouse gas emissions and level of demand on the State's sand resources.

7.3.1 Environmental impacts of beach replenishment

The potential environmental effects of beach replenishment programs fall into three categories: those at or near the placement location, those at or near the source of sand, and those from the methods of sand transport.

The Coast Protection Board has many years of experience in undertaking beach replenishment using sand from both within and external to the Adelaide beaches. As part of its beach replenishment program, the Board has undertaken and commissioned environmental impact investigations, put in place measures to minimise and manage environmental impacts, and commissioned studies to evaluate impacts that have occurred. Consequently, the Board is well placed to identify potential environmental impacts and prepare plans to manage these.

Sand placement on beaches

Placement of replenishment sand on beaches has the potential to:

- smother dune, beach face or benthic habitats
- add material that may be deleterious to habitats or ecosystems (e.g. fine materials that could increase water turbidity, or other contaminants)
- add organisms that may disrupt ecosystem integrity (e.g. seeds of invasive plants).

The strategy for 2005–2025 includes relatively frequent beach replenishment in quantities that have been selected to match littoral drift rates and are compatible with the scale of sand movement that naturally occurs on the coast. Therefore, the placement of sand can be undertaken mainly within the sandy part of the beach, without extending either into dunes or out to nearshore reefs and seagrass meadows. This would not be possible if larger beach replenishment operations were undertaken at less frequent intervals, because of the larger quantities of sand that would be involved in each operation. Beach face organisms are more resilient to smothering with sand and are better able to recolonise than dune and seabed plants and organisms. Consequently, the 'more frequent, smaller quantities' approach to beach replenishment has the lowest impact.

Most of the beach replenishment currently undertaken along the metropolitan coast is from sand recycled within the beach system, and this continues to be the case under the strategy for 2005–2025. Where sand is recycled in this way, no contaminants are added to the beach system. Where sand is obtained from external sources, fine material, such as silt or clay, should it be present within the sand, may increase water turbidity, either during sand placement or during storms when the sand is disturbed. To help minimise the potential for environmental impacts from turbidity, the strategy places a maximum limit of 5% on the amount of fine material (i.e. grain size less than 0.075 mm) that imported sand may contain.

Recycling sand from beach to beach carries a risk of spreading marine or terrestrial pests if sand is moved from affected areas to non-affected areas. The known environmental weeds on Adelaide's beaches with a high potential to be spread in this way are the dune onion weed (*Trachyandra divaricata*), perennial ragweed (*Ambrosia psilostachya*), and pyp grass (*Erhata villosa*). Subtidally, the most likely pest species to be spread are the invasive algae *Caulerpa taxifolia* and *C. racemosa*, and the sabellid fan worm, *Sabella spallanzani*. In past sand movement activities, the Board has undertaken follow-up surveys of pest dune plants and arranged for removal when pest plants were found. Continued vigilance in regard to dune weeds is inherent in the future beach management strategy. Potential marine sand sources will be examined for existence of pest species. Sabellid fan worm is already well established in northern metropolitan waters and has spread to southern areas (Brighton jetty). It may be spread more quickly by sand pumping operations under the future strategy.

Erosion of the dunes near the Semaphore jetty, July 2004

Sand removal from beaches

Coastal ecosystems can potentially be disrupted when sand is taken from beaches for recycling purposes. Those organisms that live or feed within the foredune areas are most affected, particularly dune vegetation communities. Where organisms are affected on a wide scale or over long periods, the coastal ecosystem may not be able to recover. However, in general when sand is taken from the beach in close proximity to the sand dune toe, the beach and dunes eventually readjust through movement of sand from offshore and from the sand dune, depending on sea conditions.

Organisms in nearshore beach and dune ecosystems tend to be resilient to these sand movements as beaches are a naturally high-energy environment, and sediment is transported regularly as a result of storms, waves and currents.

The impacts of sand recycling, and particularly of allowing draw-down of wider dunes, range from scarping of the dune face, causing unstable and potentially dangerous sand cliffs, to loss and changes to the vegetation communities of the dunes. If a dune face position is prevented from building seaward by continuous sand excavation, then it is likely that the primary dune will steepen compared with locations where sand builds up. This in turn will affect the composition of the colonising vegetation communities.

It is important to note that the value of recently created dunes (e.g. at the Torrens Outlet and Semaphore) is primarily for protection, beach amenity and a reservoir of sand rather than to provide a habitat for flora and fauna. The majority of dune colonising vegetation on Adelaide's coast is non-indigenous or cosmopolitan of low ecological significance, and often weed-infested. In contrast, the Tennyson and Minda dunes are remnants of the original Adelaide coastal dune field, containing many indigenous and some endemic species, and will therefore be preserved accordingly.

Transport of sand for beach replenishment

Historically, sand transport on the Adelaide coast has been by trucking, either along roads or along the beach, by dredging locally (such as harbour bypassing), or by pumping sand ashore from a dredge. The strategy for 2005–2025 precludes dredging of offshore sources in the immediate future but introduces the pumping of sand from beach to beach using shore-based pipelines. Potential environmental impacts from sand pumping and transport of sand from external sources (either dredging or sand mined from inland) are addressed in later sections of this report. The principle environmental impact of sand trucking is the resulting greenhouse gas emissions, and these are compared with the alternative approaches to pumping sand in the following section of this report.

7.3.2 Environmental impacts of using sand slurry pumping and pipelines

Potential environmental impacts of pumping and pipelines are those that directly relate to the construction, or the ongoing operation, of the infrastructure.

Impacts from the construction of pipelines and pumping stations

The land available for construction of alongshore pipelines is limited as the majority of Adelaide's coast is highly urbanised. Potential environmental impacts from pipeline construction are:

- interference with remnant dune areas
- excavation impacts such as spread of polluting materials, including clays.

Pipeline design and construction will be undertaken with reference to vegetation management plans and coastal management plans. Where damage to dune vegetation is unavoidable, care will be taken to avoid high-value habitats and species, minimise the spread of weeds and the area of disruption, and rehabilitate damaged areas.

