Shire of Wanneroo

January 1999

Quinns Beach Coastal Protection Works

Stage 1 Report

M P ROGERS & ASSOCIATES PTY LTD
Coastal and Port Engineers
Report R058 Draft 1

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1. Introduction

1.1 General

The Shire of Wanneroo (previously the City of Wanneroo) has been involved in combating coastal erosion at Quinns Rocks since 1970 when a seawall was constructed to protect the parking lot and toilet block located at the end of Quinns Road. Additional protection works were conducted in 1977, with a rubble headland built to the immediate south of Quinns Cusp to encourage accretion along the Southern Beach. Presently, coastal erosion is threatening to undermine the car park located to the north of the cusp, and there are also concerns regarding the ongoing stability of the Southern Beach and adjacent Ocean Drive (refer to Figure 1.1).

In 1997, a study of the coastal processes at Quinns was prepared by Tremarfon (1997) which recommended a combination of sand renourishment and retreat in the short term, with the construction of seawalls at defined locations in the longer term if renourishment proves ineffective and the foreshore continues to recede. The option of seawalls was reviewed by the Department of Transport (Transport*)*, and concerns were raised regarding the potentially adverse effects and likely costs.

The present study was commissioned by the Shire of Wanneroo (Wanneroo) to provide a comprehensive evaluation of the coastal protection options available. These options include renourishment, seawall construction, groynes and breakwaters. The study will be conducted in the following three stages:

- **Stage 1**

  The review of existing data and technical reports, the calculation of appropriate design criteria for coastal protection options, and the preliminary review of coastal protection options.

- **Stage 2**

  A comprehensive review of suitable coastal protection options.

- **Stage 3**

  The final design and cost estimate of the coastal management option nominated by Wanneroo.

The coastal engineering investigations, results and recommendations of Stage 1 are presented in this report.

1.2 Study Area

Quinns Beach is located approximately 35 km north of Perth, Western Australia. Thousands of years ago sand accreted in the sheltered coastal region north-east of Quinns Rocks, forming what is referred to as Quinns Cusp (Smith, 1985). However, in more recent times, sections of this cusp have incurred erosion, with the recession of the foreshore threatening to undermine public assets and reduce the recreational amenity of the beaches.

The focus of this study is the protection of amenities which are located along the section of coastline between Caldera Close in the south and Tapping Way in the north. For the purpose of the study Quinns Cusp will be referred to as the *Cusp*, the foreshore located to the south of the Cusp will be referred to as the *Southern Beach*, and the foreshore located to the north of the Cusp will be referred to as the *Northern Beach* (refer also to Figure 1.1).

Southern Beach

The Southern Beach has a moderately vegetated berm which is around 50 metres wide and ranges in height between 1 metre and 3 metres Australian Height Datum (AHD) (i.e. about mean sea level). Landwards of this berm is a steep dune which is well vegetated along the southern section. However, it has been necessary for brush to be placed on the northern section to encourage vegetation growth.

Along the dune adjacent to the Southern Car Park and toilet block is a seawall, which was built by Wanneroo in 1970. The condition of the sea wall has deteriorated over time. However, the relatively dense vegetation growing from the gaps in the rubble suggests that recent movements have been minor.

A site inspection conducted on 19 November 1998 indicated that the 6,000 m^3 sand renourishment which was deposited along the northern section of the Southern Beach dune in November 1997 appears to have remained in place and has not been removed by wave induced erosion. This renourishment was further supplemented in December 1998 with a further 3,500 m^3.

Cusp

The Cusp contains an artificial headland which was constructed by Wanneroo in 1977. The headland appears to be currently saturated with sand. However, seasonal variations in the amounts of trapped sand are likely to result from variations in the dominant wave climate. Landwards of this headland is a wide berm and steep dune similar to that which extends along Southern Beach. However, between the berm and primary dune is a small localised dune. It is likely that this dune was formed following the construction of the headland.

Northern Beach

The Northern Beach is much narrower than the Southern Beach, and has an erosion scarp along its southern section. At present there is a limited buffer between the ocean and the car park, and the trees which shade the picnic area to the south are being undermined.

The site inspection conducted on 19 November 1998 indicated that a significant amount of the 6,000 m^3 of sand renourishment which was deposited in November 1997 along the car park and picnic area to the south had been eroded. This sand was later replenished through renourishment in December 1998, with about 1,550 m^3 deposited to the north of the boat ramp and 3,800 m^3 to the south of the boat ramp.

2. Meteorological & Oceanographic Conditions

Any comprehensive study of beach stability and coastal processes must be done with a knowledge of the fundamental driving forces. Consequently, data on the magnitude and variation in the winds, waves, tides and currents is important in assessing the coastal processes.

2.1 Wind Regime

The seasonal weather patterns at Quinns are largely controlled by the position of the so called Subtropical High Pressure Belt. This is a series of discrete anticyclones that encircle the earth at the mid-latitudes (latitudes of 20 degrees to 40 degrees). Throughout the year, these high pressure cells are continuously moving from west to east across the southern portion of the Australian continent. A notional line joining the centres of these cells is known as the High Pressure Ridge.

In winter this ridge lies across Australia typically between 25 to 30 degrees south and is to the north of Quinns at 31 degrees 40 minutes south. Consequently, the migrating low pressure systems which exist to the south of the High Pressure Ridge, are located sufficiently northward to bring a westerly wind regime to the southwest of Western Australia and the adjacent waters. Cold fronts associated with these low pressure systems pass over Quinns. These can bring storm force winds with directions from northwest, through west, to southwest.

During summer, the High Pressure Ridge moves south of Quinns and lies between 35 and 40 degrees south. Under these circumstances, the region comes under the influence of the high pressure cells of the High Pressure Ridge. These cells cause anti-cyclonic winds that rotate anti-clockwise in the Southern Hemisphere. At Quinns, these winds arrive from the southeast to east as the high pressure cell approaches from the west. The winds then rotate through northeast to north as the high pressure cell passes to the Great Australian Bight.

In addition to these synoptic scale effects which cause seasonal variations, the meso-scale phenomenon of a land / sea-breeze system is commonly experienced during summer at Quinns and adjacent coastal regions. This causes variations on a daily time scale, and breezes come from the land in the morning and swing around to come from the sea in the afternoon.

From 1965 to 1978, the Bureau of Meteorology recorded the wind speed and direction at Fremantle. As there is a significant sea-breeze effect in the region, the Bureau of Meteorology took a reading each morning at 9.00 am and a second reading in the afternoon at 3.00 pm. From this data, wind roses for the mornings and afternoons for the four seasons of the year have been prepared and are presented in Figures 2.1 and 2.2. These show that winds from the northeast through east to southwest are very common on autumn, summer and spring mornings, whilst during autumn, summer and spring afternoons, the most common wind direction is from the southwest. The autumn, summer and spring wind speeds are typically between 10 and 30 kph during the mornings and can reach as high as 40 to 50 kph in the afternoons.

The wind regime during winter is much more variable. However, winds often arrive from the northeast direction during winter mornings. Winds tend to be from the southwest to northwesterly directions during winter afternoons. In winter, the wind speeds range from 10 to 40 kph and can be in excess of 50 kph during winter storms.

Occasionally in late summer, dissipating tropical cyclones may pass through the region. These have a pronounced, short term effect on the regional weather patterns.

The wind regime influences coastal processes through the generation of ocean waves and currents as well as feeding dune systems with wind blown beach sand.

2.2 Wave Climate

Wave measurements and observations taken in deep water off Fremantle, Mullaloo and Moore River indicate that the area offshore from Quinns experiences reasonably high wave energy. The main elements of the offshore wave climate are as follows.

- Seas generated locally by the passage of cold fronts during winter. The wave heights and periods vary markedly from storm to storm. Often the wave heights exceed 4 metres and the wave periods reach 6 to 10 seconds. The direction from which these storm waves approach can range from northwest to southwest during the passage of the storm.

- Swell waves from distant storms in the Southern Indian Ocean continually reach the offshore area throughout the year. The swell waves often exceed 2 metres in height, and typical periods are between 8 and 16 seconds. The swell waves commonly approach from the southwest, and tend to be slightly smaller and more southerly in summer compared to winter.

- Seas produced by the sea-breeze. The generation of these waves is limited by the duration and the offshore extent of the sea-breeze system, with heights typically 0.5 to 1.5 metres and periods of 3 to 6 seconds. The direction of these waves is generally from the southwest to south.

- Severe waves caused by dissipating tropical cyclones. These storms are infrequent in the Fremantle region, however, when they do occur they cause severe conditions for short periods of time.

As the offshore waves travel toward the shore, they are greatly affected by the nearshore bathymetry and the reefs. The bathymetry of the area and reefs are shown in Figure 2.3. Waves travelling to the coast at Quinns are modified by the following physical processes.

- Reflection off the reef faces,
- Depth limited breaking on the reef tops and in shallow areas,
- Diffraction through the gaps in the reefs,
- Attenuation due to hydraulic turbulence as the waves travel over the reefs and other areas of shallow water, and
- Refraction and shoaling.

These processes act to varying degrees, and significantly modify and attenuate the waves as they approach the coast at Quinns. The reefs and nearshore bathymetry provide good protection from the full force of the offshore waves. The dissipation processes are important to the stability of the coastline as the resultant waves that break on the beach are believed to be the most important factor in the transport of sand in the littoral zone. A detailed evaluation of the nearshore wave climate at Quinns is provided in Section 6.

2.3 Tides & Storm Surges

The astronomical tides at Quinns are believed to be very similar to those at Fremantle. The sites are described in the Western Australia's Tide Predictions Guide 1997-1998, (Maritime Transport (WA), 1997) and Transport (WA) navigation chart WA 284. The tides are predominantly diurnal (one tidal cycle each day) and relatively limited in range. The daily range is typically about 0.5 metre during spring tides and around 0.2 metre during neap tides. Other tidal characteristics are listed in Table 2.1.

Table 2.1 Fremantle Tide Characteristics

	Chart Datum	AHD
Mean Sea Level (MSL)	0.7 metre	0.0 metre
Mean High High Water (MHHW)	1.1 metres	0.4 metre
Mean Low Low Water (MLLW)	0.4 metre	-0.3 metre

Seasonal shifts in the sea level occur due to meteorological effects and the action of the Leeuwin Current. Typically, the mean sea level rises 0.1 metre during winter and falls 0.1 metre during summer.

Given the small astronomical tides, the level of the sea would generally have a secondary effect on the sand transport along the beaches, except during storm events when high water levels would enable the waves to attack the rear of the sandy beaches.

During storm events (both winter storms and cyclones) barometric and wind effects can cause significant storm surges. In rare storms, the surge can exceed 1 metre above the astronomical tide level. Steedman (1988) analysed storm tide records at Fremantle and concluded that +1.9 metres CD ($\approx$+1.2 metres AHD) was an appropriate 50 year design still water level for Mindarie Keys. This estimate has been verified in this study by analysis of extreme water levels measured at Fremantle over the last 50 years. As the tides at Fremantle, Mindarie and Quinns are very similar, +1.9 metres CD ($\approx$+1.2 metres AHD) is also considered an appropriate 50 year design still water level for the design of coastal protection at Quinns.

2.4 Nearshore Currents

A brief literature search uncovered little data on the ocean currents near Quinns. However, in the deeper water of the continental shelf, the warm Leeuwin current has been observed in various satellite images.

The tidal range in the region is quite small and unlikely to create significant tidal currents to influence the general circulation patterns. Also, there is not a sufficient amount of freshwater discharging into, or near, the Quinns site to create sufficient density gradients to drive density currents. Therefore, the circulation patterns of the nearshore waters off Quinns are likely to be dominated by the wind regime.

During spring and summer, when the winds are more consistent, it is expected that westerly to northwesterly flows would be generated in the morning due to the prevalence of east to southeasterly winds. In the afternoons during spring and summer, the on-set of the sea-breeze will drive currents flowing to an east to northeasterly direction. Data recorded on Success Bank in Owen Anchorage during the summer of 1995 shows that typical current speeds of around 0.2 to 0.3 m/s are likely during the sea-breeze (Rogers & Associates, 1997). Current speeds of this magnitude can be expected during the sea-breeze in the Quinns region.

In winter and autumn, the wind directions are more variable and less predictable than during spring and summer. However, current speeds of around 0.1 to 0.3 m/s during winter and autumn could be expected.

In addition to these nearshore circulation currents, waves breaking at an angle to the shore can generate currents parallel to the shore. These longshore currents are important in the movement of sand along the coast.

2.5 Variability

The oceanographic conditions along the south-west coast of Western Australia are known to vary considerably from year to year. Some winters are reasonably calm while others include a number of severe storms. As part of other projects being completed for Transport, MRA has developed an indicator of the storminess of each of the 50 years from 1948 to 1997. A plot of the variation in storminess from year to year is shown on Figure 2.4. The Rogers Storminess Index is the ratio of the total number of hours in a particular year when the storm surge at Fremantle was greater than or equal to 0.35 metre for the period 1948 to 1997. A storminess Index greater than 1 indicates a stormy year. The highest index in the last 50 years was calculated for 1996. From this it is believed that 1996 was a particularly stormy year, and possibly the worst in several decades.

3. Climate Change

Although the so called "Greenhouse Effect" receives much publicity, there is still no definitive evidence available that proves that the Greenhouse changes are occurring or will occur. There is certainly clear evidence that the amount of Carbon Dioxide and other "Greenhouse Gases" has increased dramatically over the last century, and is continuing to rise. However, the link to global warming and associated sea level rise is still largely based on predictive numerical models of the global atmospheric and oceanic processes. These general circulation models are currently run on coarse grids and have rather rudimentary treatment of ice melting, cloud cover and albedo feed back links and impacts. Pielke (1991) presents a good review of the scientific uncertainty with the present predictions of the "Greenhouse Effect".

Some of the possible impacts on the south coast of WA from Greenhouse Gas Warming could be:

- changes in storm frequency,
- increase in sea level, and
- change in position of synoptic features causing a changed wave climate.

The current knowledge about such possible changes is extremely limited. This coupled with the uncertainty about Global Warming, has lead many organisations and authorities to take a low key approach to the issue until more definitive proof is available.

The Institution of Engineers, Australia (1991), put forward suggestions for assessing the impacts of possible climate change on coastal engineering projects. The report is aimed at ensuring that a responsible review of the possible impacts is made. Designs should be robust and minimise future risk. This document does not say that climate change will definitely happen, but that it now seems likely that it will happen, and therefore engineering design should take this risk into consideration.

The Institution of Engineers, Australia (1991), presents three scenarios for possible changes in the Global Mean Sea Level for the years 2030, 2050 and 2100. These are reproduced below in Table 3.1.

Table 3.1 Possible Global Sea Level Rise - 1991 Estimates

	2030	2050	2100
Low Scenario	0.10 metre	0.16 metre	0.32 metre
Medium Scenario	0.20 metre	0.32 metre	0.68 metre
High Scenario	0.32 metre	0.51 metre	1.13 metres

Source: Institution of Engineers Australia (1991)

The latest research from IPCC (1995) provides new projections for the future change in sea levels (refer to Table 3.2). The increase in sea level over the next century is projected to be lower than previous estimations. The differences are due in large to lower temperature projections and changes to the glacier model used.

Table 3.2 Possible Global Sea Level Rise - 1995 Estimates

	2030	2050	2100
Low Scenario	0.03 metre	0.06 metre	0.13 metre
Medium Scenario	0.11 metre	0.20 metre	0.49 metre
High Scenario	0.23 metre	0.40 metre	0.93 metre

Source: IPCC (1995)

The issue of possible climate change and resultant effects on coastal processes is quite complex and the impact of a small rise in sea level would be quite site specific. To date there have been no studies done for the west coast of Western Australia. The most relevant of other works are Bruno (1962), which presents the results of some generalised material, and Gordon (1988) which presents some of the results of research on the east coast of Australia. In very coarse and general terms, both papers suggest that a rise in sea level would generally lead to recession of the coastline at a ratio of roughly 100 to 1. That is, a 0.2 metre rise in sea level may eventually cause a 20 metres recession of the coastline. This tendency for shoreline recession could be offset by other local effects. For example, the presence of rock under the beach and foredunes could greatly reduce or eliminate the possible erosive effects of a general rise in sea level.

Wanneroo has requested that the present evaluation of suitable coastal protection options for Quinns incorporate a performance life of 25 years (refer to Section 1.1.2 of the Consultant's Brief Schedule 1). It is predicted that if the Greenhouse Effect causes an increase in the sea level, then these changes will be small over the 25 year design life period. Therefore, rises in sea level caused by the Greenhouse Effect have been excluded from the investigation.

4. Coastal Processes

There are three fundamental mechanisms which can transport sand towards or away from a point on the beach.

The first is longshore sediment transport. A simplistic description of this mechanism is that in the surf zone of sandy beaches, the breaking waves agitate the sand and place it into suspension. If the waves are approaching the beach at an angle, then a longshore current can form and this can transport the suspended sand along the beach. The suspended load transport is accompanied by a bed load transport where sand is rolled over the bottom by the shear of the water motion. There can be considerable variation in magnitude and direction of the longshore transport from season to season and year to year.

The second mechanism is the onshore / offshore movement of beach sand, commonly referred to as cross shore sediment transport. During storm events the steep waves and high water levels cause sand to be rapidly eroded from the beach and carried offshore. Between storm events, the long, low amplitude swell that persistently arrives at the coast moves sand back onto the beach. This is shown diagrammatically on Figure 4.1. Erosion of sandy beaches during storms can be quite rapid and significant changes can occur in a matter of hours. However, the onshore movement of sand by swell is a much slower process. It may take months or even years for swell to move sand back onto the beach that was eroded in a few hours during a severe storm. Naturally, rocky coasts are affected much less by storm events because of the ability of the rock to resist the erosive forces.

The final mechanism is wind blown sediment transport. This can move sand from the beach into the nearby dunes, which helps the dunes grow and become important buffer to storm erosion.

As part of the coastal engineering investigation for the Mindarie Keys Project, a study of the coastal processes at Quinns was undertaken by Smith Corporation (1985). The results were later reviewed by Tremarfon (1997) as part of the *Quinns Coastal Processes Study*. These studies concluded the following:

- Little or no sediment enters the study area from the south.
- The exchange of sediment between the offshore and the Quinns coastline is minimal.
- Prevailing summer south-west swell produces a movement of sediment towards the Cusp from the offshore and Northern and Southern Beaches (refer to Figure 4.2).

- Summer afternoon sea-breezes produce a northwards movement of sediment (refer to Figure 4.3).
- Combined summer swell and sea-breezes produce a net onshore and northwards movement of sediment for the summer period (refer to Figure 4.4).
- West to south-west winter swell produces a movement of sediment towards the Cusp from the Northern and Southern Beaches (refer to Figure 4.5).
- West to south-west winter seas produce a northwards movement of sediment (refer to Figure 4.6).
- North of west winter storms produce a southwards and offshore movement of sediment (refer to Figure 4.7).
- Combined winter swell, winter seas and winter storms produce a net offshore and southwards movement of sediment for the winter period (refer to Figure 4.8).

The above seasonal movements produce significant seasonal variations in the sediment volumes and beach widths along the Quinns foreshore. Survey results detailed in Transport (1998b) indicate that the seasonal variations could be in the order of 150,000 m^3. In addition, fluctuations in annual weather conditions can produce differences in the volumes transported by each process, causing annual and longer term variations. Survey results indicate that annual fluctuations may be in the order of 60,000 m^3. These fluctuations can make it difficult to determine long term trends of accretion or erosion which can be small by comparison. Analysis of erosion and accretion trends at Quinns is detailed in Section 5.

5. Analysis of Coastline Movements & Surveys

5.1 General

Analysis of coastline movements and survey results by the present study found that the artificial headland constructed to the south of the Cusp in 1977, greatly influenced the Northern Beach and Southern Beach. Based on the findings described in the present section it has been concluded that the coastline movement trends prior to 1977 are not indicative of the present trends, and that they should be considered separately to those that have occurred after 1977.

5.2 Coastline Movements

Tremarfon (1997) evaluated the Transport (WA) shoreline movement plots, which contain coastal vegetation and water lines for the years 1941, 1955, 1965, 1978, 1985 and 1995 at Quinns. Based on this evaluation Tremarfon (1997) concluded the following:

- "The sandy foreshore in the Southern part of the Extended Study Area *(i.e. south of the Southern Beach)* has remained relatively stable since being eroded between 1941 and 1955."
- "The sandy foreshore in the Northern part of the Extended Study Area *(i.e. north of the Northern Beach)* has, since 1941, experienced a period of accretion to 1978 and erosion to 1995. The 1995 location of the vegetation line was approximately the same as its 1941 location."
- "The north flank of Quinns Cusp *(i.e. the Northern Beach)* was relatively stable from 1955 to between 1985 and 1995. It is likely that the erosion experienced on the north flank of Quinns Cusp and recorded on the 1995 plot of the vegetation line, occurred during the Winter of 1994, during which time much of the Perth Metropolitan coastline suffered erosion from Winter storms."
- "The south flank of Quinns Cusp *(i.e. the Southern Beach)* experienced both erosion and accretion rates in excess of 3 m per year during the period 1941 to 1995. While the north flank of Quinns Cusp was relatively stable from 1955 to between 1985 and 1995, the south flank retreated by up to 35 m."

To supplement the information provided by the Transport shoreline movement plots, the present study used controlled techniques to determine the position of vegetation at the three locations shown on Figure 5.1, from the aerial photographs detailed in Table 5.1. Although the techniques used were not to the standard used by professional photogrammetrists, steps were taken to minimise the effects of photographic distortion and the results are expected to have a resultant accuracy of about ± 5 metres.

Table 5.1 Aerial Photography used for Vegetation Line Plots

Date	Set	Number	Scale
28.10.69	WA1199	5128	1:15000
16.10.74	WA1533	5169	1:15840
28.10.75	WA1591	5542	1:15000
15.11.76	WA1648	5076	1:15000
27.1.78	WA1728	5251	1:15000
7.4.78	WA1739	5514 & 5515	1:8000
28.9.79	WA1832	5205	1:40000
8.12.80	WA1959	5466	1:15000
2.10.83	WA2170	5002	1:25000
15.12.83	WA2188	5122	1:15000
8.1.85	WA2269	5036	1:15000
20.2.87	WA2491	5038	1:15000
14.11.88	WA2651	5239	1:15000
22.6.89	WA2699	5142	1:24000
14.11.90	WA2926	5147	1:15000
17.1.93	WA3183	5031	1:15000
7.12.94	WA3481	5033	1:15000
21.10.95	WA3620	5169 & 5170	1:5000
9.1.96	WA3685	5131	1:15000
17.12.96	WA3827	5264	1:15000
3.2.98	WA4057	5002	1:15000

Figures 5.2 and 5.3 show the position of the foreshore vegetation at the two locations south of the Cusp relative to the Transport 1965 vegetation line. Also shown on the plots is the position of scattered vegetation. Generally, the berm was only moderately vegetated and most of the vegetation line plots considered the toe of the primary dune to be the permanent vegetation line. However, the existence of scattered vegetation on the berm indicates at least temporary accretion of the foreshore. It is possible that the vegetation growth has been restricted by human traffic and significant seasonal variations in the beach width. Light and photograph quality also influence the detection of scattered vegetation.

The figures identify a trend of erosion between 1965 and 1980, followed by a trend of dynamic stability or minor accretion, indicating that the headland constructed in 1977 required a number of years for sufficient material to be trapped before the Southern Beach was stabilised. This is supported by correspondence between Wanneroo and Transport (then the Public Works Department) in 1979 (refer to Appendix A) stating that the erosion of the Southern Beach was continuing. Quinns was subsequently monitored annually until 1983 when it was decided that the Southern Beach was in a trend of accretion.