Pipeline construction will require excavation and backfilling. Where the amount of excavated material exceeds backfill requirements, it will either be placed on the beach (if consisting of beach quality sand) or be disposed of off-site.

Impacts from ongoing operations

An assessment of the relative greenhouse gas emissions for alternatives means of transporting sand gives the following annual carbon dioxide emission rates:

Excavators and trucks	641	tonnes/year
Sand Shifters and pipelines	1,027	tonnes/year
Slurrytrak and pipelines	1,167	tonnes/year

In other words, the annual greenhouse gas emissions from operating Sand Shifters and pipelines is equivalent to the annual household greenhouse gas emissions for 380–400 South Australians (Australian Greenhouse Office 1998).

Carbon dioxide emissions for the trucking option are exclusively due to the use of diesel fuel as an energy source. For the Sand Shifters and pipelines option, emissions are due to the use of electrical power. For the Slurrytrak and pipelines option, emissions are due to the use of diesel fuel by the plant and electrical power to pump the slurry mix.

The substantial difference in emissions between the excavators and trucks method and the sand pumping methods is due to the fact that not only sand but also water is being pumped through the pipelines, in the form of a slurry mixture. The percentage of sand in the slurry mixture is in the order of up to 40% by weight. Hence, the sand pumping methods are moving at least 60% more mass than the excavators and trucks method. This requires a greater quantity of energy to be expended per volume of sediment transported, which increases the total volume of carbon dioxide being released to the atmosphere.

7.3.3 Environmental impacts of adding sand from external sources

The potential environmental impacts of adding sand to the beach from external sources are similar to beach replenishment generally, but include potential impacts at the source area. Use of sand from external sources is considered below, under three categories: effects at or near the placement location, those at or near the source of sand, and those arising from sand transport.

Placement of sand from external sources onto beaches

Potential issues reflect those for beach replenishment, considered in section 7.3.1, and are managed in similar ways. These are localised smothering of flora and fauna, introduction of contaminants, and spread of pest plants or animals. Of these, the latter two are of particular relevance to placement of sand from external sources.

Where sand is from non-coastal sources, the inclusion of contaminants is the main concern. Investigation of contaminant levels is integral to the selection of sand sources, and limits are placed on fines content of sand. Introduction of a new weed species is unlikely, due to the harsh conditions in dunes and the tendency of most non-coastal plant seeds to be sterilised by salt water.

Effects of sand mining at external sand sources

Potential land-based external sources with sand suitable for beach replenishment include Mount Compass, Nalpa (near Lake Alexandrina) and the northern Yorke Peninsula (see section 5.1.3). Impacts from sand mining can be considerable and include issues such as erosion, the loss of other land uses, potential groundwater pollution and the spread of soil-borne diseases such as the fungus *Phytophora cinnamomi*. Many of these impacts are managed and minimised by operators of existing mines through government legislation and mining lease conditions. The strategy for 2005–2025 includes the use of these existing mechanisms to minimise impacts from land-based sand mining.

The Coast Protection Board has expended much effort since the 1970s searching for suitable offshore sand sources to further replenish Adelaide's metropolitan beaches (see section 5.1.2). Over 1 million m^3 of sand was dredged during the 1990s offshore from Port Stanvac and placed into Adelaide's beach system at Brighton and Seacliff. Dredging can cause sediment plumes. In 1997, a sediment plume extended many kilometres from the dredge site at Port Stanvac. The plume was caused at least partly because a very large dredge was used (an 8000 m^3 capacity dredge compared with the previously used 965 m^3 capacity dredge).

Important lessons were learnt from this dredging incident. The potential effects of dredging sand from offshore sources have been carefully considered during the selection of future sand sources for the strategy for 2005–2025. Recent investigations for new marine sand sources have included research and field inspections to determine the potential impacts of sand removal. These include investigations into direct impacts on local benthic fauna and indirect impacts (e.g. from turbidity plumes or changes in wave conditions that may result from dredging).

Many marine organisms in the immediate vicinity of the dredging operation are scooped up with sand and cannot survive. However, some organisms are able to sink back down to the substrate and become re-established. In any case, many marine organisms are adapted to living in physically unstable environments, so they have characteristics such as a high reproductive output and fast growth that enable rapid re-colonisation of nearby disturbed habitats. Indeed, studies of the former dredge site offshore from Port Stanvac have shown that recruitment of organisms back into the area has occurred rapidly such that the marine community has recovered within 12 months of dredging. Nevertheless, there is the potential that ecosystems could be disrupted during dredging beyond their ability to recover.

The sediment plumes that can be created by dredging can affect nearby seagrass or reef habitats. The extent to which sediment plumes affect seagrasses or other habitats depends on the tide and wave currents during and immediately after dredging, as well as the overall health and ability of the ecosystem to recover from smothering. A reef health study carried out after the Port Stanvac dredging indicated long-term impacts on some southern metropolitan reefs such as Noarlunga. Turner and Cheshire (2002) clearly demonstrated that such a dispersed sediment plume could cause serious impacts to reef systems with effects still visible after five years.

Where dredging occurs, the seabed is deepened and this can change wave conditions in the area. This in turn may affect mangrove and samphire communities, where present, or alter sediment drift rates along the coast and therefore beach and dune widths. It is important in situations where these effects need to be avoided to appropriately design the dredge area so that its depth, distance offshore and configuration have taken these considerations into account. For this reason, a nearshore limit was placed on the area for dredging near Port Stanvac. However, studies of sand movement onshore from the former Port Stanvac dredging site have shown that seabed deepening has not affected sand movement and local beaches.

A numerical model of waves, including how they would be affected by sand dredging, has been undertaken for the Section Bank area. When dredging of the area is considered further, this model will be used to guide the selection of dredge locations so that changes to waves conditions have the least impact on the adjacent coast.