Figure 5.4 shows the position of the foreshore vegetation at the Northern Car Park relative to the Transport 1965 vegetation line. It identifies a trend of stability between 1965 and 1978, followed by a trend of erosion with a net recession of about 20 metres between 1978 and 1998 (about 1 metre/year). Although the post 1978 erosion trend contains some fluctuations, it does appear to be a progressive process with a gradual foreshore recession over the 20 year period. This does not support the Tremarfon (1997) comment that the erosion experienced on the north flank was likely to have occurred during the winter of 1994, but instead suggests a longer term trend of erosion.

5.3 Survey Results

The following is a list of Transport survey plans of Quinns coast reviewed by the study:

Quinns Rocks Wanneroo Beach
Beach Erosion Surveys
(P.W.D., W.A.)

November 1974	50669-1-1
November-December 1977	50669-1-2
October 1979	50669-1-3

Quinns Rocks
Beach Monitoring Survey
Levels and Soundings

May 1980	871-4-1
	871-4-2
May 1981	871-2-1
	871-2-2
May 1982	871-3-1
	871-3-2
October 1996	871-1-1
	871-1-2

December 1996	871-5-1
	871-5-2
March 1997	871-13-1
	871-13-2
December 1997	871-16-1
	871-16-2
Quinns Rocks	
Analysis of Surveys	
Depth Changes	
December 1997 Minus March 1997	871-18-01
December 1997 Minus October 1996	871-20-01
December 1997 Minus December 1996	871-21-01
December 1997 Minus December 1977	871-22-01

Figure 5.5 is a reduced copy of Transport Plan 871-22-01, and shows the changes in sediment levels between December 1977 and December 1997. Significant erosion is observed to the north coupled with accretion to the south, supporting the results of the coastline movement analysis in Section 5.

Also observed is a band of erosion along a section of the primary dune of the Southern Beach. This suggests that although the Southern Beach is relatively stable, severe storms may be able to erode the berm and attack the primary dune causing a recession of the foreshore.

Transport (1998b) conducted a volume change analysis of the survey results at Quinns to determine the volume of sediment movements within the study area. Figure 5.6 provides a summary of the findings, showing the cumulative volume changes at the Northern Beach, Southern Beach, the Cusp and Offshore. The key elements of the findings are:

- The Southern Beach accreted by about 80 000 m^3 between 1977 and 1997.
- The Northern Beach incurred a loss of about 170 000 m^3 between 1977 and 1997.
- The Cusp eroded between 1979 and 1983, but accreted back to the 1977 volume by the late 1990's.
- The Offshore has accreted by about 70 000 m^3 between 1977 and 1997. It is possible that an offshore movement of sediment produced by the particularly severe winter storms of 1995 and 1996 has contributed to the observed Offshore accretion.

Figure 5.7 shows the change in beach cross-section at the end of Quinns Road between December 1977 and December 1997. The figure shows the formation of the 50 metres wide berm described in Section 1.2. This degree of foreshore accretion is not reflected in the coastline movement analysis described in Section 5.2, which indicates that the Southern Beach remained stable during this period with only minor, if any, accretion of the vegetation line. However, it should be noted that the berm is only moderately vegetated and most of the vegetation line plots considered the toe of the primary dune to be the permanent vegetation line. Unfortunately, the lack of survey information between May 1982 and October 1996 make it difficult to determine whether the 80,000 m^3 of accretion between 1977 and 1997 is long term change, or whether the severe storms of 1995 and 1996 contributed to the accretion by supplying sediment from the north.

Figure 5.8 shows the change in beach cross-section adjacent to the Northern Car Park between December 1977 and December 1997. This figure shows significant erosion of the foreshore with the dune receding by about 20 metres. This confirms the findings of the coastline movement analysis described in Section 5, which shows a similar recession of the vegetation line.

5.4 Sediment Budget

Sediment budgets were derived from the combined analysis of the coastline movement plots and survey results. Based on the findings of Smith (1985) and LeProvost (1987), it was assumed that there was limited sediment exchange between the study area and the rocky shore to the south, and between the study area and the offshore. However, it was considered possible that there may be a small ($\approx$1,000 m^3/yr) onshore feed of sediment from Quinns Rocks.

Figure 5.9 shows the net average annual sediment budget derived for the period from 1941 to 1978. Figure 5.10 shows the net average annual sediment budget derived for the period from 1978 to 1997. These budgets show that the loss of sediment from the study area (i.e. south of Tapping Way) decreased from 6,000 m^3/year between 1941 and 1978, to 4,000 m^3/year between 1978 and 1997. However, changes in trends to the immediate north of the study area indicate an increase in the volume of sand exiting northwards from 3,000 m^3/year to 7,000 m^3/year.

Figure 5.11 shows a possible future net average annual sediment budget assuming the artificial headland and Southern Beach are fully saturated and remain stable.

It should be noted that the sediment budgets are approximate averages and should only be used as a rough guide to long term trends. The volume changes determined for the net annual budgets are small in comparison to the seasonal (refer to Figure 5.12) and annual fluctuations (refer to Figure 5.13) produced by variations in weather conditions. Therefore, the development of coastal protection options using the derived sediment budgets must include consideration of these fluctuations.

5.5 Conclusions

Based on the findings described in Sections 5.2, 5.3 and 5.4, the following points can be concluded:

- The artificial headland constructed to the south of the Cusp in 1977, greatly influenced the stability of the Northern Beach and Southern Beach.
- The coastline movement trends prior to 1977 are not indicative of the present trends, and these trends should be considered separately to those that have occurred after 1977.
- Between 1941 and 1977 the Southern Beach exhibited a trend of erosion, while the Northern Beach remained relatively stable. Sediment budget calculations indicate that during this period an average net volume of about 6,000 m^3/yr was exiting the northern end of the study area each year.
- The headland was constructed in 1977 to combat the erosion to the south.
- Since 1977 the Northern Beach has incurred a gradual trend of erosion. The foreshore receded by about 20 metres between 1977 and 1997, with a net loss of about 170,000 m^3 of sand.
- The Southern Beach continued to recede for a number of years after the construction of the headland. Then in the early 1980's it began to accrete, with a net accretion of about 80,000 m^3 recorded between 1977 and 1997.
- Sediment budget calculations indicate that after the construction of the headland an average net volume of about 4,000 m^3/yr exited the northern end of the study area each year.
- Between 1977 and 1997 the offshore region accreted by about 70,000 m^3. The severe winter storms of 1995 and 1996 may have contributed to this accretion.

The results of the study indicate that the Southern Beach has remained relatively stable since the construction of the headland in 1977, and is not experiencing a long term trend of erosion. Erosion of the berm and possibly the primary dune may occur during severe storm events. However, subsequent calm conditions could return lost sediment to the foreshore. The vulnerability of the Southern Beach and Ocean Drive to severe storm events is analysed in Section 7.

The study results indicate that the Northern Beach has experienced a trend of erosion since the construction of the headland in 1977. Without management of this erosion process, it is likely that the Northern Car Park will be undermined and Ocean Drive could become vulnerable to storm attack.

6. Nearshore Wave Analysis

6.1 Wave Model & Set-up

The computer model selected for the study was 2GWAVE. This is an enhanced version of the general purpose spectral wave model developed by Professor Ian Young at the Australian Defence Force Academy. It is a finite difference model that accounts for the wave transformation processes of:

- wave refraction (change in wave energy and direction with variation in seabed topography),
- wave shoaling (change in wave height with depth),
- atmospheric forcing (ie. wave generation by winds),
- dissipation due to bottom friction and white capping,
- wave breaking in deep and shallow water, and
- non-linear wave-wave interactions.

The model has been extensively tested in Owen Anchorage and proved to be quite accurate (Rogers & Associates, 1995). The results for Owen Anchorage showed that the model consistently performed well, with the model output in close agreement with the measured directional wave spectra. More details of the model are provided in Appendix B.

6.2 Model Grids

For this study, the model was set-up in a nested grid mode. A coarse primary grid with 2 km spatial resolution was used to cover the waters extending out to deep water (>100 m), from south of Rottnest Island to north of Guilderton (refer to Figure 6.1). To enhance modelling efficiency, the primary grid was oriented approximately parallel to the coastline. An anticlockwise rotation of about 20° from True North was used.

A secondary grid, of higher resolution and nested inside the primary grid, was used to more accurately represent the nearshore waters surrounding Quinns. Possessing the same orientation as its primary counterpart, the secondary grid provided a resolution of 200 metres.

The model was set-up to use different friction factors to represent the main types of seabed encountered in the area. These are reef, seagrass meadows and bare sand. The friction factors used for this study were based on the values used in Rogers and Associates (1995). The distribution of these seabed types was taken from navigation charts and aerial photography.

6.3 Verification of Wave Model

In order to verify that the wave model was correctly modelling the wave field for the conditions experienced at Quinns, a simulation was completed using general swell conditions. The input for the swell event was obtained from directional wave data recorded in close proximity to Transport's deepwater buoy offshore of Rottnest Island (refer to Figure 6.1).

The simulated wave heights were compared with the wave heights recorded by Transport's 038 Buoy (refer to Figure 6.1), and the offshore and nearshore wave heights at Mindarie measured by Steedman (1988). Also, the results of the model were visually evaluated to confirm that the simulated wave directions were in general agreement with wave patterns observed in aerial photography and wave directions predicted through intuitive analysis of wave refraction. Both methods of verification indicated that the model was satisfactory, and was capable of modelling the extreme event wave conditions required for the study.

6.4 Extreme Event Simulations

Simulations were completed for extreme storm events with an estimated Average Recurrence Interval (ARI) of about 10 years, 20 to 30 years and 50 to 100 years. The events were based on directional wind and offshore wave data recorded during a severe west-north-westerly storm event in 1995, with the magnitudes increased proportionally using appropriate extrapolation techniques. Maximum water levels and offshore wave heights were based on the predictions of Steedman (1988), while the maximum wind speeds were based on the transformation of gust wind speeds from AS 1170.2 (1989), *SSA Loading Code, Part 2: Wind Loads*.

To confirm the accuracy of the model, the resulting nearshore wave heights at Mindarie were compared with the predictions of Steedman (1988) and were found to be consistent.

Table 6.1 lists the maximum significant wave heights for each ARI event at the Quinns locations shown in Figure 6.2. The maximum nearshore wave heights were modelled at Location 1 of the Northern Flank, with the wave heights modelled south of the Cusp less due to increased protection from the west-north-west waves provided by offshore reefs including Quinns Rocks. However, these reefs provide less protection to the southern flank when the waves approach from the south-west. It is predicted that during a severe south-westerly storm event the southern flank could incur maximum wave heights similar to those predicted for the Northern Flank Location 1. Therefore, it is recommended that a maximum significant wave height of 2.8 metres (50 to 100 year ARI, Northern Flank Location 1) be used as the nearshore design wave height for both the northern and southern flanks.

The dissipation of wave energy in the vicinity of reefs can be seen in Figure 6.3, which contains a colour plot of significant wave height during the peak of the 50 to 100 year ARI storm. Smaller wave heights (light to dark blue) are observed in the lee of reef systems, including Quinns Rocks which provides a degree of shelter to the southern flank. Figure 6.3 also contains a vector arrow plot, with the direction of the arrow signifying the mean spectral direction and the length of the arrow signifying the mean wave period.

Table 6.1 Maximum Significant Wave Height for W.N.W. Storm

ARI Event	Offshore	Nth Flank Location 1	Nth Flank Location 2	Sth Flank
10 years	7.9 metres	2.5 metres	1.8 metres	1.9 metres
20 to 30 years	8.7 metres	2.6 metres	1.9 metres	2.1 metres
50 to 100 years	9.6 metres	2.8 metres	2.2 metres	2.2 metres

7. Severe Storm Erosion

7.1 Storm Erosion Model & Set-up

During significant storm events, the strong winds generate high steep waves and an increase in water level known as wind set-up. The lower atmospheric pressure associated with the storm system further draws up the water level. These factors, acting in concert, allow the waves to attack the higher portion of the beach that is not normally vulnerable. The initial width of the surf zone can be insufficient to dissipate the increased wave energy of the storm waves. The residual energy is often spent in eroding the beach face, beach berm and sometimes the dunes. The eroded sand is carried offshore with return water flow where it is deposited and forms an offshore bar. Such bars can eventually grow large enough to break the incoming waves further offshore, causing the wave energy to be spent in a wider surf zone (refer to Figure 4.1).

The technique used to estimate storm erosion of Quinns Beach focussed on the use of a computer model called SBEACH. SBEACH (**S**torm induced **BEA**ch **CH**ange) has been developed by the Coastal Engineering Research Centre, which is part of the US Army Corps of Engineers. The model takes into account a variety of factors including wave height, period and direction, tidal elevations, wind speed and direction, duration of the storm, sediment grain size, and an initial beach profile. Using this information, SBEACH estimates the beach profile that would result from the given storm conditions.

For this investigation, extreme events with an estimated Average Recurrence Interval (ARI) of about 10 years, 20 to 30 years and 50 to 100 years were simulated, using wind and wave information obtained from the nearshore wave analysis described in Section 6, and an extreme water level analysis of tide records at Fremantle between 1948 and 1997.

7.2 Southern Beach Storm Erosion

The changes in beach profile produced by storm erosion were investigated at two locations south of the Cusp. Using the beach profile recorded seawards of the end of Quinns Road in December 1997, the effect of each of the ARI storm events were modelled. The results indicated that the 10 year and 20 to 30 year ARI events were capable of eroding the berm back to the primary dune, while the ARI 50-100 year event was capable of eroding the berm and also the toe of the dune (refer to Figure 7.1). To evaluate the effect of seasonal sediment movements the 50 to 100 year ARI event was also applied to the March 1996 profile. However, it was found that the use of this profile did not increase the extent of foreshore recession.

The second location investigated south of the Cusp was located seawards of the boundary of Lots 11 and 12, about 120 metres south of Pearce Street. The affect of the 50 to 100 year ARI storm event was modelled on profiles recorded at this location in December 1977, May 1980 and December 1997. The results indicated that the 1977 and 1980 profiles were susceptible to significant erosion, with the model predicting the total loss of the beach berm and erosion to the face of the primary dune (refer to Figures 7.2 & 7.3). This finding is supported by comments made by Phil Calley (Wanneroo) in the meeting held with Wanneroo on 19 January 1998. Mr Calley stated that following the severe winter storms of 1996, he had observed that a section of the primary dune seawards of Pearce Street had been eroded, and the ocean was lapping at the base of the dune.

The size of the foreshore berm recorded in December 1997 was far greater than the size of the berms recorded in 1977 and 1980. This provided additional protection to the primary dune, and the modelling of the 1997 profile indicated that it was less susceptible to erosion of the dune. The model predicted that although the toe of the dune may erode during the peak of the storm, recession of the dune would be minor and about 30 metres of beach width would remain after the storm (refer to Figure 7.4).

In general, the SBEACH results indicate that the present berm may be eroded during a severe storm, causing a temporary reduction or loss of beach amenity. Under very severe conditions the primary dune which supports Ocean Drive may also incur some degree of erosion. At present, Ocean Drive is not considered to be under threat of being undermined by a single storm event. However, a succession of storm events may be able to produce a recession of the primary dune and eventually threaten Ocean Drive.

7.3 Northern Beach Storm Erosion

For the evaluation of the Northern Beach a profile recorded seawards of the Northern Car Park in December 1997 was used. The SBEACH simulations indicated that all of the modelled ARI events were capable of causing the temporary loss of the beach and erosion of the primary dune. Figure 7.5 shows the final beach profile following the modelled 50 to 100 year ARI event. To evaluate the effect of seasonal sediment movements the 50 to 100 year ARI event was also applied to the March 1996 profile. However, it was found that the use of this profile did not increase the extent of foreshore recession.

Although the simulations indicate that the car park is not under threat while the December 1997 buffer is maintained, it should be noted that results are approximate estimates only and the present buffer is minimal. Additional losses caused by longshore movements or successive storm events may produce further foreshore recession and possibly undermine the car park. If the long term preservation of the current width of car park is desired, it is recommended that additional protection to the Northern Car Park be provided through an increase in the buffer or through structural protection.

8. Initial Assessment of Coastal Protection Options

8.1 Option 1 - Do Nothing

Although significant seasonal sediment movements occur and the berm may erode during severe storm events, the Southern Beach has remained relatively stable since the construction of the artificial headland in 1977. It is likely that without additional protection only minor changes will occur south of the Cusp in the short to medium term (1-10 years). However, very severe storm events are capable of eroding the toe of the primary dune supporting Ocean Drive, and a succession of severe storms may deplete the present buffer and threaten to undermine Ocean Drive.

The study indicates that a gradual trend of erosion is occurring along the Northern Beach. Without protection works it is likely that the erosion will continue and the Northern Car Park and adjacent picnic area will be undermined. In the longer term the erosion of the Northern Beach may impact on the stability of the Southern Beach, as the volume of sand returning to the south during storm events may be reduced.

A more comprehensive evaluation of the Do Nothing option will be undertaken in Stage 2.

8.2 Option 2 - Renourishment

The sediment budget analysis described in Section 5.4 suggests that between 5,000 m^3 and 8,000 m^3 of appropriate sand will be required annually to maintain the present beach widths at Quinns.

The evaluation of possible storm erosion described in Section 7 indicates that the primary dune of the Northern Beach is susceptible to storm erosion, and an increase in the present buffer seawards of the Northern Car Park may be required to prevent undermining of the car park during a very severe storm event.

Although the evaluation of storm erosion to the south of the Cusp indicated that Ocean Drive is not presently under threat, it may also be desirable to increase the buffer south of the Cusp, seawards of Ocean Drive.

A more comprehensive evaluation of the renourishment option will be undertaken in Stage 2

8.3 Option 3 - Seawall Construction

Although the Southern Beach has remained relatively stable since the construction of the artificial headland in 1977, minor erosion of the primary dune is possible during very severe storm events. A seawall would be able to prevent the recession of the dune during these events and provide increased protection for Ocean Drive.

The Northern Beach has incurred a progressive trend of erosion since the construction of the artificial headland in 1977. A seawall may be used to prevent further recession of the primary dune from undermining the car park. However, this is likely to cause the loss of the beach seawards of the seawall and increase the erosion of adjacent beaches. It is likely that the seawall will be frequently exposed to direct wave action, and significant wave heights at the seawall may exceed 2 metres during severe storm events. Therefore, sand filled geofabric tubes are not recommended as they are susceptible to vandalism when exposed, and mortar filled revetment mattresses are not recommended as they are unable to withstand severe wave climates when installed at appropriate revetment gradients (e.g. 1 Vertical : 2 Horizontal).

An alternative solution for the Northern Beach may be the combination of a lower strength seawall to provide adequate protection during severe storm events, and annual renourishment to prevent the loss of the beach located seawards of the wall. Geofabric tubes or revetment mattresses may be appropriate in this application.

It is recommended that Stage 2 include an evaluation of two seawalls:

- a high strength seawall to protect the Northern Car Park, capable of withstanding direct wave action following the probable erosion of the beach, and
- a lower strength seawall to protect the Northern Car Park and the southern flank of Ocean Drive. This seawall should be capable of withstanding depth limited waves, and serve as additional protection during severe storm events. However, if this option is implemented, continued renourishment will be required to maintain the beaches and protect the seawalls from excessive wave action.

8.4 Option 4 - Headland/Groyne Protection

The erosion trend of the Northern Beach is caused by a net longshore movement to the north produced by wave action and insufficient material entering the system from the south. However, the extent of the resulting erosion is greatly reduced by large volumes of the sand re-entering the system from the north during westerly and north-westerly storm events. It may be possible to reduce this problem by constructing low profile headlands or groynes which reduce the movement of sediment northwards during normal conditions, while producing minimal obstruction to the southerly movement of sediment during storm events. However, the beach to the north of the most northern headland/groyne is likely to erode as a result of the reduced sediment supply from the protected area. This may produce a gradual reduction in the volume of sand returning to Quinns from the north during storm events. Therefore, in the longer term, occasional renourishment may be required to replace minor losses from Quinns which the headlands/groynes are unable to prevent.

A more comprehensive evaluation of the headland/groyne option will be undertaken for the Northern Beach in Stage 2. However, at present the Southern Beach does not require significant additional trapping of material for protection purposes. Therefore, investigation of headland/groyne protection for the Southern Beach is not proposed.

8.5 Option 5 - Offshore Breakwater

The Northern Car Park can be protected by constructing an offshore breakwater which forms a cuspate spit in the lee of the structure (refer to Figure 8.1). However, very large volumes of sand would be required to form the spit without denuding sand from the beaches to the north and south.

The construction of offshore breakwaters is costly. The structure is built in deeper water requiring larger size and greater quantities of armour stone for the breakwater, and temporary vehicle access from the shore. Alternatively, construction can be undertaken using a barge.

Although an offshore breakwater can form a stable beach in the lee of the structure, is likely to increase erosion to the north by reducing the sediment feed during normal sea and swell conditions, and may destabilise the Southern Beach by obstructing southerly sediment transport during north-westerly storm events.

Given the likely adverse affects and inhibitive costs, the protection of Quinns using offshore breakwaters is not recommended.

8.6 Option 6 - Submerged Offshore Breakwater

A section of submerged offshore breakwater can perform a similar function as a standard offshore breakwater. However, the degree of protection offered is generally less. A section of submerged offshore breakwater is not recommended for similar reasons to those outlined in Option 5.

Alternatively, a perched beach can be created using a continuous length of submerged breakwater parallel to the shore which is linked back to the foreshore at either end (refer to Figure 8.2). This method is most appropriate in locations where the beach is generally stable under normal conditions, but erodes during severe storm events. The raised level of the beach reduces storm erosion by dispersing a greater amount of wave energy and by allowing the formation of a storm induced profile without the need for an excessive offshore movement of sediment. However, raising the level of the Northern Beach would not reduce the losses which result from a net northwards longshore movement of sediment without sufficient sediment feed from the south. Also, raising the level of the beach may interfere with the return of sediment from the north during north-westerly storm events when significant sediment transport occurs further offshore. Therefore, this method of foreshore protection is not recommended for the Northern Beach.

The construction of a perched beach south of the Cusp to provide increased protection during storm events is not recommended because the long term stability of the Southern Beach relies on the return of sediment from the north during storm events and the raising of the beach is likely to interfere with this process.

9. Stage 1 Conclusions & Recommendations

9.1 Coastal Processes

Existing data and technical reports were reviewed. This information was supplemented through further investigation and analysis described in the report. The results of the study indicate that the artificial headland constructed to the south of the Cusp in 1977, greatly influenced the stability of the Quinns coast. Since its construction, the Southern Beach has remained relatively stable while the Northern Beach has incurred a progressive trend of erosion.

Sediment budgets based on shoreline movements and a comparison of surveys recorded between 1977 and 1997 indicate that the volume of sand along the Quinns beaches varies significantly with both seasonal and annual fluctuations. However, on average, between 4,000 m^3 and 8,000 m^3 is being lost each year from the Quinns area.

9.2 Design Criteria

Based on the results of Steedman (1988) and analysis completed as part of the present study, a 50 year design still water level of +1.9 metres CD ($\approx$+1.2 metres AHD) is recommended.

The computer model 2GWAVE was used to analyse the wave climate at Quinns. Simulations of severe storm events indicated that nearshore significant wave heights of up to 2.8 metres can be expected during a 50 to 100 year ARI event. It is recommended that this height be used as the design nearshore wave height for the protection of both the Northern and Southern Beaches. However, it is likely that in many cases the height of incident waves will be depth limited as they approach the foreshore and enter shallower water.

9.3 Preliminary Analysis of Management Options

Southern Beach

The evaluation of coastal processes at Quinns has indicated that since the construction of the artificial headland in 1977, the Southern Beach remained relatively stable, with survey results indicating that the beach accreted by about 80,000 m^3 between 1977 and 1997. The present berm provides effective protection to the primary dune. However, during very severe storm events the dune may incur some erosion.

To protect Ocean Drive from being undermined by erosion of the primary dune caused by a succession of severe storm events, it is recommended that the following management options be considered in Stage 2:

1) Do nothing.

2) Sand renourishment on an as needed basis in response to severe storm erosion.

3) Increase the present buffer through an initial sand nourishment project, plus sand renourishment on an as needed basis in response to severe storm erosion.

4) Low strength seawall construction.

However, it should be noted that if the Northern Beach is not appropriately managed, the coastal processes presently maintaining the Southern Beach may change and the beach may re-enter the trend of erosion which existed prior to 1977. If this eventuated the management of the beach may need to be reviewed.

Northern Beach

The evaluation of coastal processes at Quinns has indicated that since the construction of the artificial headland in 1977, the Northern Beach has progressively eroded. Survey results indicate that the beach eroded by about 170,000 m^3 between 1977 and 1997. The preliminary evaluation of management options recommended investigation of the following options in Stage 2:

1) Do nothing.

2) Regular sand renourishment.

3) Seawall construction.

4) Combined lower strength seawall construction and regular renourishment.

5) Groyne/Headland construction.

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Figure 1.1 - Location Diagram

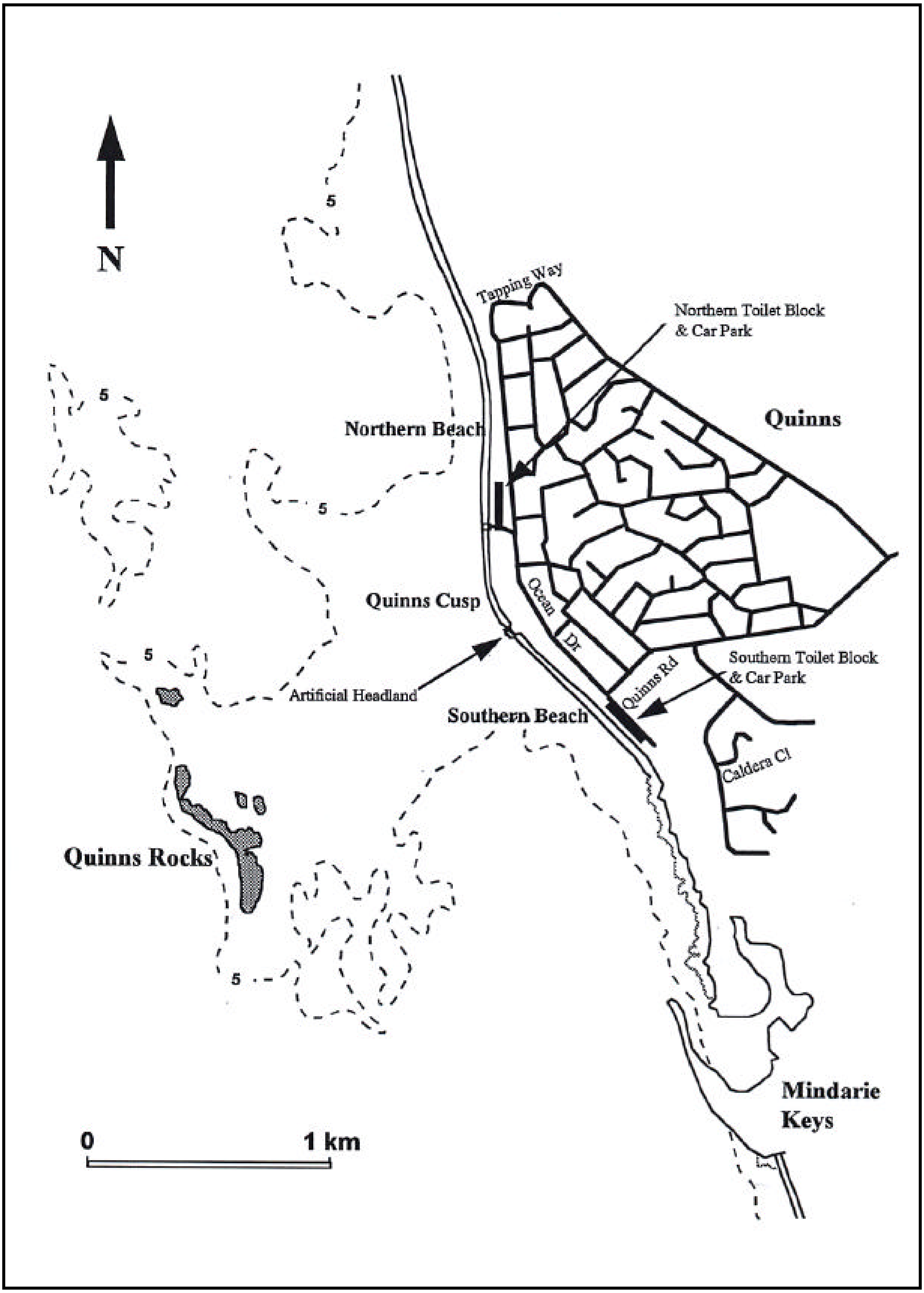


Figure 2.1 - Fremantle Seasonal Wind Roses
Spring & Summer

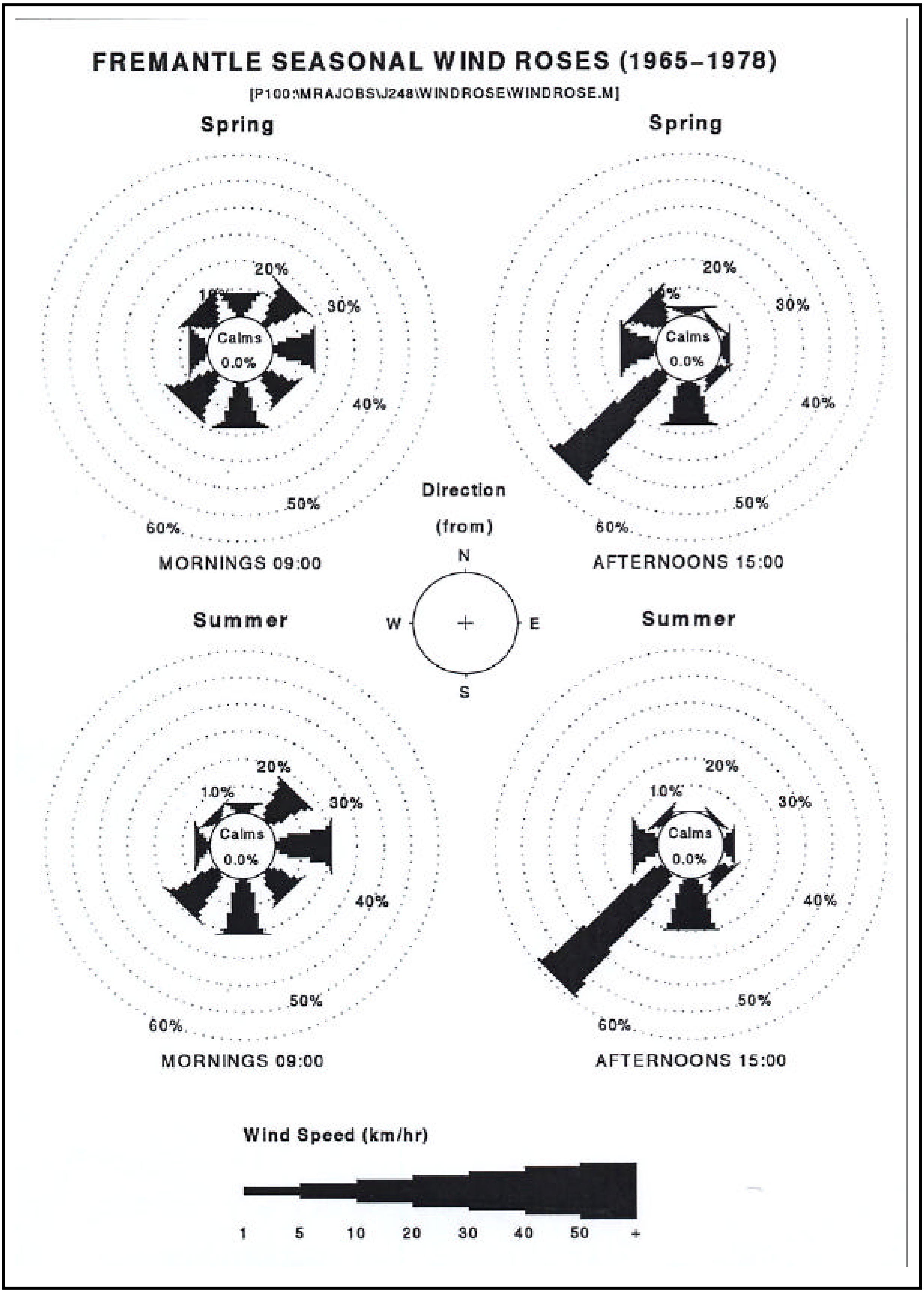


Figure 2.2 - Fremantle Seasonal Wind Roses Autumn & Winter

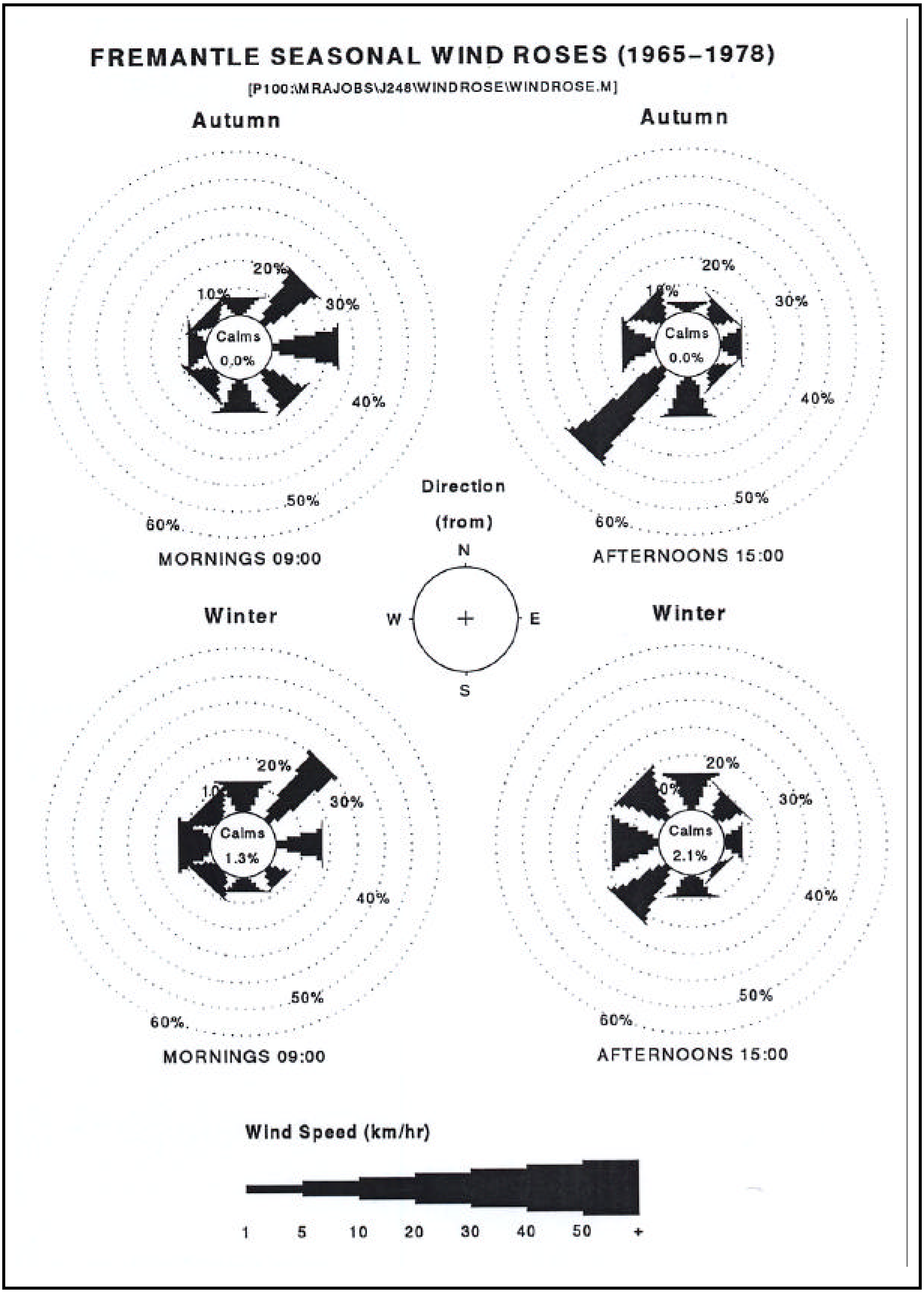
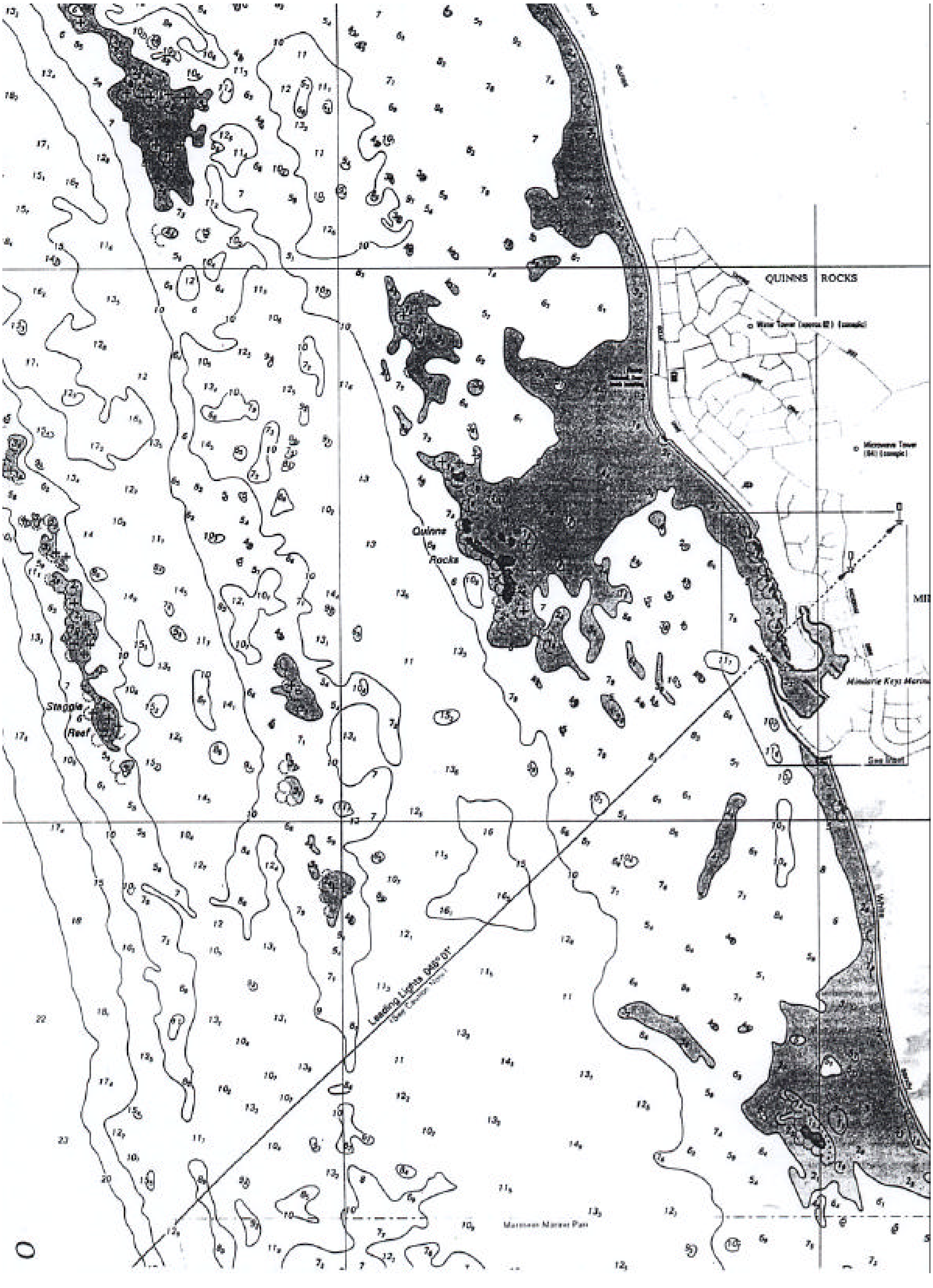


Figure 2.3 - Bathymetry of Quinns Region



Source: Transport (WA) Chart 284

Figure 2.4 - Rogers Storminess Index
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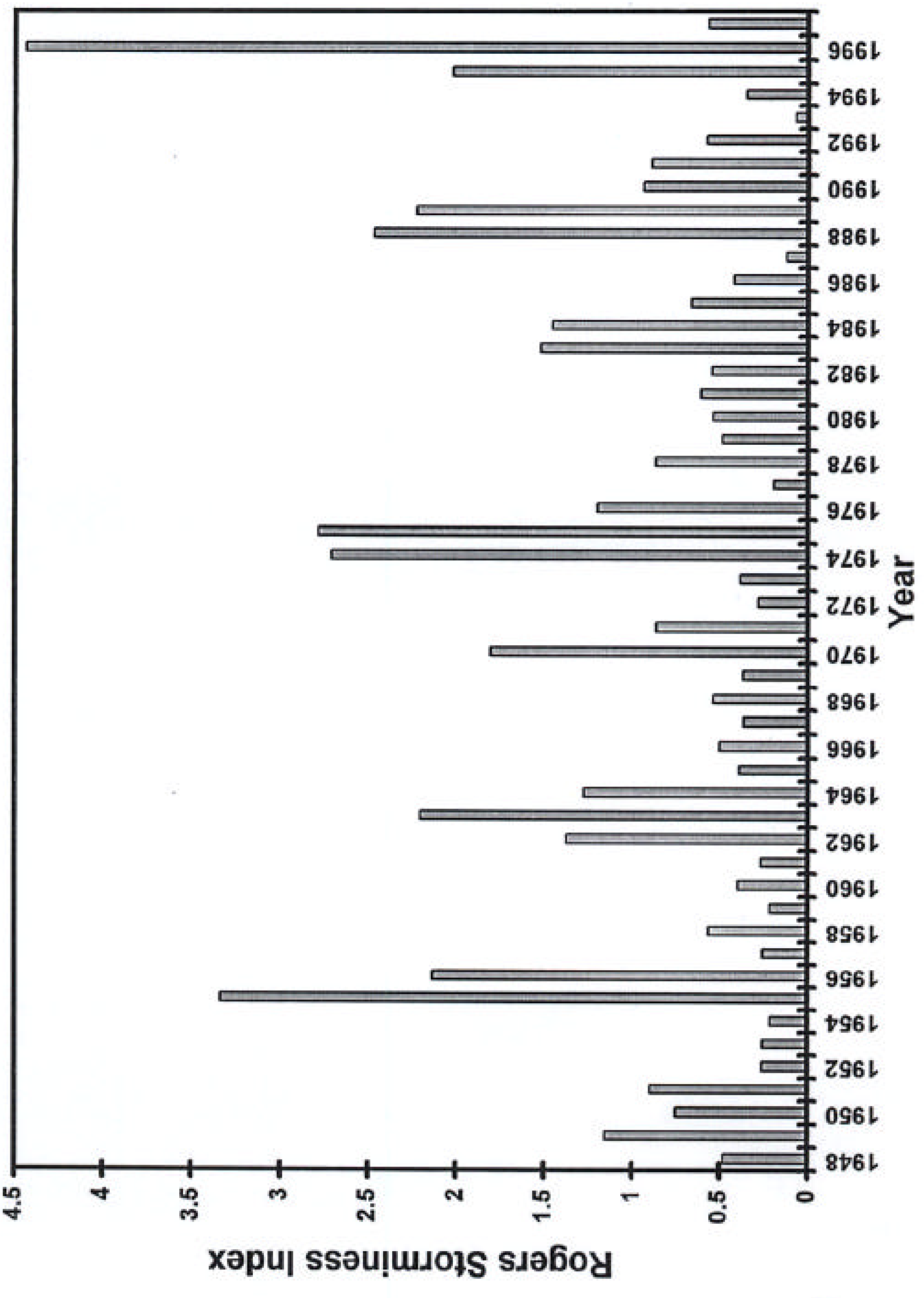
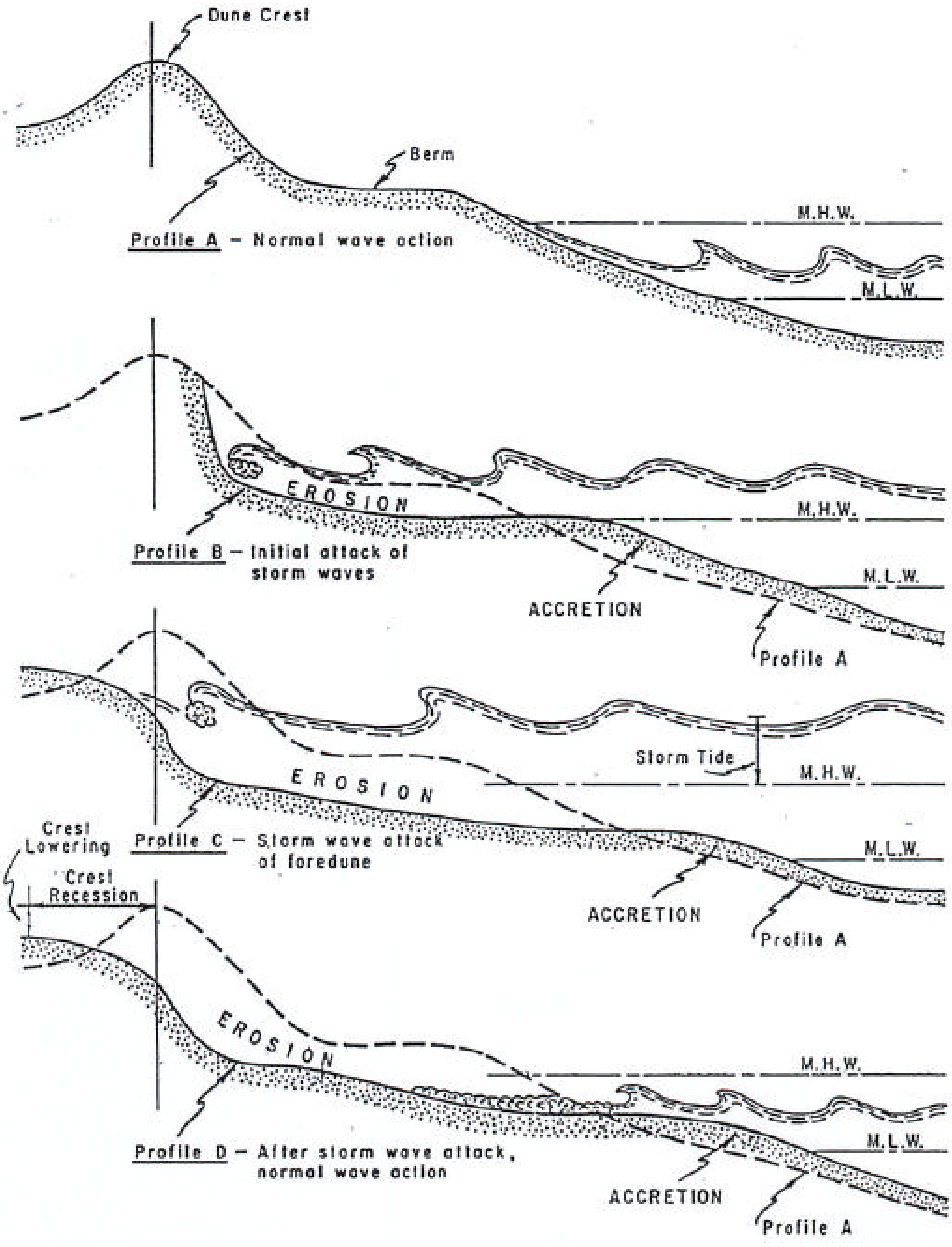
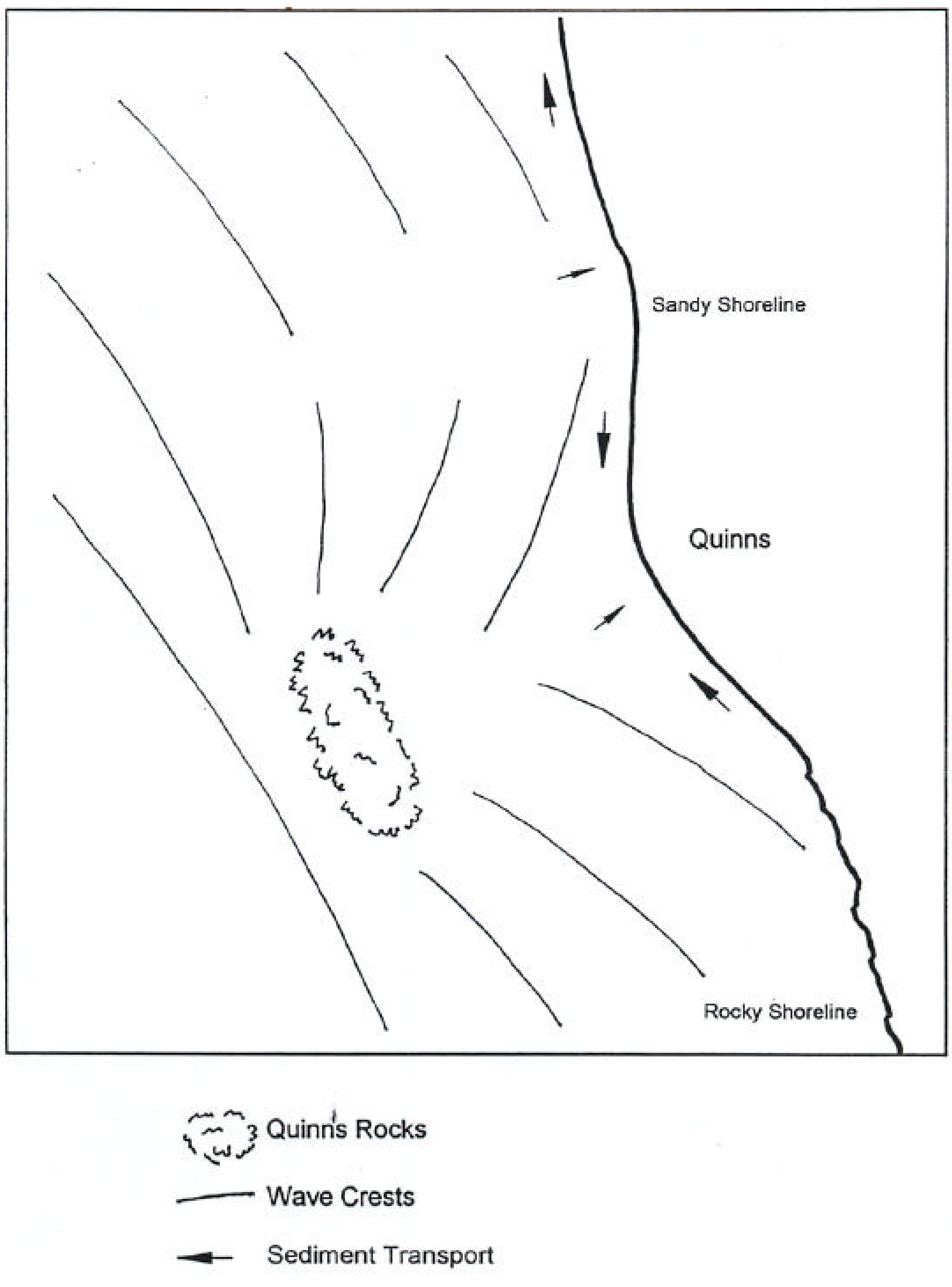