Investigations into the vulnerability of the seagrass and mangrove ecosystems in the Barker Inlet to turbidity plumes and changed wave conditions from seabed deepening have also been undertaken. These show that the ecosystems in the area are already highly stressed and vulnerable to further damage. The investigations showed that it was unlikely that dredging would present a high risk of further environmental harm, but that it may speed the loss of seagrass and mangroves somewhat. Due to the risks that dredging may be seen to pose to these coastal ecosystems, it has been decided that alternative external sand sources will be used to replenish Adelaide's beaches in the immediate future (over the next five years or so). This could be reviewed when methods for sand extraction and site rehabilitation have been determined that would minimise environmental risks.

Transport of sand from external sources

Where sand is moved from inland sources to the coast, potential environmental impacts are limited to those that may occur if additional roads or railways are constructed, or existing infrastructure altered. Importing sand from one of these land-based sources will require the use of extra trucks, which will result in an increase in greenhouse gas emissions. This will be considered further at the development application stage, as the strategy allows for a number of alternative routes and methods of transport. It is noted, however, that these alternatives are located in rural and urban areas where sand trucking (for other purposes) already occurs.

The method of transferring sand from a dredge to shore also presents environmental risks. Adelaide's nearshore seabed is shallow relative to the draught of dredges, and the alternative of barging sand has significant economic and environmental implications (such as spillage of sand during loading and travel, and direct impacts at the discharge location). Therefore, sand is pumped onshore in large pipes, which are floated into position then sunk onto the seabed. This can have direct impacts on benthic fauna. While not of ecosystem significance, there is the potential that any impacts will be long-lasting due to the poor health of the nearshore seagrass beds along the Adelaide coast. Consideration therefore needs to be given to the location of temporary nearshore pipelines and the method of placement of the pipes.

7.3.4 Environmental impacts of using structures to slow sand

Possible environmental impacts, in a general sense, from the construction of groynes or breakwaters include:

- direct impact from construction (seagrass meadows are particularly vulnerable)
- turbidity during construction causing light attenuation and/or sedimentation (smothering)
- impacts on benthic fauna from loss of space and ongoing changes to currents and waves
- creation of conditions suitable for pest species
- environmental effects on sand source areas (to supply sand for salients or fillets).

Impacts on coastal flora and fauna

It is important to note that structures to slow sand movement along the Adelaide coastline will not be built over existing seagrass. This is because the structures need to be built within 500 m offshore, and seagrass loss has already progressed well beyond this point. Moreover, the Coast Protection Board supports the preservation of the remaining seagrass meadows, so would not act to harm them.

Similarly, the sites where sand-slowing structures have been identified as feasible are far enough from existing seagrass meadows that any turbidity created by the structure's construction is not likely to be a risk (ID&A 2001). Nevertheless, detailed assessments of this would be required as part of the design and environmental assessment process. Other structures that will be considered in implementation of the strategy would similarly be sited far from seagrass meadows.

Benthic infauna are generally capable of quick re-establishment if disturbed, and in many cases their communities are likely to recover from a disturbance within a 12-month period.

Pest species

New structures might provide conditions that favour pest species over endemic species. The effect of harbouring pest species would be incremental, as there are a significant number of structures along the coast capable of this. These include the metropolitan jetties, existing groynes and breakwaters, the blocks at Glenelg and reef outcrops. However, it is noted that new constructions provide empty spaces for settlement in which pest species are more likely to gain a foothold.

Impacts on sand source sites

Structures such as groynes and breakwaters lock up considerable quantities of sand, which is relatively scarce. For example, the breakwater recently built at Semaphore South used 120,000 m^3 of sand in the structure itself and the salient created. The possible impacts on sand source sites are dealt with in sections 7.3.1 and 7.3.3.

Because the sand locked up in groynes and breakwaters is unlikely to be affected by almost all but the most severe storms, fine sand from the northern beaches might eventually become sufficiently economical to be used for this purpose. However, this will only be likely when the alternative existing impounded sand sources have all been redistributed. In particular, it could be economical to link the dredging of the North Haven marina channel with the construction of further breakwaters at Semaphore Park, using the temporary pipeline installed for backpassing sand from the existing breakwater.

7.3.5 Environmental impacts of integrating sand bypassing at harbours with beach management

The integration of sand bypassing requirements at the Glenelg and West Beach harbours with the beach management program will reduce the amount of sand and seagrass that will need to be dredged from the harbours. There will be changes in how dead seagrass is handled and this is anticipated to reduce impacts on water quality. The sand pumping trials conducted during the implementation of the strategy for 2005–2025 will establish the relative effectiveness of different types of sand collection equipment in this regard.

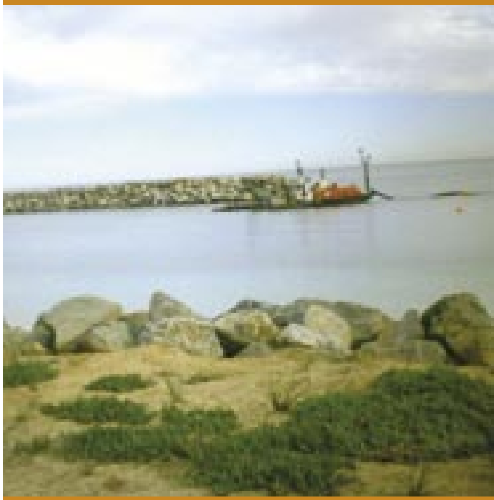
7.3.6 Summary of environmental impact assessment

Due to the scale of erosion taking place along the Adelaide metropolitan coast and the vulnerable state of coastal ecosystems, especially seagrass meadows, sand management activities and hence environmental effects are unavoidable. The Department for Environment and Heritage has identified potential consequences from the range of coast protection alternatives and weighed up the likely risk and extent of these, and the degree to which they can be avoided.

The Department considers that the greatest environmental risk associated with future beach replenishment and sand management activities is the risk of continued degradation of seagrass meadows and other marine ecosystems. Furthermore, the Department concludes that the highest risk activities are those that add to the turbidity load of the local waters. This is most likely to occur when sand is introduced to the beaches from external sources. Consequently, the Department has favoured beach management approaches that require the minimum volume of sand to be added to the system, although some additional sand is needed to compensate for sea level rise and other changing coastal conditions.