Figure 4.1 - Storm Wave Attack



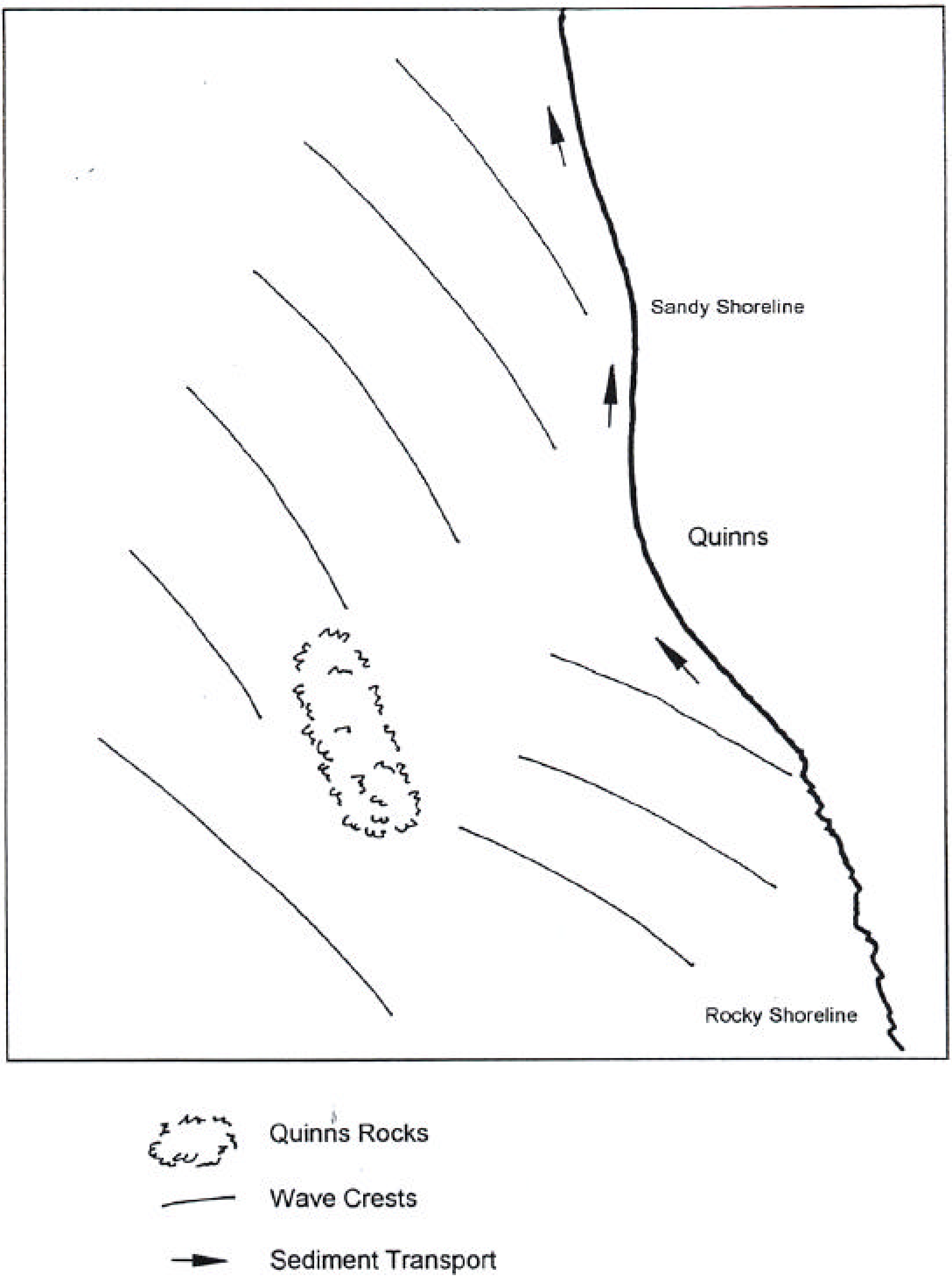
Source: Shore Protection Manual (1984)

Figure 4.2 - Sediment Transport
Prevailing Summer South-West Swell



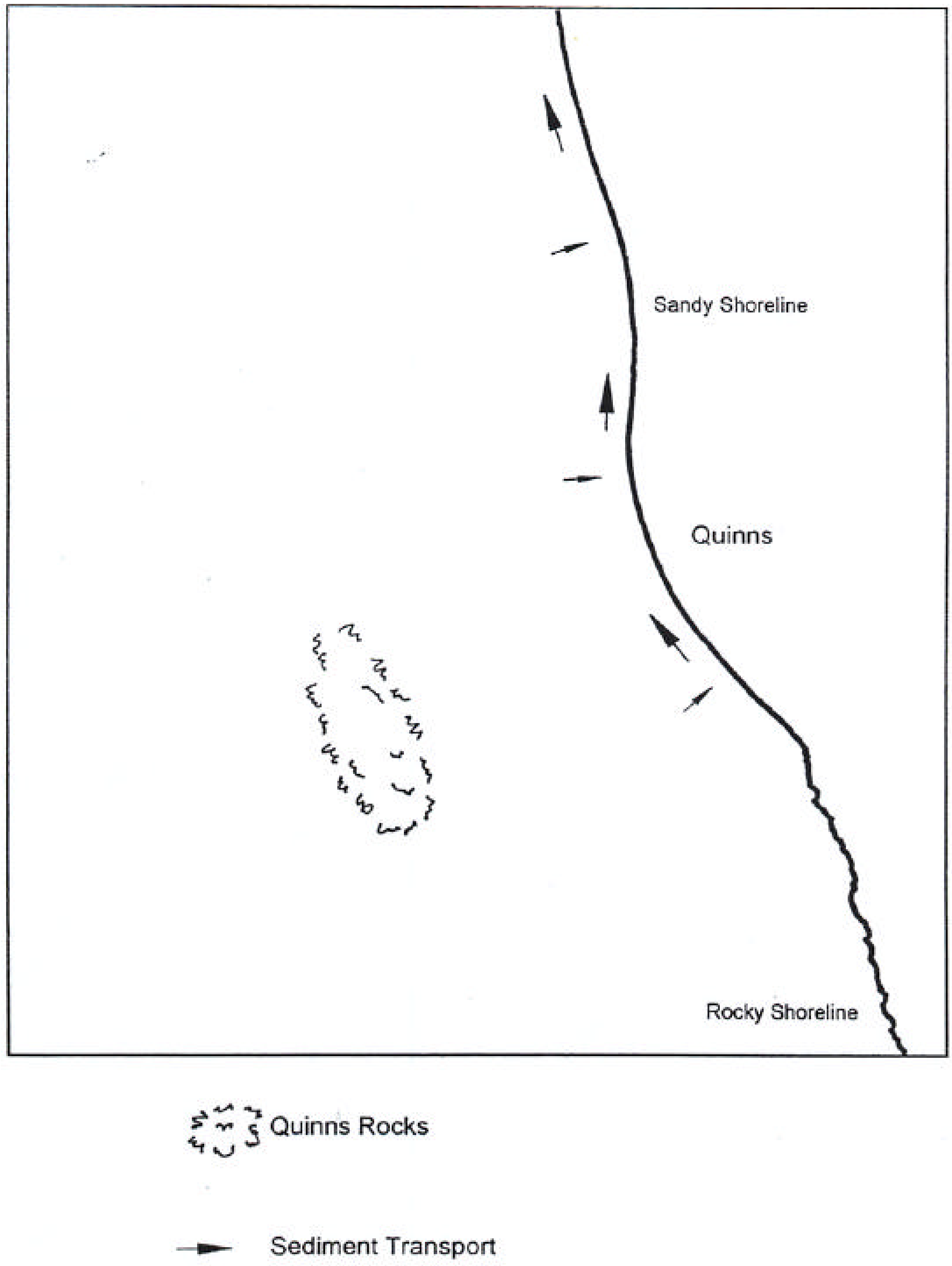
Source: Tremarfon (1997)

Figure 4.3 - Sediment Transport
Summer Afternoon Sea-Breeze



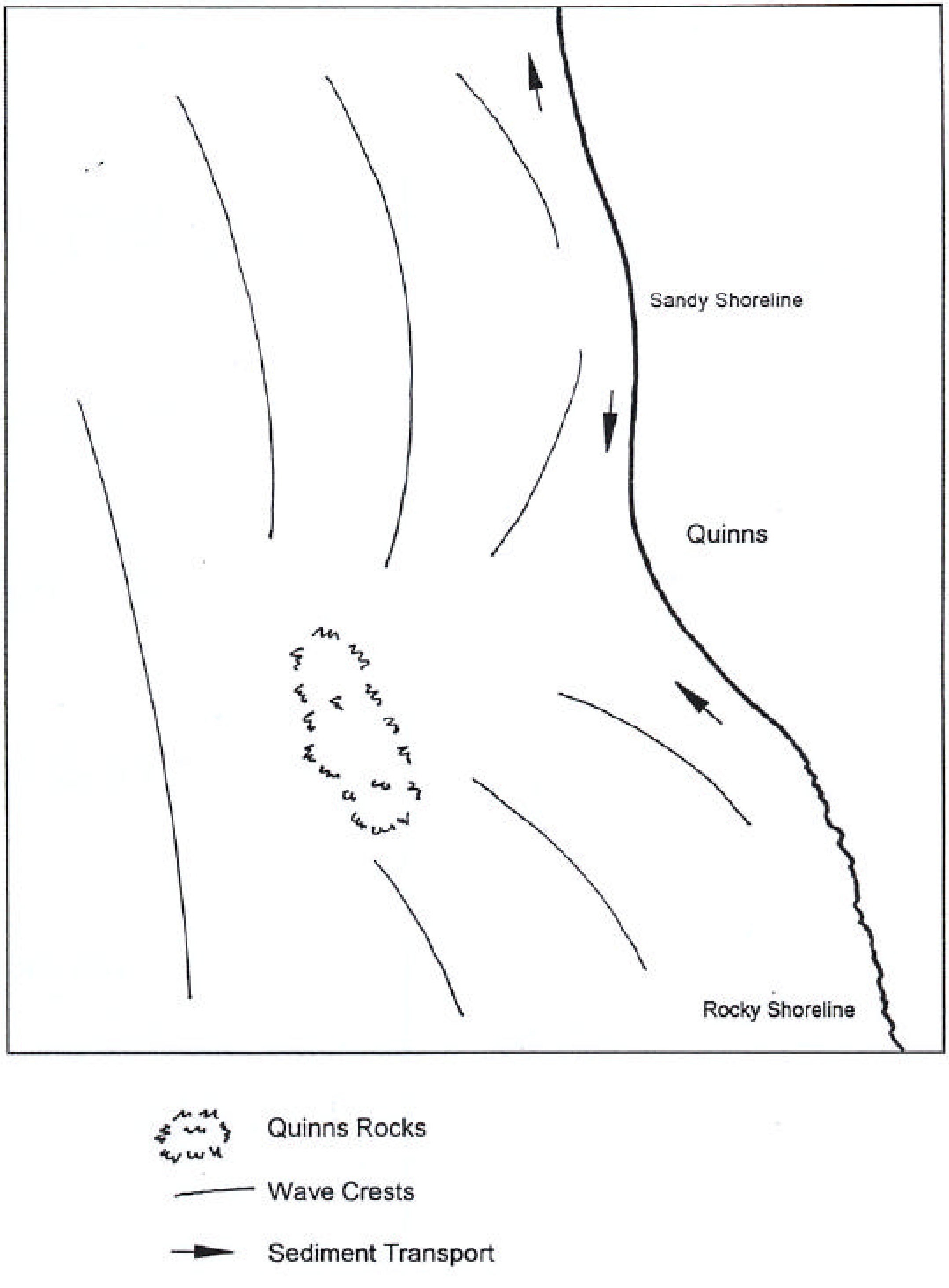
Source: Tremarfon (1997)

Figure 4.4 - Sediment Transport over Summer



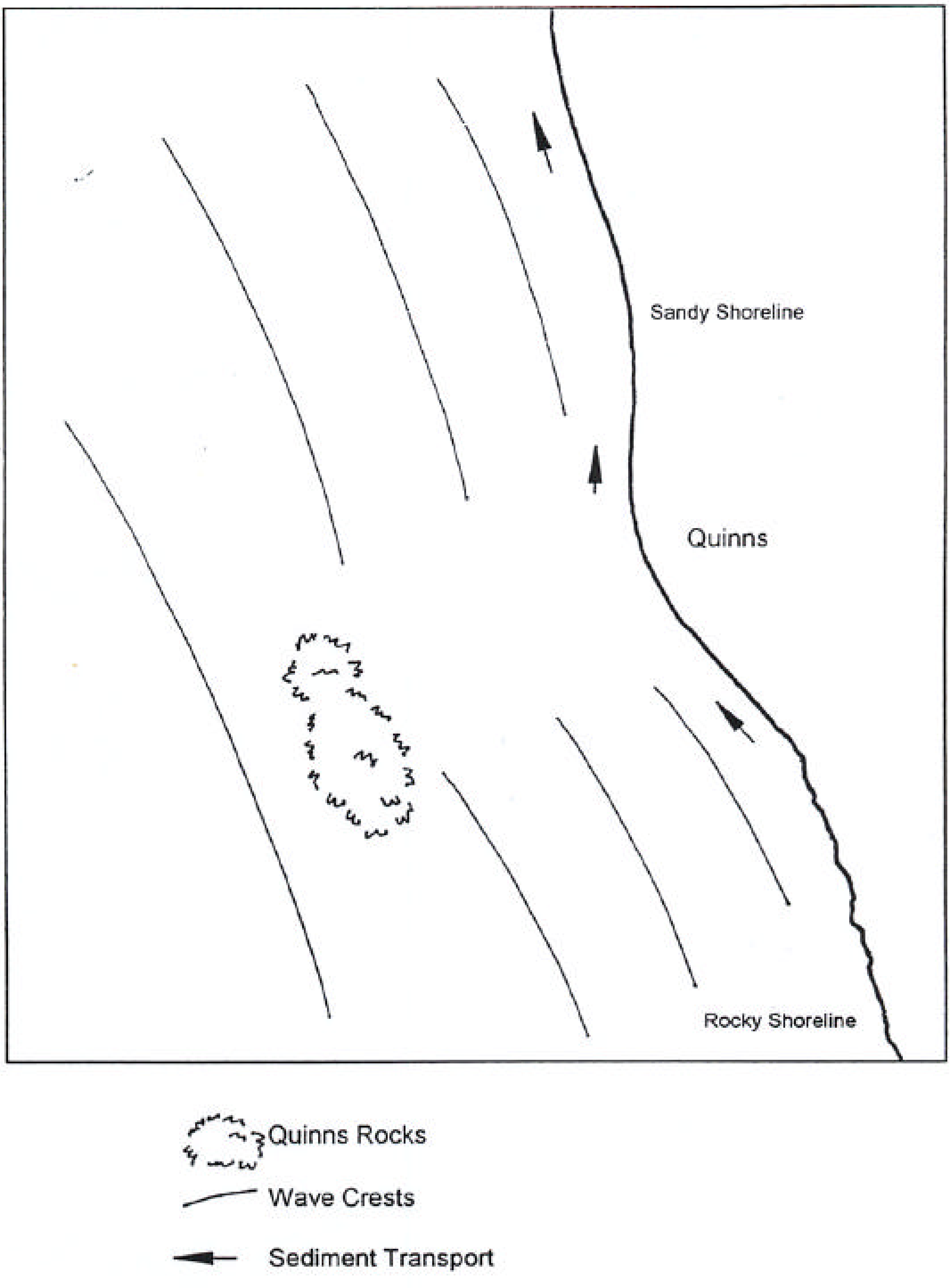
Source: Tremarfon (1997)

Figure 4.5 - Sediment Transport West to South-West Winter Swell



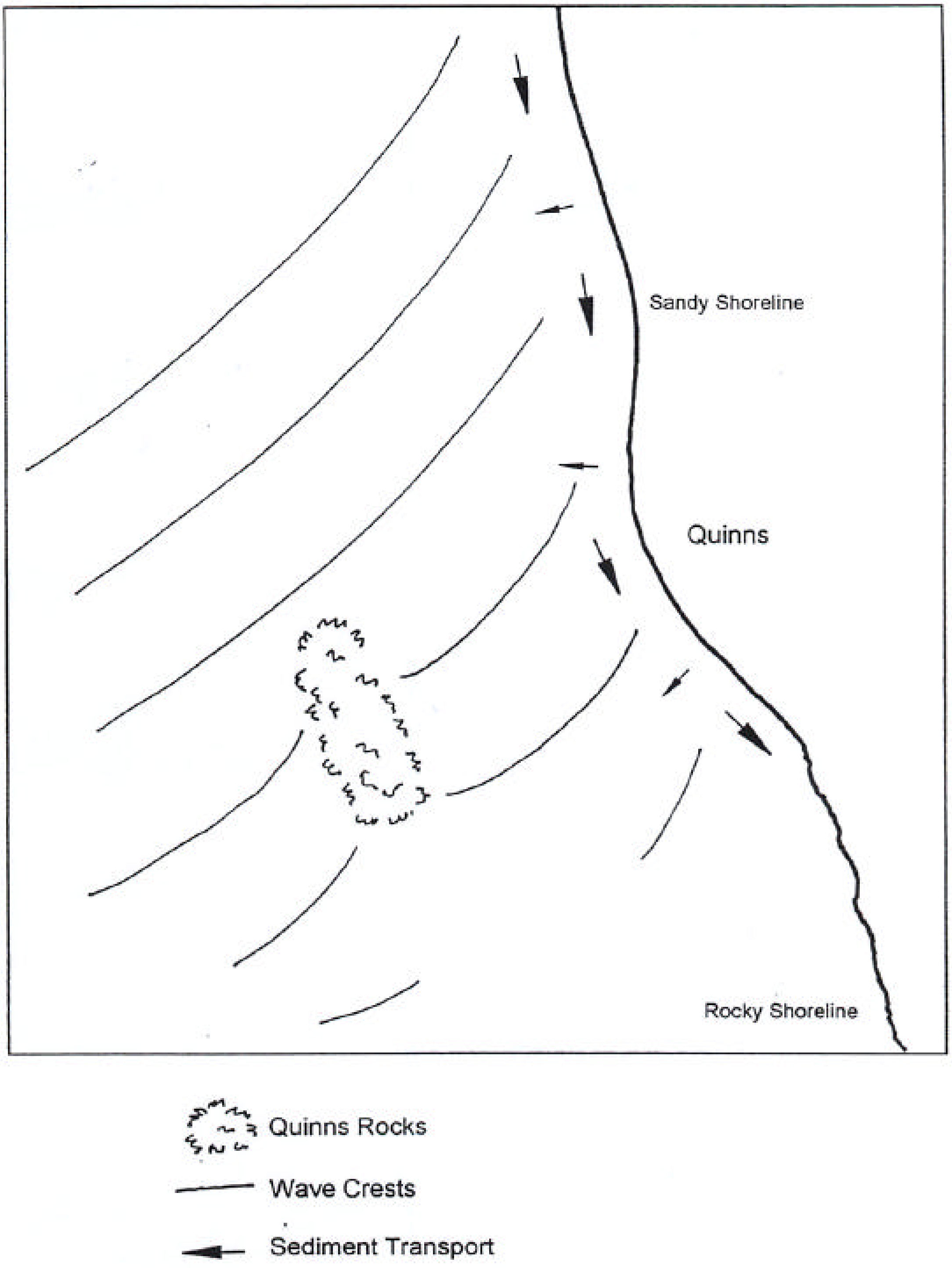
Source: Tremarfon (1997)

Figure 4.6 - Sediment Transport
West to South-West Winter Seas



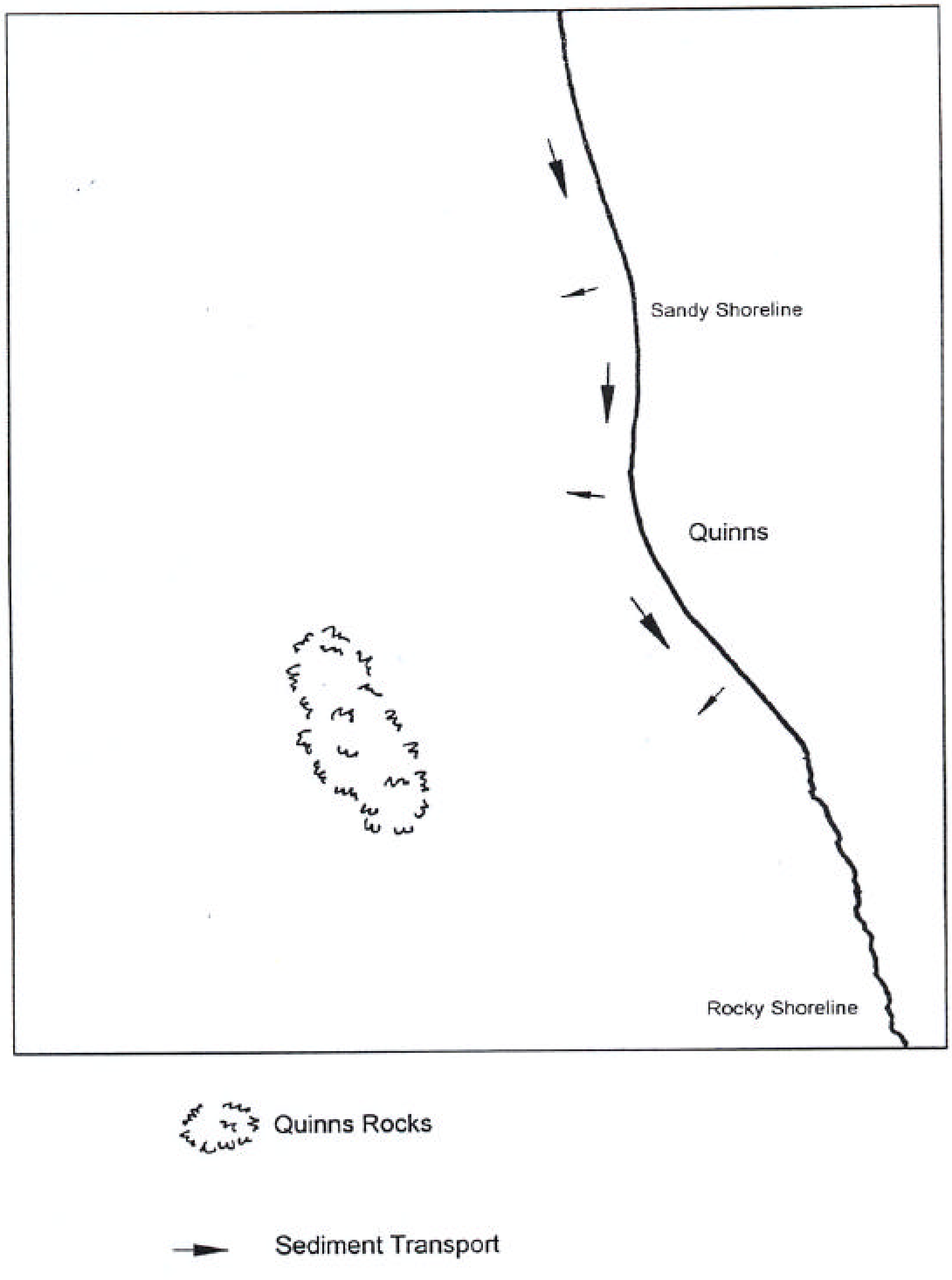
Source: Tremarfon (1997)

Figure 4.7 - Sediment Transport North of West Winter Storms



Source: Tremarfon (1997)

Figure 4.8 - Sediment Transport over Winter



Source: Tremarfon (1997)

Figure 5.1 - Coastline Movement Plot Locations

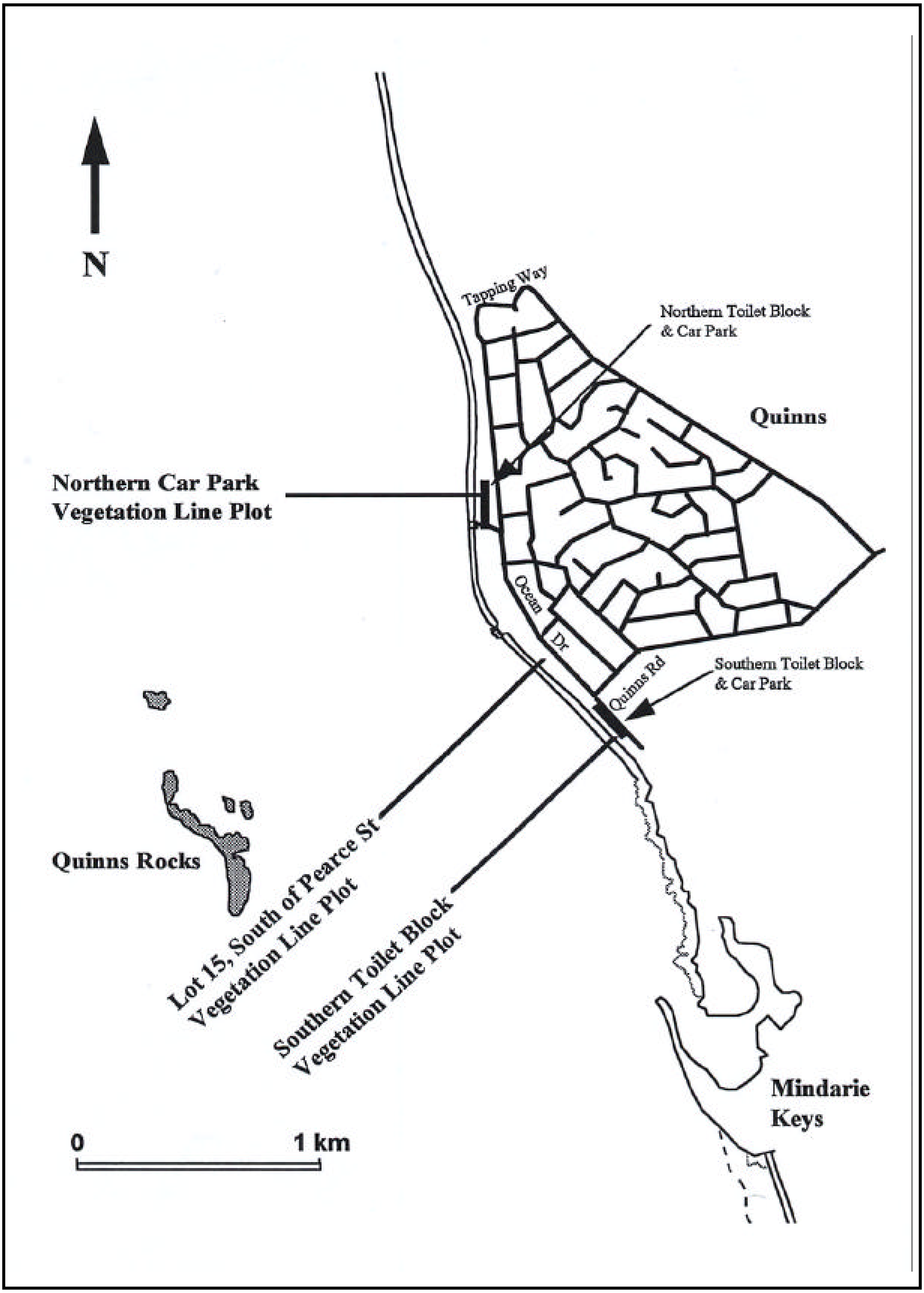


Figure 5.2 - Vegetation Line Plot for Foreshore Seawards of Southern Toilet Block

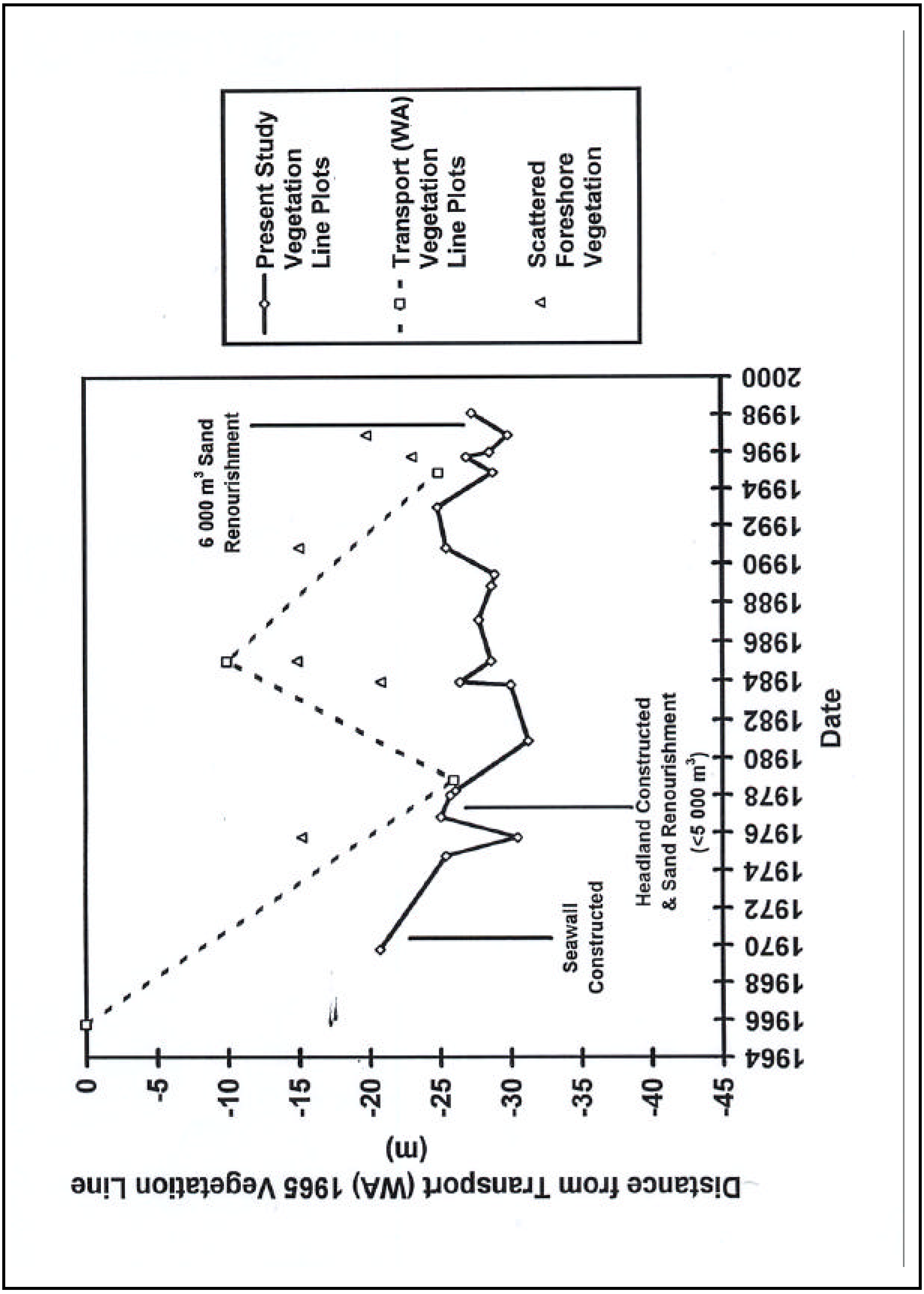


Figure 5.3 - Vegetation Line Plot for Foreshore Seawards of Lot 15, South of Pearce St.