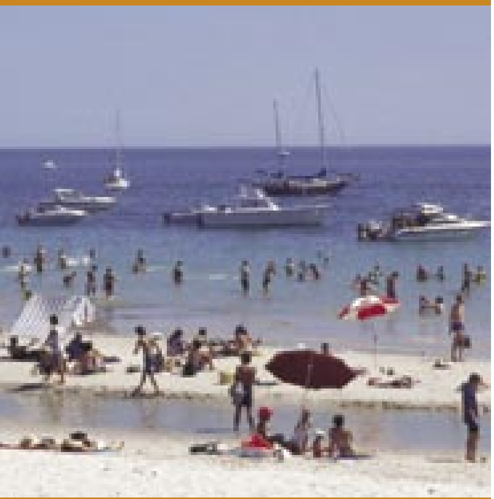
On the basis of the environmental impact assessment contained in this report, the Coast Protection Board has concluded that the strategy for 2005–2025 provides an approach to future sand management activities that will maintain good beach conditions without significantly affecting the environment. Where there are impacts on the environment, they are less than those associated with alternative approaches. In addition, there are feasible means of minimising the impacts. In reaching this conclusion, the Board noted that:

- all construction activities will require planning approval and a more detailed impact assessment
- there will be a reduction in the area of vegetated sand dunes along the Adelaide coast, but vegetated areas of particular value (e.g. the Tennyson and Minda dunes), along with the landward portions of dunes that form part of the buffer to storm damage, will be rehabilitated or preserved
- further dredging of offshore sand deposits is not proposed unless studies can demonstrate that environmental impacts are less than those associated with alternative approaches
- where sand is obtained from external sources, conditions will be placed to limit the amount of fine material contained
- assessment of environmental impacts and mitigation measures is included in the strategy for sand extraction at external sources, whether land or marine deposits.



Dredge operating in the West Beach harbour, 2005

Brighton jetty



Glenelg

Tennyson dunes

8. Community Education and Consultation

Adelaide's coastline is one of the defining characteristics of the city, widely recognised as an integral component of our cultural identity and quality of life. As well as being a focus for urban development, industry, employment and tourism, the coast caters for a range of recreational activities including walking, swimming, sailing, and simply relaxing and enjoying the scenery. In addition, the beaches provide a venue for social gatherings and functions, sporting clubs and events, and environmental care and education.

Community involvement in coastal management is supported by various Australian, State and local government policy statements. For example, the State Government's *Living Coast Strategy* (2004) states that 'all levels of government, industry and the community need to share responsibility for the management and protection of our coast'. In other words, the community has the right to not only be informed about issues facing the beaches and their possible solutions, but also to be involved in decisions about how the beach is managed. Community members often bring valuable experience, knowledge and skills to coastal management activities.

The 1997 *Review of the Management of Adelaide Metropolitan Beaches* found a need to devote more attention to public education and consultation on Adelaide beach management. The Coast Protection Board has since undertaken a detailed community education and consultation strategy. Community views on the management of Adelaide beaches have been used to inform the development of *Adelaide's Living Beaches: A Strategy for 2005–2025*.

8.1 Information resources

Several information resources have been produced during recent years to educate the community about the need for an effective future beach management strategy, including the brochures *Protecting Adelaide's Beaches* and *Do Adelaide's Beaches Need Help?* These brochures have been distributed through local councils, community centres and libraries, and are available on the Coasts and Marine section of the Department for Environment and Heritage's website at <www.environment.sa.gov.au/coasts/>. The website provides useful information on Adelaide beach management and other coast and marine strategies and policies, and has links to a wide range of educational resources and activities.

Public information session held in November 2004 at the Henley Sailing Club

8.2 Public meetings

A number of public meetings since the 1997 review have informed local residents and community groups about future beach management activities. For example, a series of meetings was held before the Semaphore Park Coast Protection Strategy began. A meeting was also held in November 2004 on removal of sand over the next five years from the beach south of the Torrens Outlet.

Further public meetings will be held prior to the installation of a permanent sand slurry pumping system, in conjunction with the necessary development applications.

8.3 Local government and community partnerships

For a number of years, representatives from the Department for Environment and Heritage have been involved in the Metropolitan Seaside Councils Committee, which represents the Cities of Port Adelaide Enfield, Charles Sturt, West Torrens, Holdfast Bay, Marion and Onkaparinga, as well as Adelaide Shores. Councils have been encouraged to assist the Department by keeping residents and business informed of relevant issues.

Participation in the City of Charles Sturt Community Coastal Reference Group has facilitated communication between the Department, community groups and the council on coastal issues, activities and management strategies. The group, which was formed in mid-2003 and meets once a month, has 12 members including two elected members appointed by the council, seven coastal community representatives and a representative from the Department for Environment and Heritage.

8.4 Focus group

In early 2003, a focus group was formed to gain some initial insights into community views on beach management and provide assistance in identifying potential stakeholders. The focus group included representatives from Coastcare, the Conservation Council of SA, the Port Adelaide Residents Environment Protection Group, the Henley and Grange Residents Association, the Friends of Patawalonga Creek and the Marine Discovery Centre.

Stakeholders identified to date are listed in Table 8.1. Stakeholders will be notified regarding major developments associated with the implementation of the strategy.

Table 8.1 *Adelaide beach stakeholders*

General community/beach users, coastal residents, coastal community groups	
City of Charles Sturt Community Coastal Reference Group	Henley and Grange Residents Association
City of Holdfast Bay Environmental Advisory Committee	Marine and Coastal Community Network
Coastal Ecology Protection Group	Port Adelaide Residents Environment Protection Group
Friends of Fort Glanville Conservation Park	Semaphore Park Coastcare Group
Friends of Gulf St Vincent	Southern Districts Environment Group
Friends of Patawalonga Creek	Tennyson Dunes Group
Glenelg Residents Association	West Lakes/Grange Kiwanis
Henley and Grange Dunecare Group	
Indigenous groups	
Local communities	South Australian Aboriginal Heritage Committee
Environmental groups	
Conservation Council of SA	Reefwatch
Greening Australia (SA)	Trees For Life
KESAB (Keep SA Beautiful)	Wetlands Care Australia
National Trust of SA	
Recreational activity groups	
Cruising Yacht Club of SA	South Australian Recreational Fishing Advisory Council
Royal South Australian Yacht Squadron	Surf Life Saving SA
State Government	
Adelaide and Mount Lofty Ranges Natural Resource Management Board	Department of Water, Land and Biodiversity Conservation
Adelaide Shores (West Beach Trust)	Environment Protection Authority
Barker Inlet Port Estuary Committee	LMC
Department for Aboriginal Affairs and Reconciliation	Mount Lofty Ranges and Greater Adelaide Integrated Natural Resource Management Group
Department for Environment and Heritage	SA Tourism Commission
Department for Families and Communities	SA Urban Forest Biodiversity Program
Department for Transport, Energy and Infrastructure	SA Urban Forest Million Trees Program
Department of Primary Industries and Resources SA	SA Water
Department of Trade and Economic Development	South Australian Research and Development Institute
Department of Treasury and Finance	
Local government	
City of Charles Sturt	City of Port Adelaide Enfield
City of Holdfast Bay	City of West Torrens
City of Marion	Local Government Association of SA
City of Onkaparinga	Metropolitan Seaside Councils Committee
Commercial and industrial enterprises	
Boating Industry Association of SA	Local businesses and traders
Business SA (SA Employers' Chamber of Commerce & Industry)	North Haven marina
Coastal developers	Port Adelaide Enfield Chamber of Commerce
Engineering service providers	South Australian Fishing Industry Council
Holdfast Bay Chamber of Commerce	Tourism representatives
Holdfast Shores (Baulderstone Hornibrook & Urban Construct)	

8.5 State and local government consultation

The Department for Environment and Heritage has undertaken consultation with relevant State and local government bodies during the development of the strategy for 2005–2025.

State Government agencies all supported the proposed strategy when it was distributed for comment as part of the Cabinet submission process in 2005.

Preliminary meetings about the strategy took place with representatives from directly affected councils (the City of Port Adelaide Enfield, the City of Charles Sturt, the City of West Torrens and the City of Holdfast Bay) and Adelaide Shores (the West Beach Trust) in early 2005. The participants indicated their provisional support for the basic elements of the strategy, particularly regarding the reduced impact on beach users and local residents, but requested more detailed information on future council responsibilities and financial obligations. Further discussions to clarify these issues are scheduled to take place with councils after the public launch of the strategy. However, at this stage there is no expectation that local government will be required to adopt new or expanded services or functions under the strategy. Rather, it is expected that the current arrangements will continue – whereby the Coast Protection Board provides grants to councils to assist in coastal works – subject to possible preparation of a Bill to amend the *Coast Protection Act 1972*. In keeping with the *State–Local Government Relations Agreement 2004*, consultation will take place with affected councils prior to implementing a new service or significantly varying an existing service or program that impacts on local government.

8.6 Summary of the community's views on beach management

Comments from the beach users survey (see section 5.5) have been incorporated with submissions from the 1997 *Report of the Review of the Management of Adelaide Metropolitan Beaches* to produce a summary of the community's views on beach management. Views have been categorised according to stakeholder groups and the attributes of the beach these groups consider a priority (Tables 8.2–8.8).

Table 8.2 *Views of the general public/beach users*

Priorities	Views on beach management
Clean beach and water	Discharging stormwater and effluent into the ocean is a major cause of poor water quality.
	Better management of stormwater and effluent would assist in maintaining sand on the beaches, due to decreased loss of seagrass.
Maintenance of sand on beaches for social/ recreational opportunities	Better 'dune care' (including drift net fencing, revegetation and prohibitions on access) would assist in maintaining sand on the beaches, due to keeping the sand in place and providing sand reservoirs.
	Beach replenishment (sand carting and/or dredging) maintains sand on the beaches but has several disadvantages: • interferes with social/recreational activities • 'band aid' measure that cannot go on indefinitely • 'unnatural' • detrimental to the natural habitat • ineffective because sand dumped in the tidal zone gets washed away • beneficial to one beach at the expense of another • traffic congestion • high cost.
	Using pipelines to pump sand from areas of accumulation to areas of erosion would be an effective method of maintaining an even distribution of sand on the beaches. This method would also cause little interference to the lifestyle of local residents once construction was complete. Disadvantages: • massive operation • very expensive • interferes with social/recreational activities during construction phase.
	Offshore breakwaters and groynes may be effective methods of maintaining sand on the beaches, and would cause less interference to social/ recreational activities than beach replenishment. Disadvantages: • visually intrusive • alter shape of the coast • interfere with some social/recreational activities.
	Offshore breakwaters preferred to groynes because: • less visually intrusive • less interference with natural sand movement • reduce the impact of waves reaching the shore • retain more of a natural look to the beach.
	More effective development controls and selective buy-back of coastal properties would help restore the dune system. Disadvantages: • 'impractical' • very expensive • unfair to coastal residents.
Toilets/ shops/kiosks	Beach replenishment/recycling and structural solutions protect foreshore development and infrastructure.