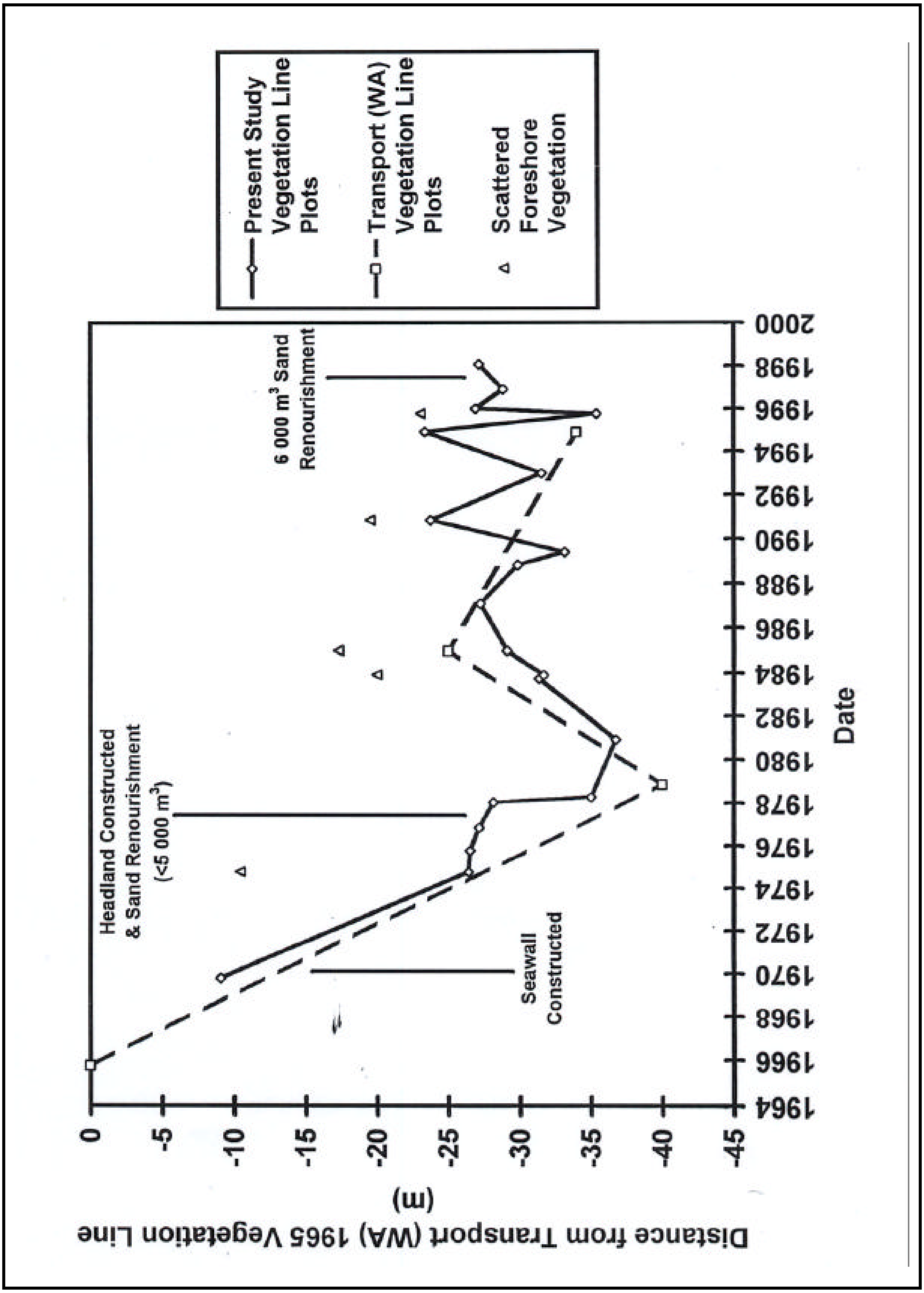


Figure 5.4 - Vegetation Line Plot for Foreshore Seawards of Northern Car Park

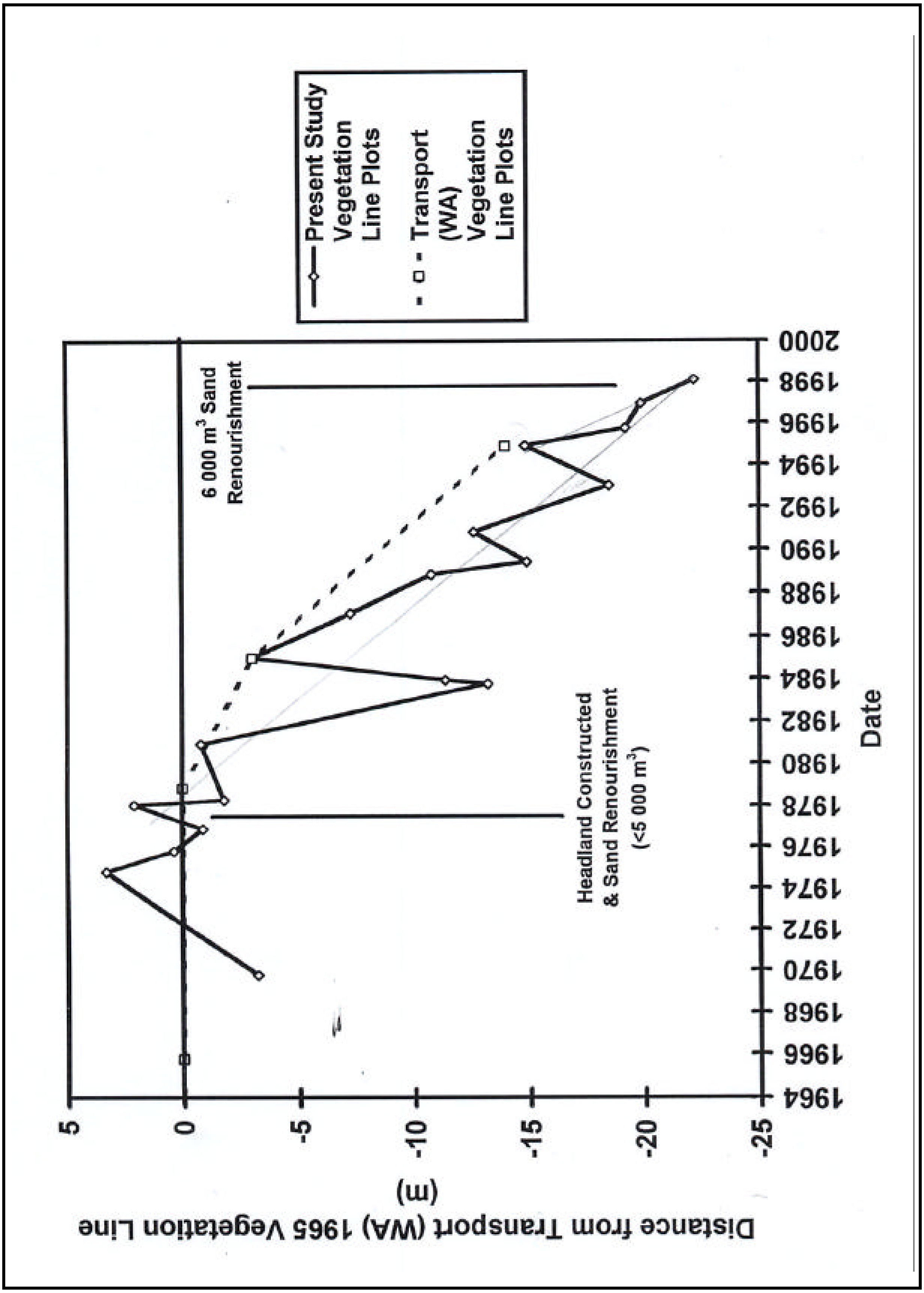


Figure 5.5 - Depth Change Plot DOT 871 - 22 -01

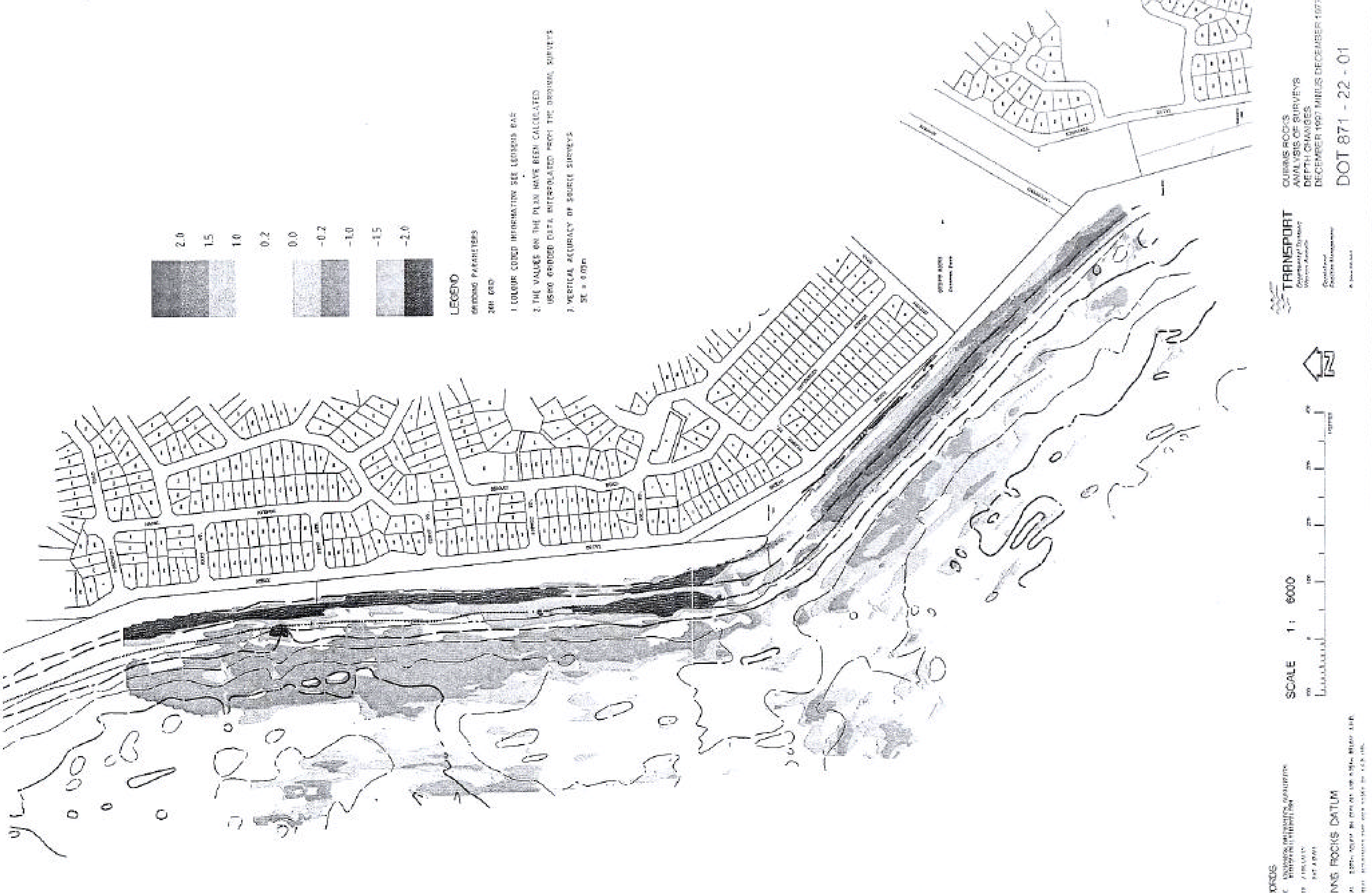


Figure 5.6 - Sediment Volume Changes

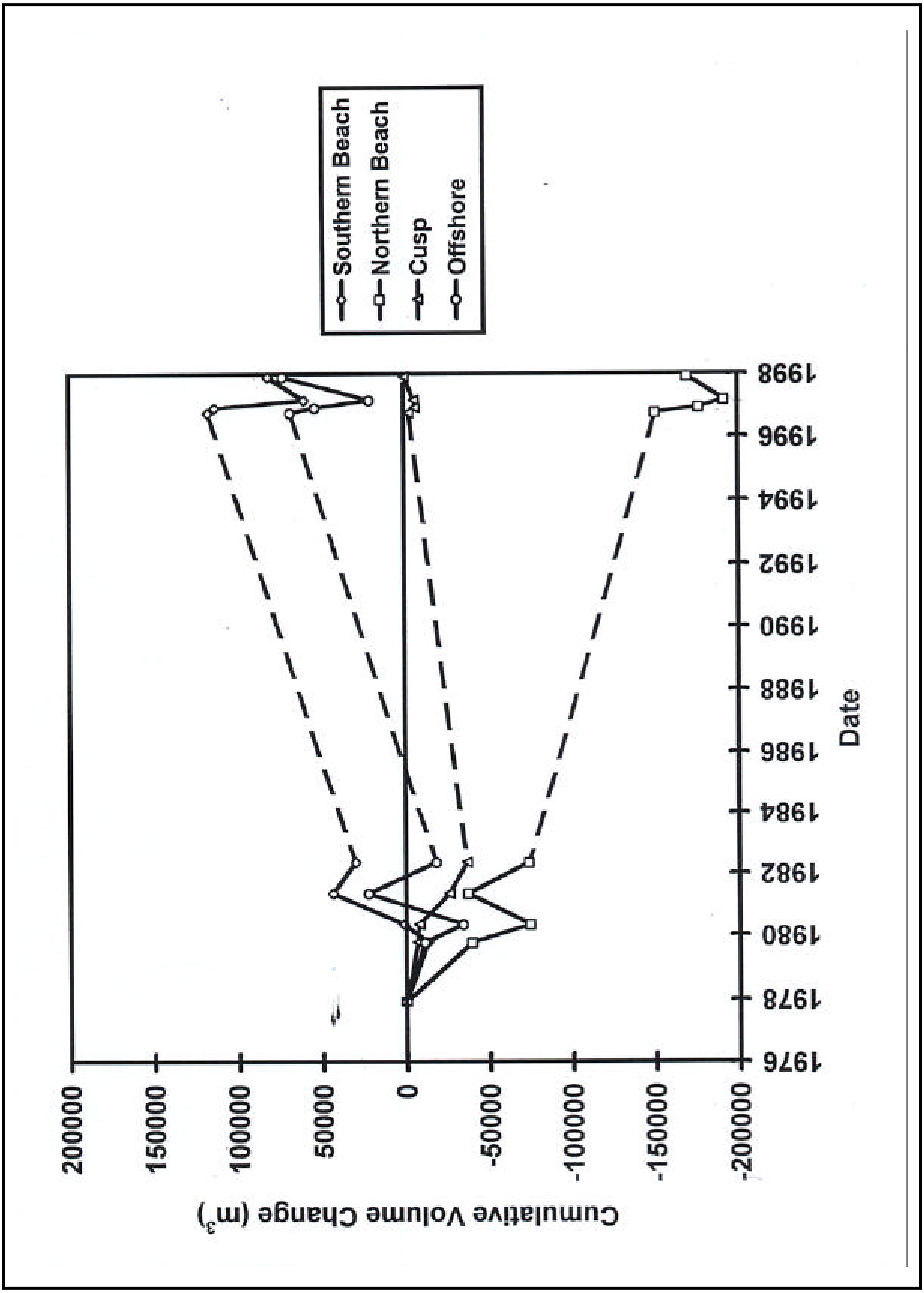


Figure 5.7 - Beach Profile Changes Seawards of Quinns Road

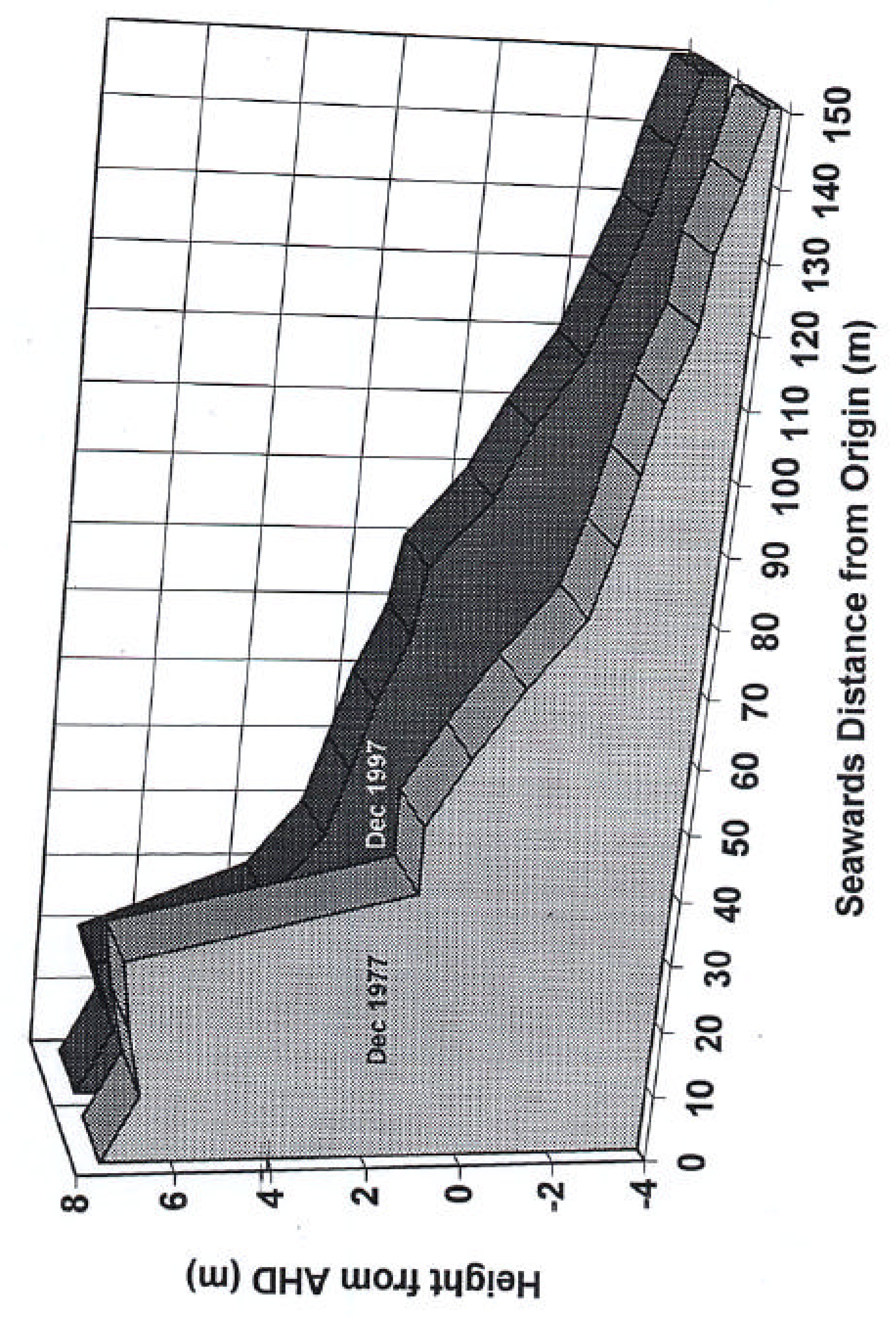


Figure 5.8 - Beach Profile Changes
Seawards of Northern Car Park

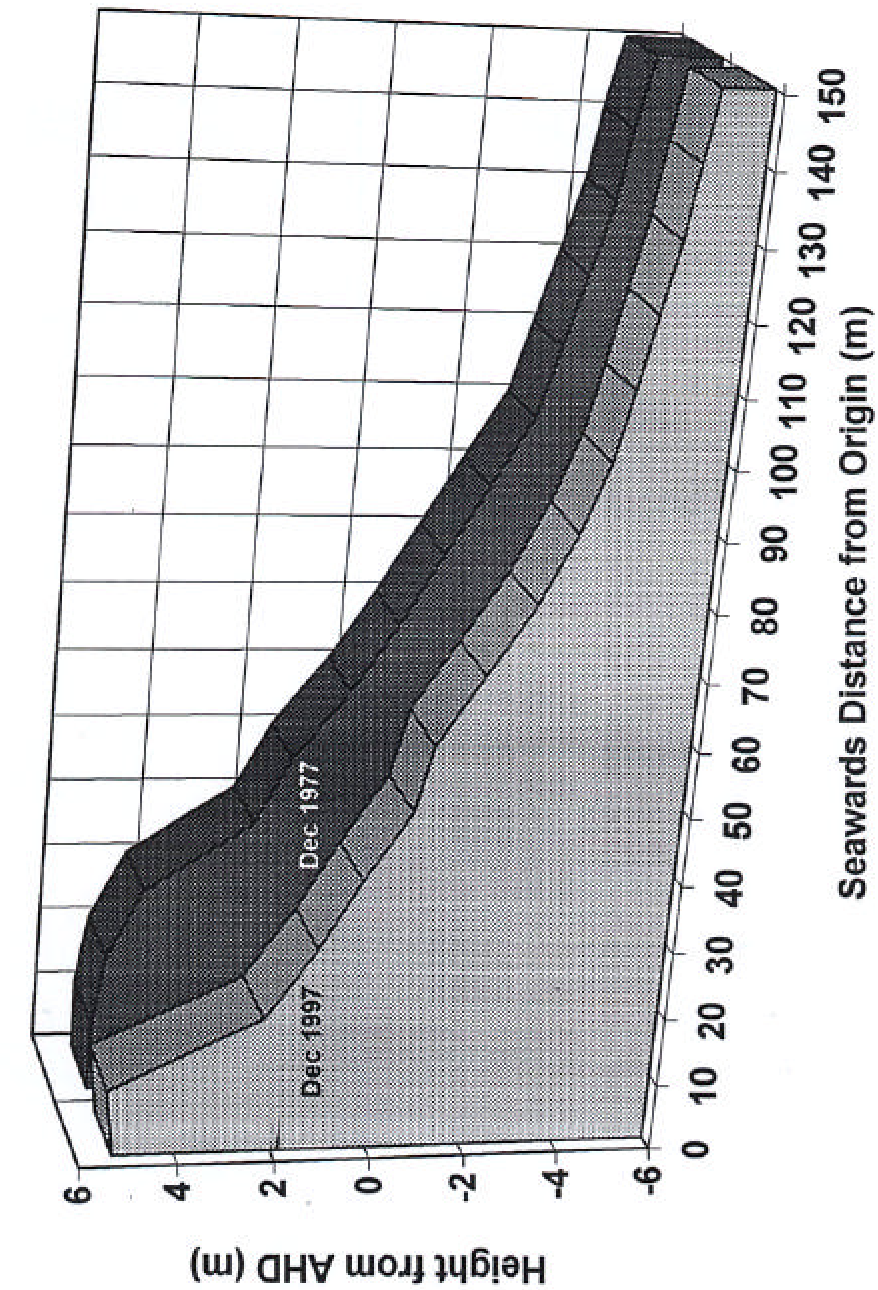


Figure 5.9 - Sediment Budget 1941 - 1978

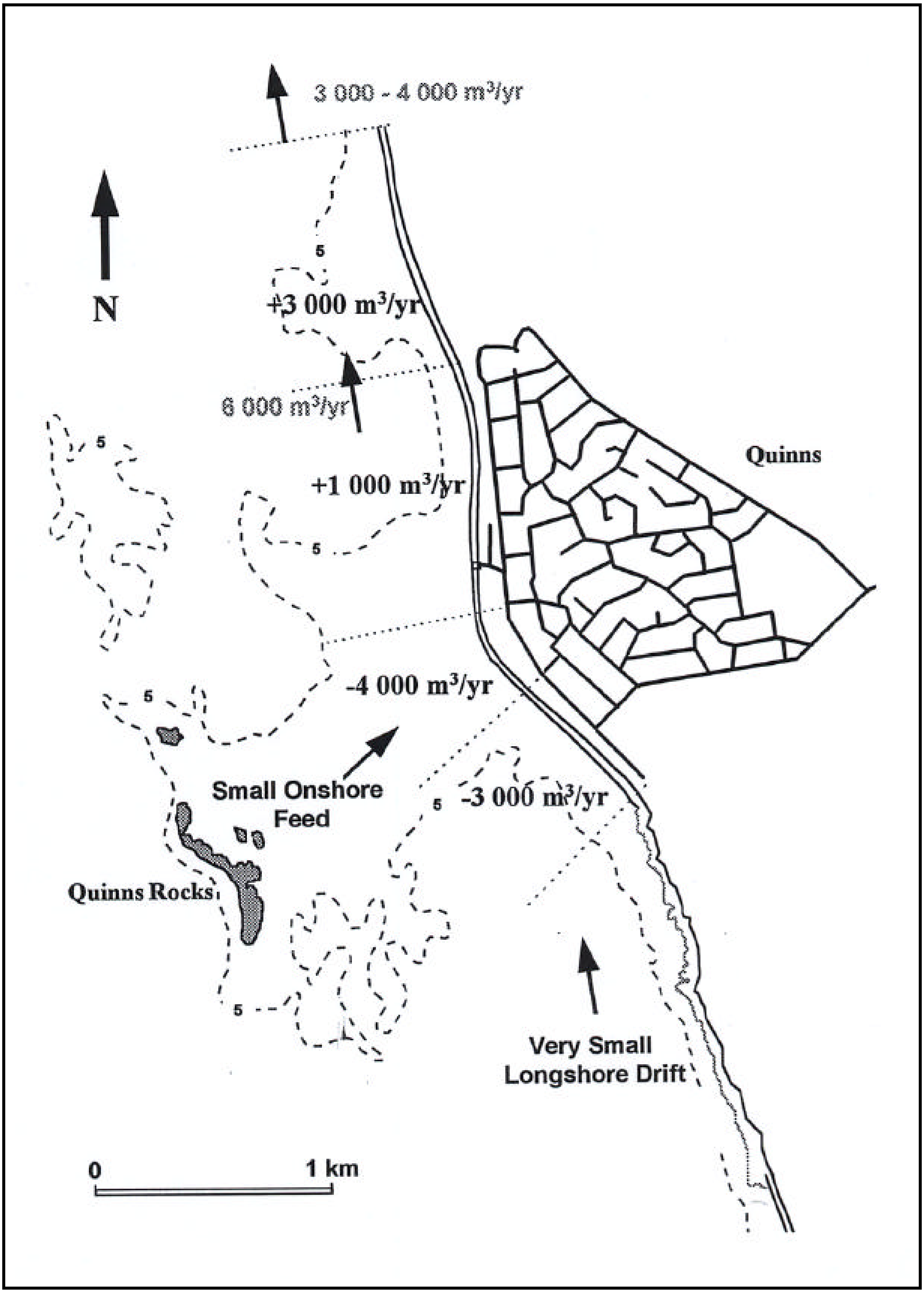


Figure 5.10 - Sediment Budget
1978 - 1997

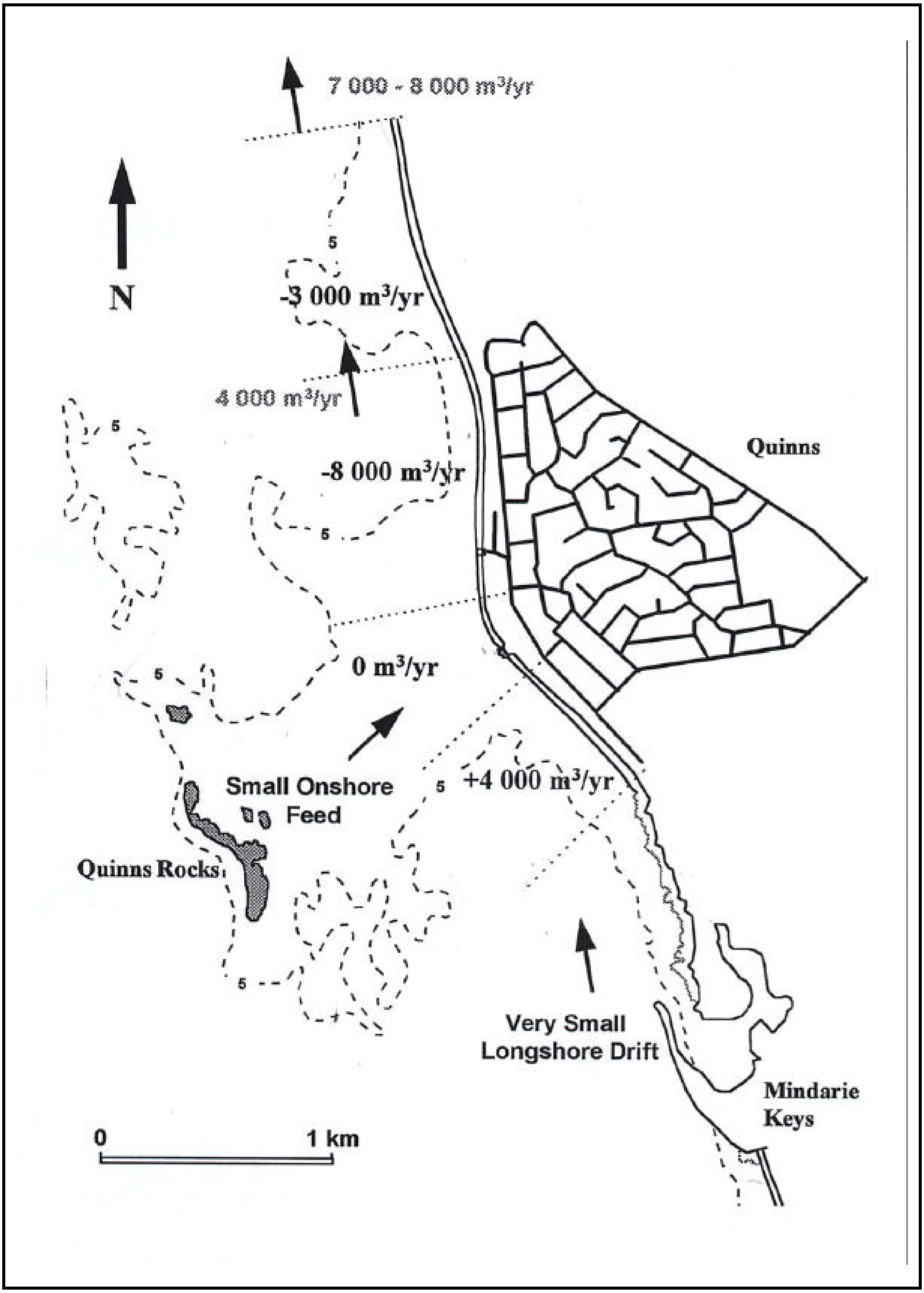


Figure 5.11 - Sediment Budget
Possible Future Budget

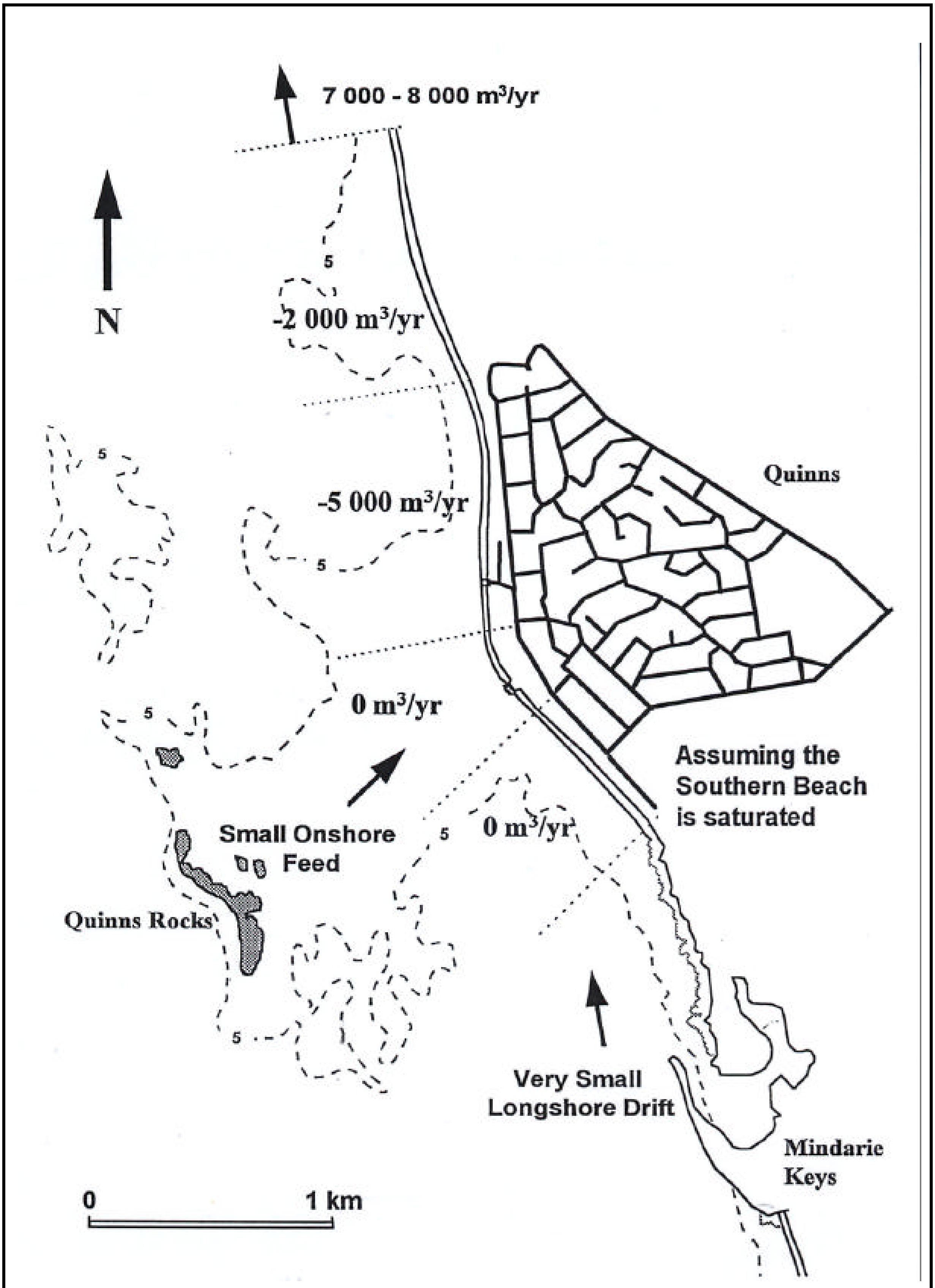


Figure 5.12 - Sediment Budget Seasonal Variation

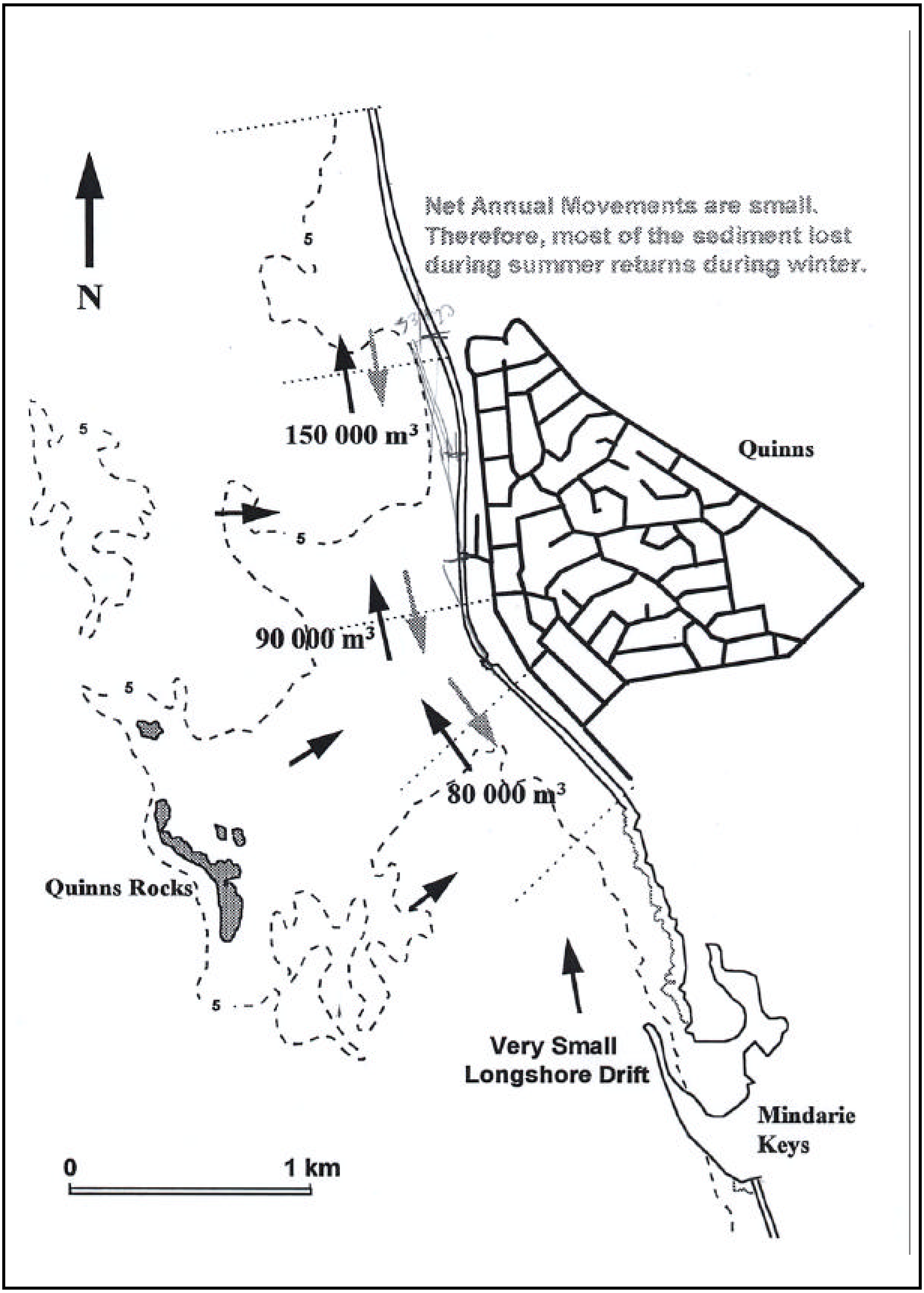


Figure 5.13 - Sediment Budget
Annual Variation

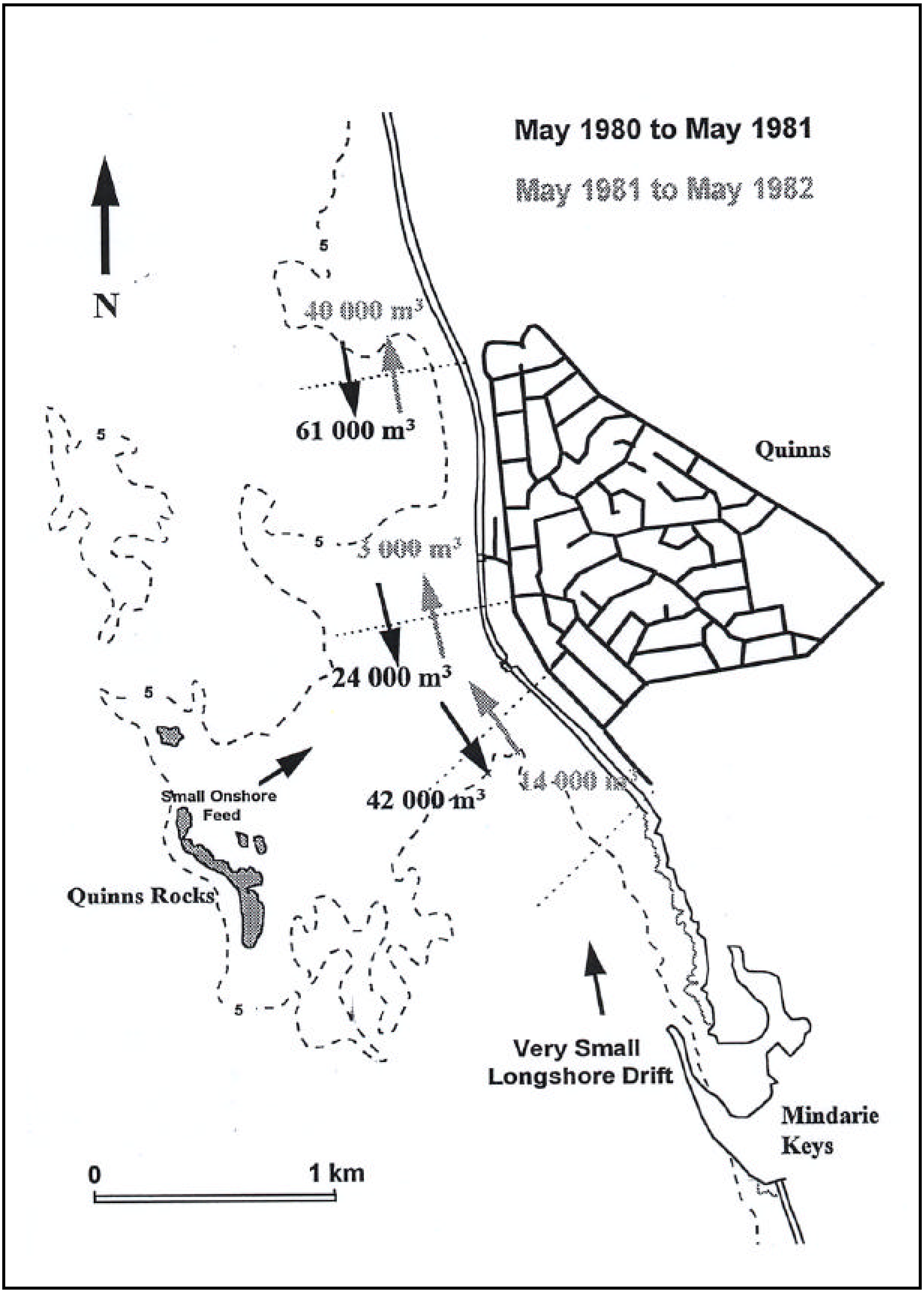
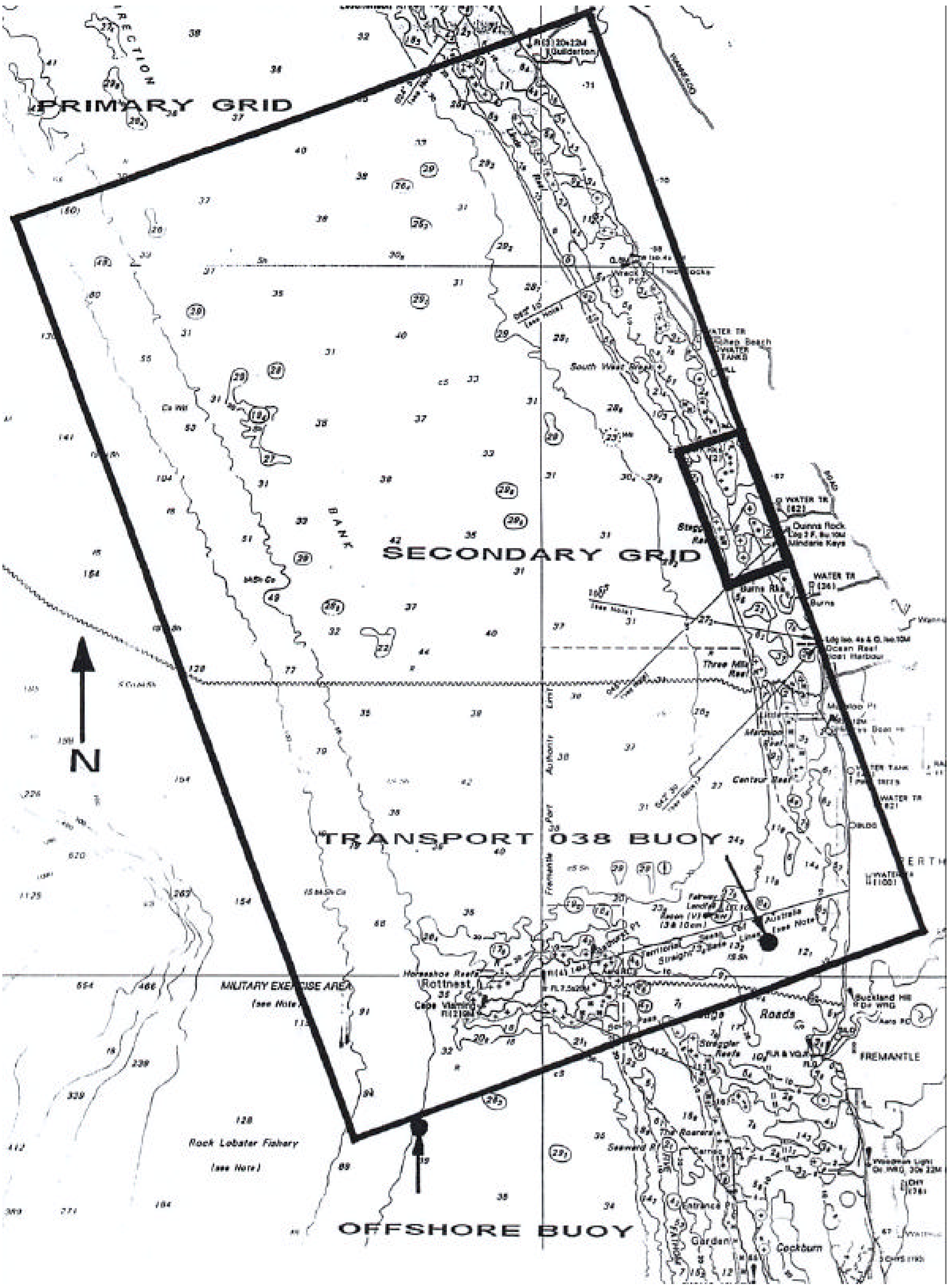


Figure 6.1 - 2GWave Model Grid Locations



Source: AUS Chart 334

Figure 6.2 - Key Locations for 2GWave Model Outputs

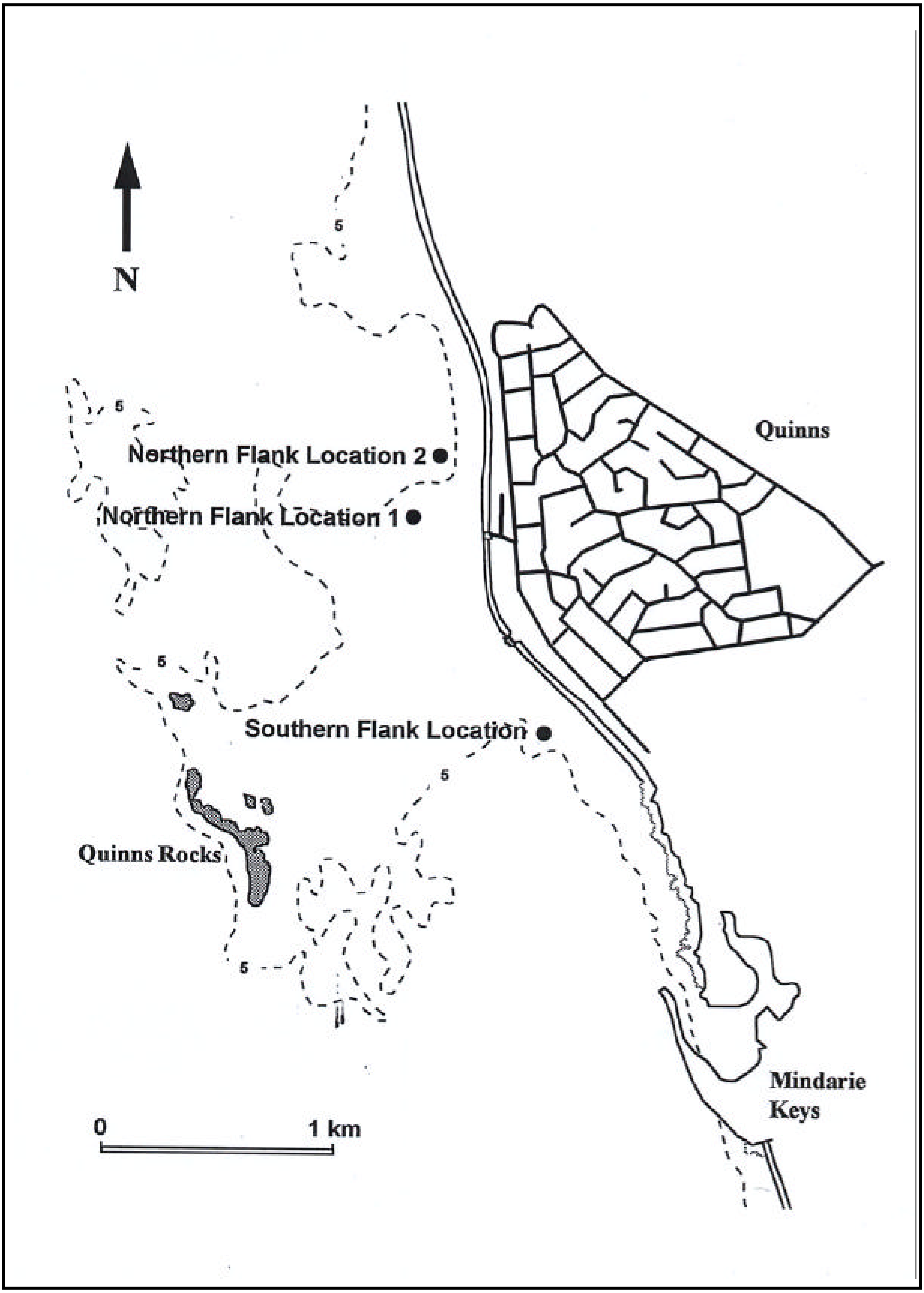


Figure 6.3 - 2GWave Model Results
50 to 100 year ARI Storm Event

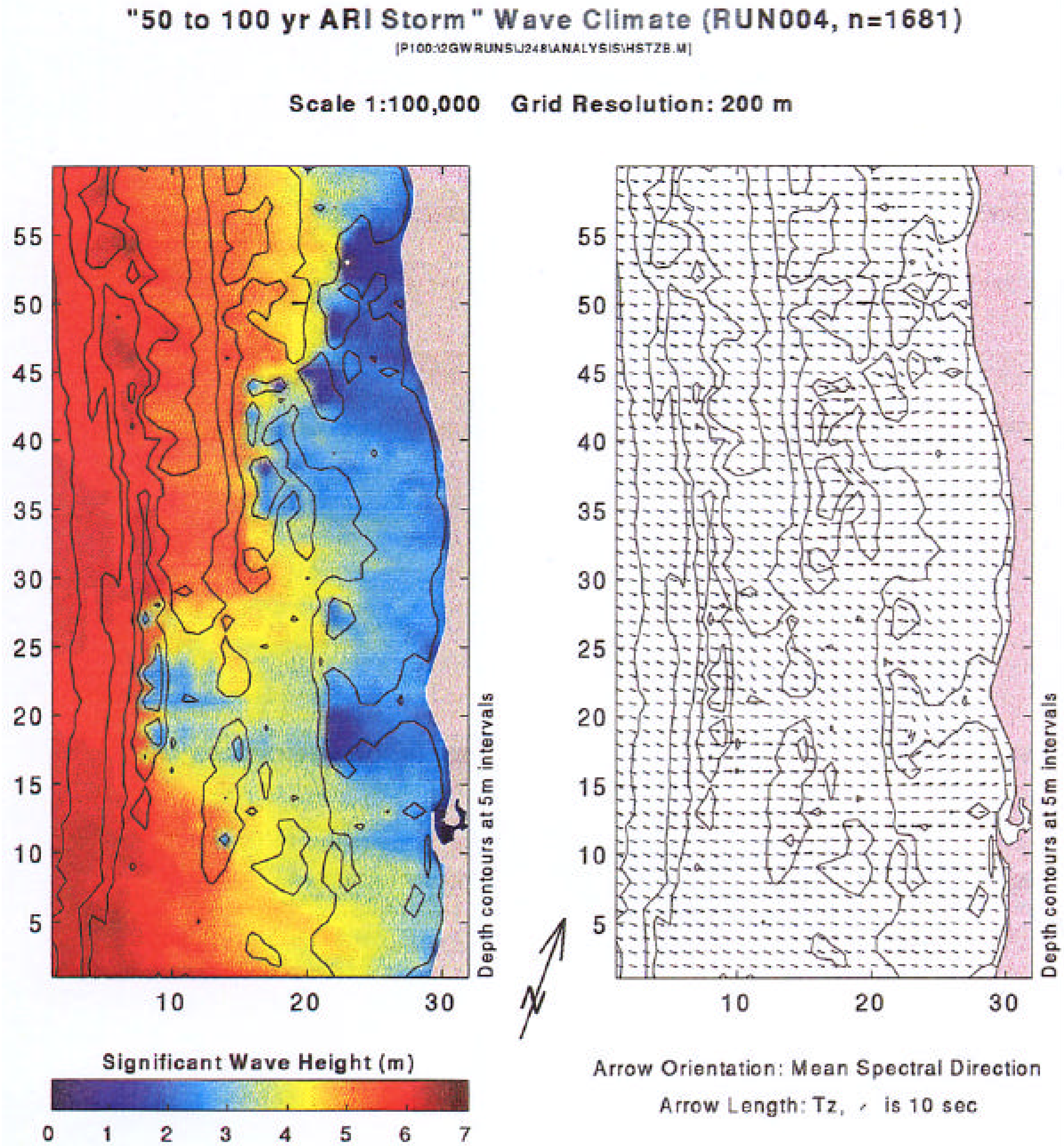


Figure 7.1 - SBEACH Model Results 50 to 100 yr ARI
1997 Beach Profile from Quinns Road

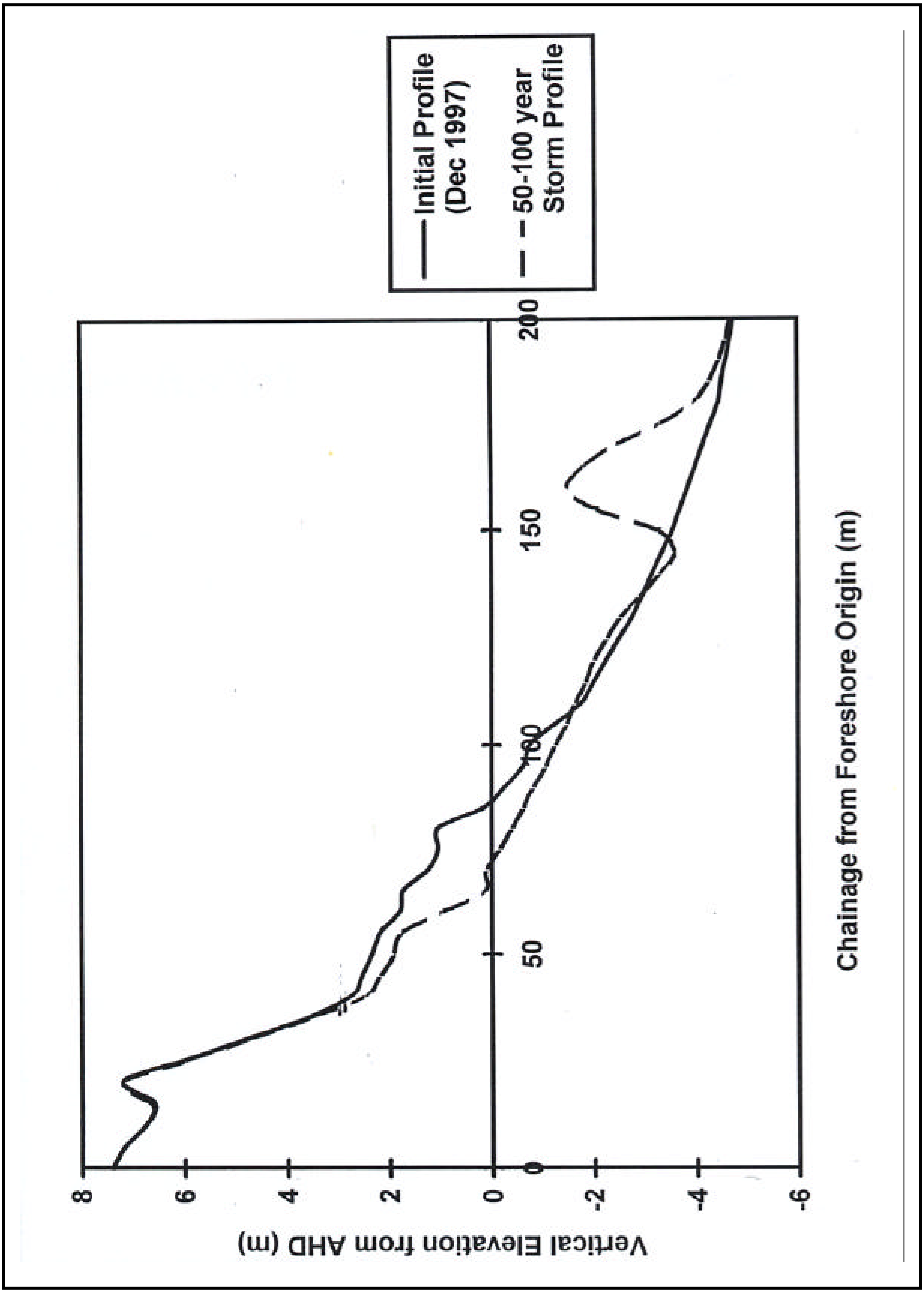


Figure 7.2 - SBEACH Model Results 50 to 100 yr ARI 1977 Beach Profile South of Pearce St.

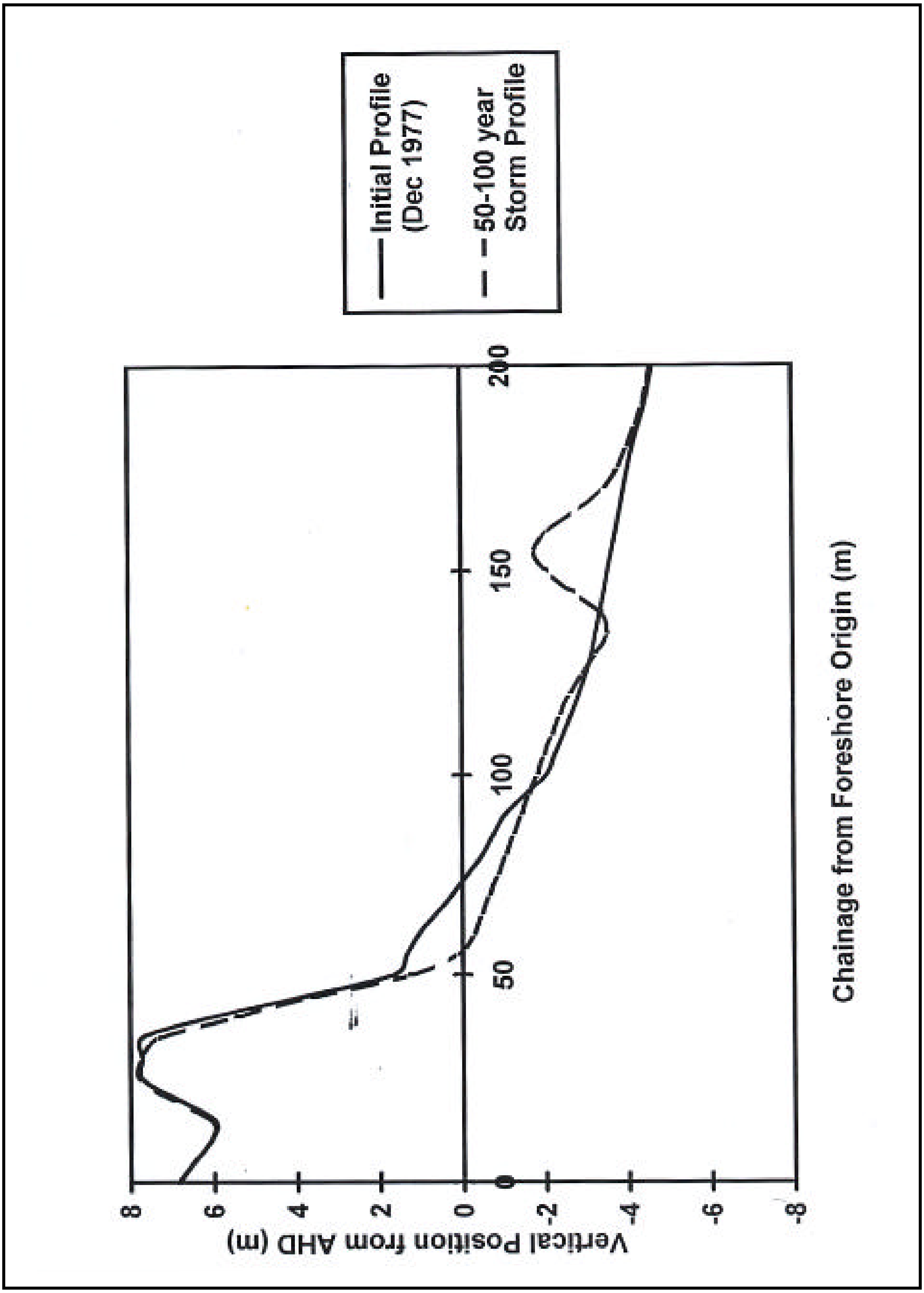


Figure 7.3 - SBEACH Model Results 50 to 100 yr ARI 1980 Beach Profile South of Pearce St.