Table 8.3 *Views of coastal residents and community groups*

Priorities	Views on beach management
Protection from erosion and storm damage for properties and infrastructure	Beach replenishment/recycling and structural solutions protect foreshore development and infrastructure.
	If beach replenishment is carried out, the sand should be placed at the back of the beach and secured with drift net fencing and revegetation.
	Seawalls are the only way to protect property against major storms.
Property values	Maintenance of sand on beaches protects property values.
	Structural solutions may decrease property values if visually unappealing.
	There is considerable economic pressure to maintain, if not extend, the area of encroachment onto dunes.
	Taking sand from the beaches of the Lefevre Peninsula to replenish other parts of the coast decreases local property values.
'Coastal lifestyle', including scenic amenity, physical proximity, clean beach, clean water and social/recreational opportunities	Beach replenishment (sand carting and/or dredging), structural solutions and retreat/buy-back all interfere with the lifestyle of local residents.
	Using pipelines to pump sand from areas of accumulation to areas of erosion would be an effective method of maintaining an even distribution of sand on the beaches. This method would also cause little interference with the lifestyle of local residents once construction was complete.
	Better 'dune care' (including drift net fencing, revegetation and prohibitions on access) would assist in maintaining sand on the beaches, and contribute to the lifestyle of local residents. It may be a cheaper, more effective and more natural way to maintain sand on the beaches than beach replenishment.
	Better management of stormwater and effluent would assist in maintaining sand on the beaches, and ensure cleaner water.
Conservation and/or restoration of sand dunes, dune vegetation, and associated habitats for birds, reptiles and other animals	Beach replenishment/recycling and structural solutions protect sand dunes, dune vegetation, and associated habitats.
	Dune build-up on the beaches of the Lefevre Peninsula (e.g. at Semaphore) creates a larger area for dune plants and animals.
	Sand should not be taken from the beaches of the Lefevre Peninsula to replenish other parts of the coast.
Maintenance of sand dunes/beach width because of inherent natural and cultural value	The northerly drift of sand is a natural process, so it should not be interfered with. Sand should not be taken from the beaches of the Lefevre Peninsula to replenish other parts of the coast.

Table 8.4 *Views of Indigenous groups*

Priorities	Views on beach management
Kaurna heritage sites	Sand management activities may interfere with Kaurna heritage sites.

Table 8.5 *Views of environmental groups*

Priorities	Views on beach management
Reluctance to interfere with the natural coastal processes	Beach replenishment/recycling and structural solutions all interfere with the natural coastal processes.
	The northerly drift of sand is a natural process, so it should not be interfered with. Sand should not be taken from the beaches of the Lefevre Peninsula to replenish other parts of the coast.
	Retreat/buy-back allows the natural coastal processes to determine the structure of the coast and the distribution of the sand.
	Retreat/buy-back would provide a wider buffer zone between the coast and foreshore development, release sand locked underneath developments, and counter the effects of ongoing sea level rise.
	Better management of stormwater and effluent would ensure cleaner water and prevent loss of seagrass.
	'Dune care' (including drift net fencing, revegetation and prohibitions on access) may be a cheaper, more effective and more natural way to maintain sand on the beaches than beach replenishment.
Conservation and/or restoration of sand dunes, dune vegetation, and associated habitats for birds, reptiles and other animals	Beach replenishment/recycling and structural solutions protect sand dunes, dune vegetation, and associated habitats.
	Dune build-up on the beaches of the Lefevre Peninsula (e.g. at Semaphore) creates a larger area for dune plants and animals.
	The beaches of the Lefevre Peninsula are a unique and environmentally sensitive part of the coastline. Sand should not be taken from the area to replenish other parts of the coast.
	'Dune care' (including drift net fencing, revegetation and prohibitions on access) important for protecting coastal environment.
Terrestrial biodiversity	Terrestrial organisms are affected by taking sand from the beach, sand deposits or quarries.
Marine water quality and biodiversity	Sand management activities (such as beach replenishment, harbour bypassing, and especially dredging) may lead to increased suspension of sediment and organic particulate, which decreases water clarity and can increase nutrient levels and biological oxygen demand.
	Sand from land-based sources may contain fine particles such as clay and silt.
Coastal ecosystems	Mangroves in the Barker Inlet may be affected by dredging of the Section Bank.

Table 8.6 *Views of recreational activity groups*

Priorities	Views on beach management
Clean beach and water	Better management of stormwater and effluent would improve water quality.
Maintenance of sand on beaches for recreational activities	Beach replenishment (sand carting and/or dredging), structural solutions and retreat/buy-back may interfere with recreational activities.
	Using pipelines to pump sand from areas of accumulation to areas of erosion would be an effective method of maintaining an even distribution of sand on the beaches. This method would also cause little interference with recreational activities once construction was complete.
Public safety	Beach replenishment/recycling and structural solutions may endanger the public.
Viable boat ramps and marinas	Harbour management is important for maintaining the viability of marinas.
	Beach replenishment and subsequent sand drift can result in boat ramps being covered with sand.
	Natural processes cause sand build-up at North Haven, which clogs the entrance channel to the marina, resulting in high management costs.

Table 8.7 *Views of local government*

Priorities	Views on beach management
Maintenance of sand on beaches for constituents	Beach replenishment (sand carting and/or dredging), structural solutions and retreat/buy-back all interfere with the social/ recreational opportunities of constituents.
	Using pipelines to pump sand from areas of accumulation to areas of erosion could be an effective method of maintaining an even distribution of sand on the beaches. This method would also cause little interference with the lifestyle of constituents once construction was complete.
Protection from erosion and storm damage for residential and commercial property, foreshore reserves and public infrastructure	Beach replenishment/recycling and structural solutions protect foreshore development and infrastructure.
	'Dune care' (including drift net fencing, revegetation and prohibitions on access) is important for protecting foreshore reserves. It may be a cheaper, more effective and more natural way to maintain sand on the beaches than beach replenishment.
	Wind-blown drift of replenishment sand may cover boat ramps, paths and roads, and block stormwater drains.
Increased residential and commercial property values leads to increased revenue	Maintaining sand on beaches protects property values.
	Structural solutions may decrease property values if visually unappealing.
Conservation and/or restoration of sand dunes, dune vegetation, and associated habitats for birds, reptiles and other animals	Beach replenishment/recycling and structural solutions protect sand dunes, dune vegetation, and associated habitats.
	Dune build-up on the beaches of the Lefevre Peninsula (e.g. at Semaphore) creates a larger area for dune plants and animals.

Table 8.8 *Views of commercial and industrial enterprises*

Priorities	Views on beach management
Protection for commercial and industrial property and investments	Beach replenishment/recycling and structural solutions protect foreshore development and infrastructure.
	Maintenance of sand on beaches protects the value of investments.
	Retreat/buy-back could decrease the value of property and investments.
	Harbour management is important for maintaining viability of marinas, businesses and residential property.
Maintenance of sand on beaches for customers	Beach replenishment (sand carting and/or dredging), structural solutions and retreat/buy-back all interfere with the social/ recreational opportunities of customers.
	Using pipelines to pump sand from areas of accumulation to areas of erosion would be an effective method of maintaining an even distribution of sand on the beaches. This method would also cause little interference with the social/recreational opportunities of customers once construction was complete. Cost of this strategy is not a factor because it would be borne by the community as a whole.

8.7 Outcomes of community consultation to date

The community's views on beach management have been given due consideration in the development of the strategy for 2005–2025.

The community clearly agrees that sand must be maintained on the Adelaide beaches, not only for protecting coastal properties and infrastructure but also for the social, recreational and economic benefits a sandy beach provides. However, they see a need to reduce the impact of beach replenishment and sand slowing activities on beach users and coastal residents.

In response, the strategy for 2005–2025 will use sand pipelines to recycle sand more effectively and minimise the need for trucks and earthmoving equipment on beaches and suburban roads. Sand bypassing at harbours will be integrated with the management of the rest of the metropolitan coast to manage the whole beach system more effectively. Structures such as groynes and breakwaters will only be used in critical locations, because of their visually intrusive nature and potential interference to beach users and coastal residents. Seawalls are the last line of defence against erosion by waves and storms and will be upgraded where necessary to modern standards including future sea level rise predictions. Some external sand will need to be added to the Adelaide beaches to counter the ongoing loss from relative sea level rise and sand 'escaping' from the system. Selective buy-back of coastal properties is extremely expensive and unfair to coastal residents, so this option has been dismissed.

The spread of sand along the coast will need to be altered from its present distribution to provide greater equity and the best possible use of resources. Some community members wish to retain the current width of the beaches and dunes of the Lefevre Peninsula, but much of this sand has only recently drifted into the area from the south. Erosion and accumulation patterns have been altered by factors such as seagrass loss, so some of the sand in this area will need to be used to protect areas of erosion on other parts of the coast.

The value of recently created dunes (e.g. at the Torrens Outlet and Semaphore) is primarily as a buffer to provide protection and beach amenity rather than for the conservation of biodiversity. The dunes need to be vegetated to prevent sand drift and this provides a secondary benefit as habitat for birds and animals. Even so, part of these dunes could be eroded away in one storm event and should therefore be seen as expendable. In contrast, the Tennyson and Minda dunes are remnants of the original Adelaide coastal dune field and will be preserved and restored accordingly.

Operations such as water quality monitoring and stormwater management are administered primarily by other government agencies. The Adelaide Coastal Waters Study, established by the EPA in 2001, is investigating the decline in water quality and continuing loss of seagrass on the Adelaide metropolitan coast. For more information on water quality monitoring and stormwater management, visit the following websites:

- Department for Environment and Heritage <www.environment.sa.gov.au>
- Environment Protection Authority <www.epa.sa.gov.au>
- Department of Water, Land and Biodiversity Conservation <www.dwlbc.sa.gov.au>
- Department for Transport, Energy and Infrastructure <www.dtup.sa.gov.au>
- SA Water <www.sawater.com.au>
- Local Government Association of SA <www.lga.sa.gov.au>

The Coast Protection Board is continuing to take part in seagrass rehabilitation investigations in conjunction with SARDI. The investigations are producing encouraging results and it may be possible to reduce further increased rates of coastal erosion as well as provide benefits to the marine ecosystem (see section 5.3).

Adjunct operations such as drift fencing, dune revegetation and access control are important components of protecting the coastal environment and will be incorporated into the strategy for 2005–2025 where possible. However, these activities alone would never be able to maintain sufficient sand on the Adelaide beaches (see section 4.5). Information about dune care programs can be accessed through each of the seaside council websites or via links from the Local Government Association of South Australia <www.lga.sa.gov.au>.

8.8 Future community consultation on the strategy

Adelaide's Living Beaches: A Strategy for 2005–2025 has not been released for a period of formal public consultation because of the extensive consultation on various management options that has already taken place over recent years. However, over the coming years, affected individuals and groups will be consulted before components of the strategy (e.g. pumping stations and pipelines) are constructed, in conjunction with the necessary development applications.

Glossary

Interpretation of terms used in this report

Accretion	any gradual increase in size of a land or dune area through growth or external addition of material such as sand
Active beach zone	the section of the beach from where the waves start to break to where the wave uprush finishes, including areas affected by storms
Ascidians	soft-bodied marine animals that attach to a hard substrate (e.g. seafloor or reef)
Australian Height Datum (AHD)	an assigned sea surface curve based on mean sea level at 30 tide gauges around the Australian coast
Benthic	existing on, in or near the seafloor
Bioclasts or biogenic fragments	angular fragments in sediments of biological origin (e.g. fragments of shells, foramina, sponges and diatoms)
Beachface	the section of the beach normally exposed to the action of wave uprush
Beach replenishment	a management process to resupply sand to sandy beaches undergoing erosion
Breakwater	a structure of rocks and/or other materials usually built in the water and often parallel to the coast; in dynamic environments, a breakwater creates a physical barrier that slows down the alongshore movement of sand
Bypassing	manual movement of sand from one side of a coastal structure to the other to continue sand movement as if unobstructed (e.g. moving sand from the south of the West Beach boat haven to the north)
Carbonate sand	sand consisting of calcium carbonate ($CaCO_3$) grains and fragments of biological origin (e.g. shells and coral) or from the breakdown of carbonate minerals (e.g. gypsum)
Chart datum* (CD)	a permanently established surface from which tide heights or chart soundings are referenced, usually Indian spring low water (ISLW) or lowest astronomical tide (LAT); the zero level of tide heights
Consumer price index (CPI)	a measure of changes, over time, in retail prices of goods and services representative of expenditure by consumers
Coralline algae	small marine plants that incorporate calcium carbonate into their tissues and often live as colonies in temperate waters
Diatoms	microscopic freshwater to saline algae consisting of a siliceous skeleton
Discount rate	the rate, per year, at which future costs are diminished to make them more comparable to values in the present
Effective beach width	the width of the dry sandy part of the beach
Ephemeral (foredune vegetation)	existing for a fleeting period due to limitations in water availability or other suitable conditions
Epiphytes	plants and animals that grow on other plants but that do not obtain food, water or minerals from them

Equilibrium angle	the angle of the beach (as viewed from above) at which the breaking wave crests during average conditions are parallel to it
Equilibrium beach alignment	the plan alignment of the beach for which net longshore transport is zero
Eutrophic conditions	very high nutrient levels, particularly of phosphorus and nitrogen
External replenishment	beach replenishment from a sand source external to the Adelaide beach system
Facies	sedimentary units containing sand, silt and/or clay layers, with each unit relating to a different depositional environment
Fillet	sand that collects in the updrift side of a coastal structure such as a groyne or headland
Fineness modulus (FM)	a calculated value based on grain-size percentages that describes a range of sand sizes in a single number
Foraminifera	a large group of marine protists that generally produce multi-chambered shells made of calcium carbonate
Gabion	structures composed of rocks, rubble or masonry held tightly together by wire mesh to form blocks or walls
Glenelg and West Beach harbours	general terms for the Holdfast Shores marina and extension of the Patawalonga breakwater at Glenelg, and the Adelaide Shores boat haven at West Beach
Groyne	a structure of rock and/or other materials generally built out from the shore seaward; in dynamic environments, a groyne creates a physical barrier that slows down or stops the alongshore movement of sand
Holocene highstand	the highest point to which sea level rose between 7000 and 6000 years before present; in the Adelaide region, it reached approximately 2 m AHD
Hydroisostatic rebound	the bouncing back of the Earth's surface due to water loading from rapid sea level rise and then unloading when sea level stabilises
Indian spring low water* (ISLW)	the lowest level, for most practical purposes, to which the tide falls; only in exceptional circumstances will the tide fall lower
Infauna	animals that live within the seabed
Interdecadal oceanographic and climatic processes	variations in sea and weather conditions that fluctuate over a long period
King tide	colloquial term for an unusually high tide, usually resulting from a high tide combining with a storm surge
Littoral cell	a contained unit along the seashore for sediment deposition, transport and erosion
Littoral zone	the zone bounded by the seaward extent of wave breaking and the landward limit of wave action on the coast, i.e. the same as active beach zone

Lowest astronomical tide* (LAT)	the lowest level of the tide that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions
Marine transgression	rising sea level and marine inundation of the land due to geological cycles of climate change and global temperature rise
Mean high water springs* (MHWS)	the level that is the average of all the twice-daily high tides at spring periods
Mean low water springs* (MLWS)	the level that is the average of all the twice-daily low tides at spring periods
Mean sea level* (MSL)	the average level of the surface of the sea over a long period of time in all stages of oscillation, or the average level which would exist in the absence of tides
Neap tide*	the tides which happen near the first and last quarter of the moon, when the difference between high and low water is less than at any other part of the month; opposite to spring tide
Net present value (NPV)	today's value of future costs and benefits
Progradation	deposition outward and upward of sediments over time as a result of rising or falling sea level
Prograding spit	a long, narrow accumulation of sand or shingle, lying generally in line with the coast, with one end attached to the land and the other projecting into the sea or across the mouth of an estuary
Reno-mattress	flat wire mesh baskets filled with rocks, used to prevent erosion by water
Rip-rap seawall	a seawall constructed with layers of stones, the largest layers on top, known as armour stones, and decreasing size of stones underneath, so as to provide a barrier between waves and eroding land
Sabkha	salt lake or salt pan where, on average, evaporation far exceeds rainfall or groundwater recharge
Salient	sand slowed down by a breakwater or reef and trapped nearshore, with the effect of building up the beach in that area
Samphire	coastal salt marshes and bushes growing in the intertidal (subject to tidal inundation) to supratidal (land surface above the reach of a king tide) zones
Sand rod	rods pushed into the seabed so that divers can periodically locate the same location and observe changes
Seagrass matte	organic and inorganic debris from seagrasses and other organisms that builds up as part of the seabed within seagrass meadows
Scarp	a steep face on the side of a hill, a sand dune or the seabed
Significant wave height	the average height of the highest one-third of the waves; the likely maximum wave height can be up to twice the significant wave height

Siliceous sand	sand consisting of silica (SiO_2) grains and fragments from the breakdown of minerals such as quartz (and feldspars) or of biological origin (e.g. sponge spicules and diatoms)
Spring tide*	the tide that happens at, or soon after, the new or full moon, which rises higher than the common tides
Storm surge	an onshore rush of water associated with a low pressure system, caused mainly by strong onshore winds pushing on the ocean's surface and raising the sea level
Taxa (plural of taxon)	groupings of animals or plants at any taxonomic level (e.g. species, genus, family)
Tectonic movement	vertical or horizontal movements of the Earth's crust, often as the result of earthquakes
Toe-stone	a large stone placed at the lowest part of a rip-rap seawall, which is intended to prevent the seawall being undermined in a catastrophic manner during an extreme storm event
Tombolo	sand trapped by a breakwater or reef (a salient) that extends all the way from the shore to the structure
Vibrocoring	using cylinders pushed into the beach with compressed air to obtain a sample of the sand and other sediment within the beach
Wave run-up	height to which a particular wave will run up a certain slope
Wave set-up	the amount by which the stillwater sea level inshore of the breaking wave zone exceeds that outside; in part due to the energy in the breaking waves being converted into an elevated inshore water level; for the South Australian coast, values are usually less than 0.4 m
Wrack	any seaweed or marine vegetation cast ashore

* definition from the Tide Tables for South Australian Ports (Transport SA)

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