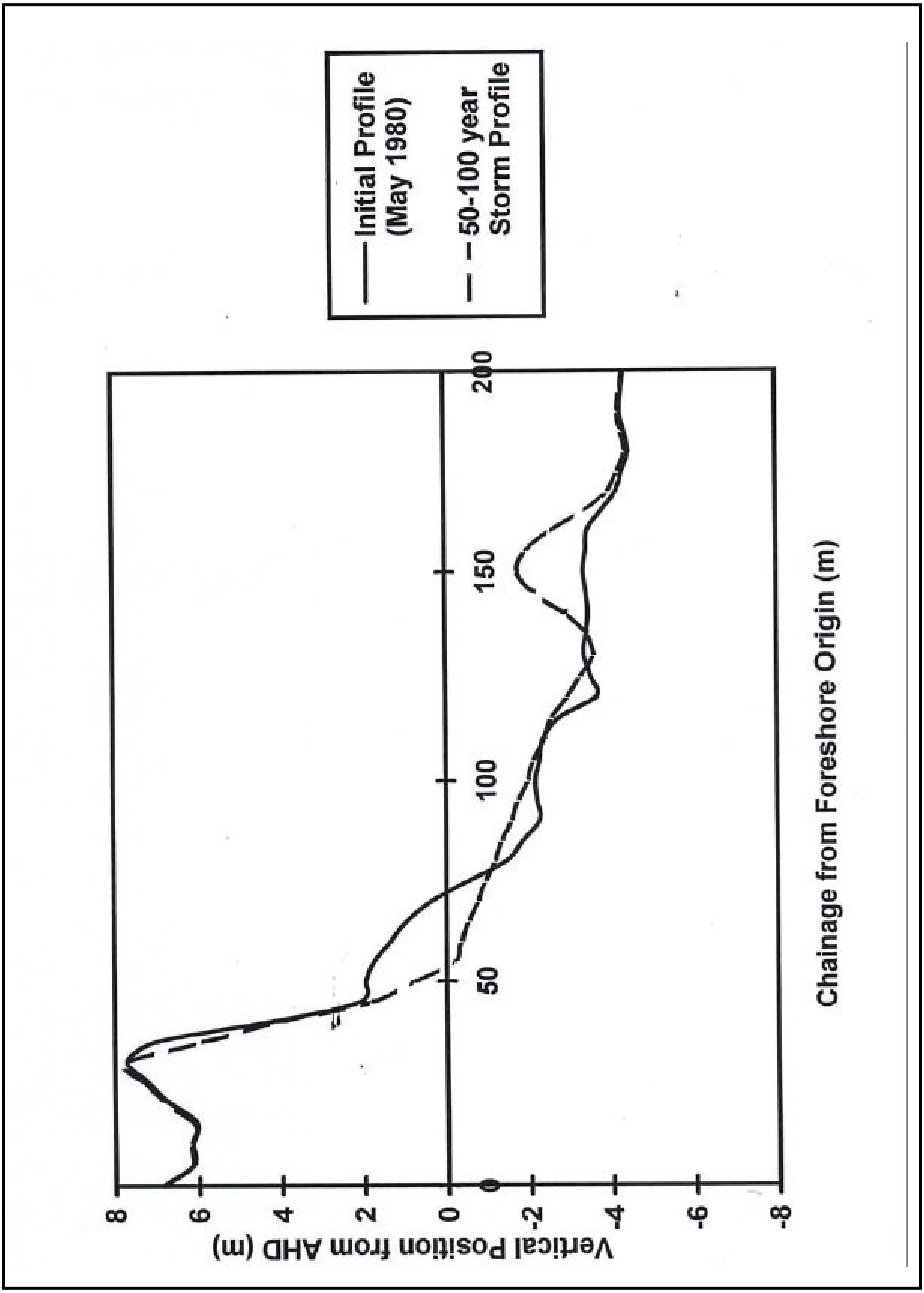


Figure 7.4 - SBEACH Model Results 50 to 100 yr ARI
1997 Beach Profile South of Pearce St.

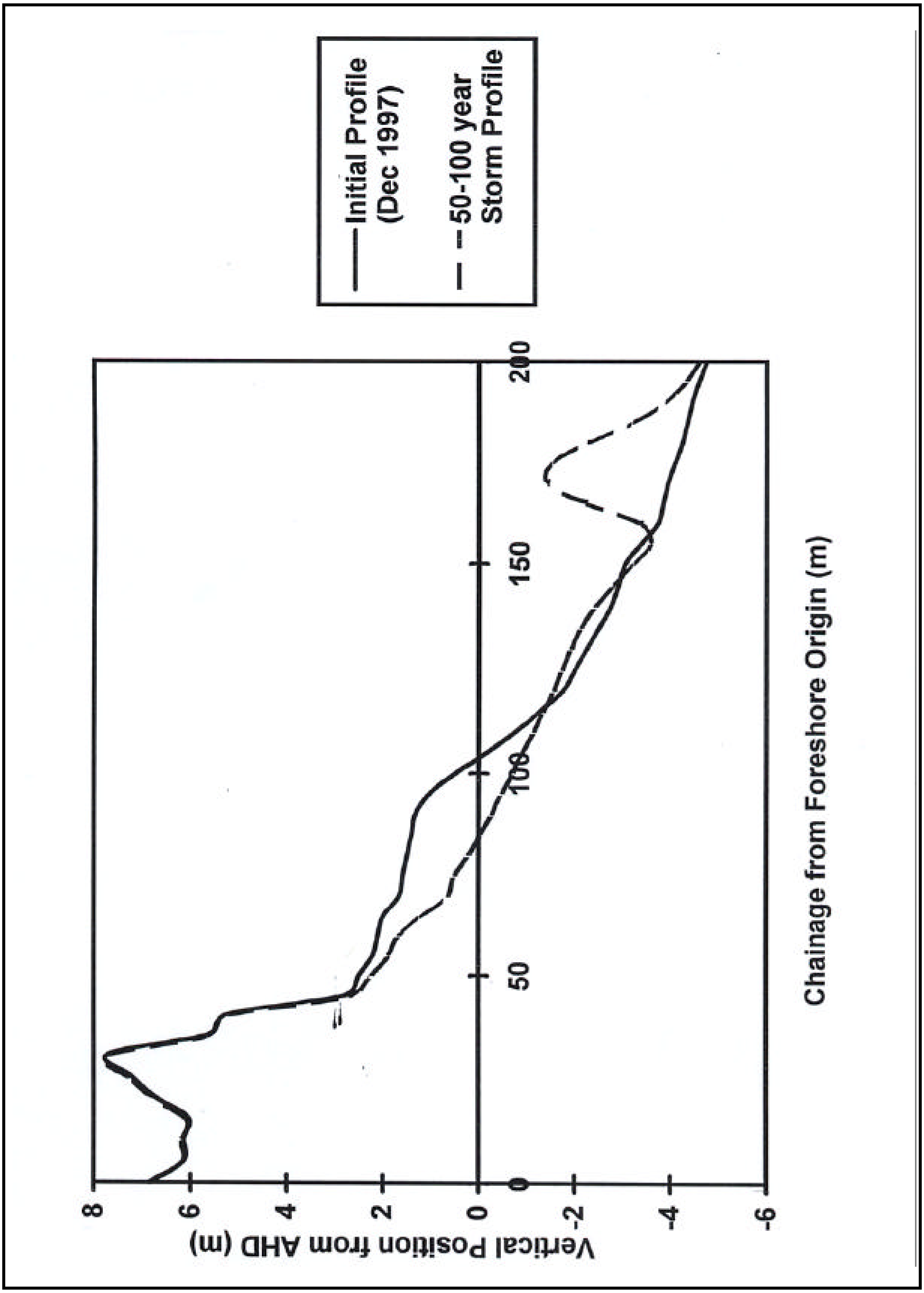


Figure 7.5 - SBEACH Model Results 50 to 100 yr ARI
1997 Beach Profile at Northern Car Park

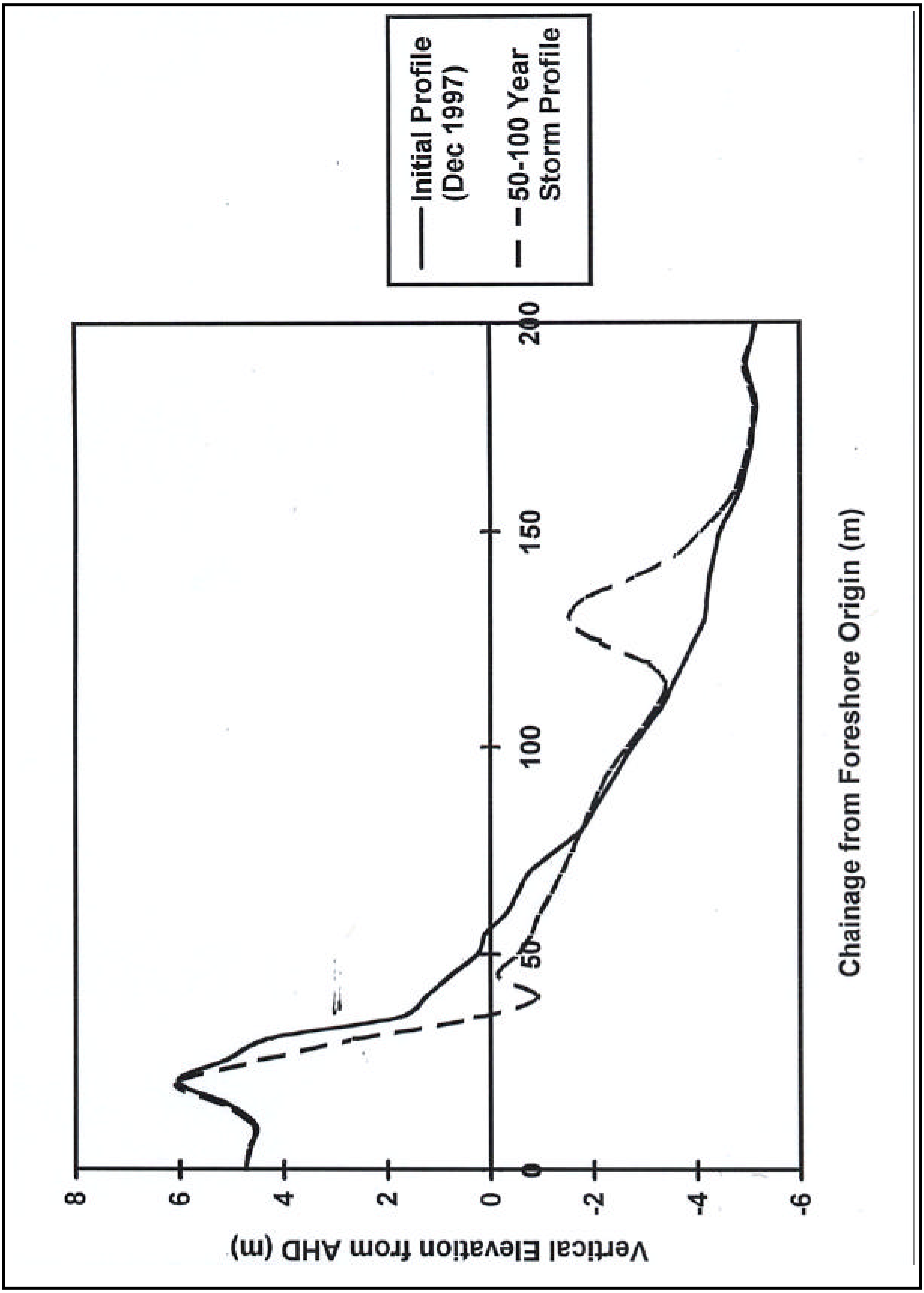


Figure 8.1 - Offshore Breakwater

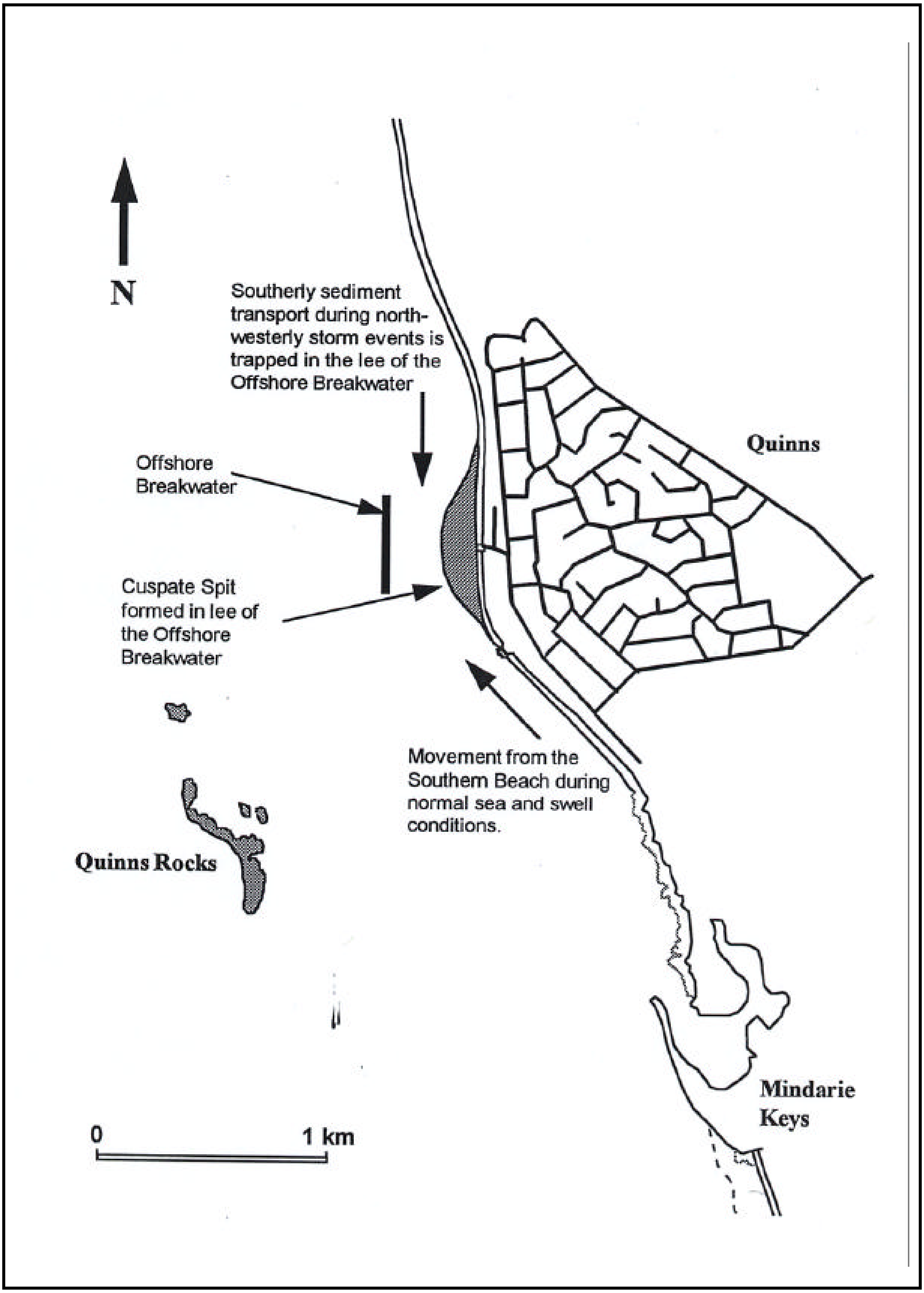
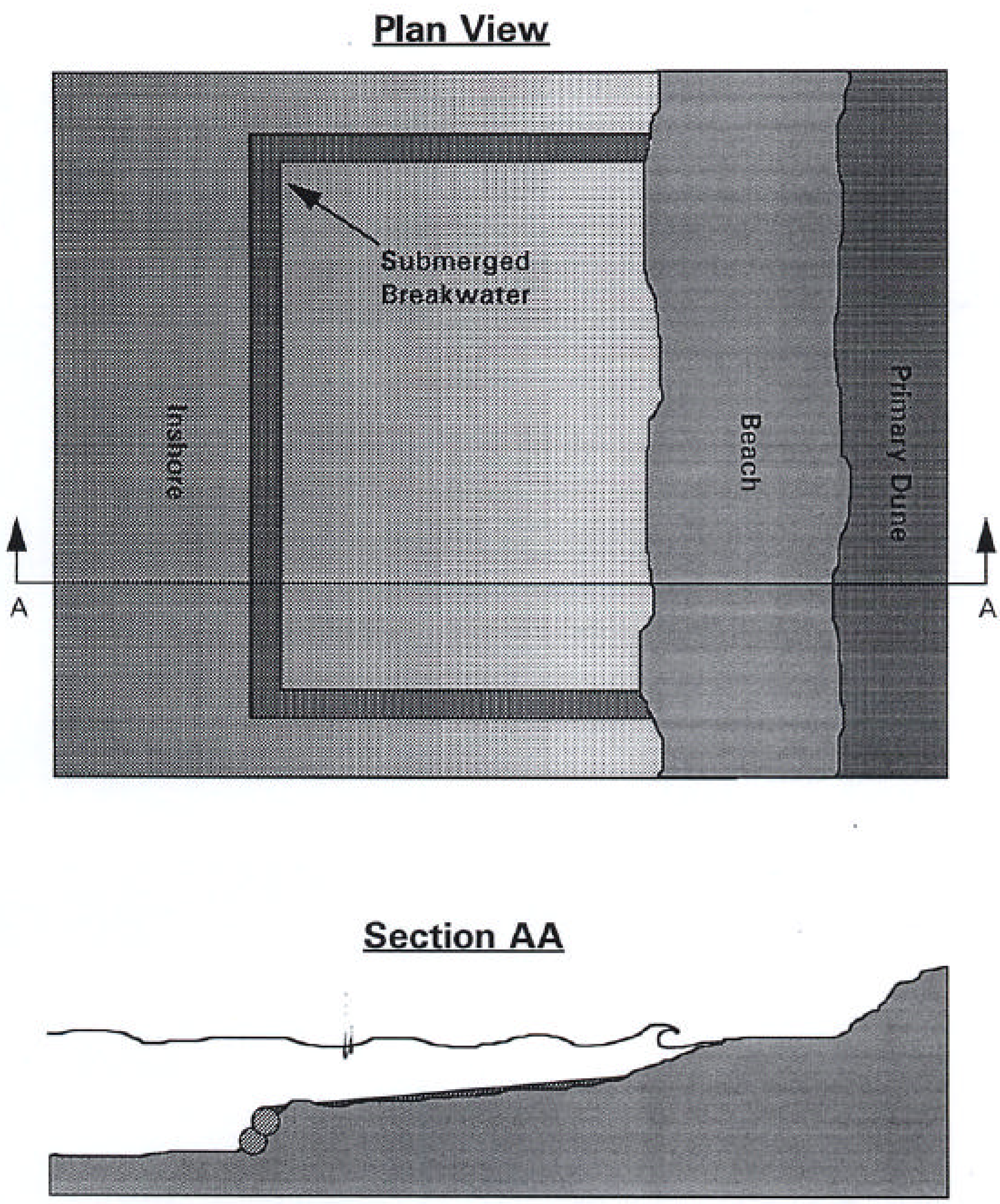


Figure 8.2 - Perched Beach



12. Appendices

Appendix A Relevant Correspondence

Appendix B Technical Description of Wave Model

Appendix A - Relevant Correspondence

Shire of Wanneroo

23023

Telephone 405 1199 - All communications to be addressed to the Shire Clerk,
Post Office Box 21, Wanneroo, 6065.

RTMcN:SF

When replying please quote:

Our Ref.: DR 10

August 16 1979

Your Ref.:

The Under Secretary for Works
Public Works Department
Harbour & Rivers Branch
2 Havelock Street
WEST PERTH WA 6005

ATTENTION DR W ANDREW

Dear Sir

COASTAL EROSION - QUINNS ROCK, WANNEROO

I refer to previous correspondence and discussion on the erosion problem at Quinns.

During the winter of 1977, Council proceeded with the construction of a 'headland' at Quinns on the advice of Dr R Silvester and approval given by your Department.

Results of its construction were to be observed to establish whether or not a second structure, or some other form of protection, would be required to maintain adequate protection of this severely eroded section of coastline.

These observations have now confirmed that a problem still exists and that further study and expenditure will be necessary to define and act on what should be done.

The continuation of your past assistance in Analysing the problem would be most appreciated and it is requested that adequate funds to overcome the situation be placed in your grants list.

Yours faithfully

N S BENNETTS
Shire Clerk

DR 10
PW 756/73

Shire Clerk
Shire of Wanneroo
P.O. Box 21
WANNEROO WA 6065

Dear Sir

Reference is made to your letter of August 16 and our previous correspondence concerning the erosion problem at Quinns Rock.

As indicated by your own observations and those of the Department, the recession of the beach at Quinns Rock is not yet under control and further work will be required to prevent the loss of shore assets. Monitoring surveys of the beach have been taken, but not yet formally studied.

Unfortunately, it is not possible to easily identify the best solution to this problem, or its potential cost. However, works of substantial scale are probably necessary, and a thorough investigation is thus justifiable.

In accordance with past practise, this Department is prepared to assist Council in a joint investigation of the problem, commencing as soon as is convenient with the intention of identifying the details and costs of necessary works for inclusion in the budget estimates of the 1980/81 financial year. As Council's contribution to the investigation, it is therefore desirable that you make available the services of your previous consultant, Dr Silvester, and also assist in shore survey work. Every effort can then be made to ensure that appropriate funds will be provided to overcome the situation.

Yours faithfully

UNDER SECRETARY FOR WORKS

November 1, 1979 GP:AN

Appendix B - Technical Description of Wave Model

Appendix B - Technical Description of Wave Model

B1. General Description - 2GWAVE

2GWAVE is a second generation spectral wave model developed from ADFA1, a wave model written by Professor Ian Young of the Australian Defence Force Academy. 2GWAVE is a finite difference model which accounts for the wave transformation processes of refraction, shoaling, atmospheric forcing, white-cap and bottom friction dissipation, deep and shallow water wave breaking, and non-linear wave-wave interaction. Wave diffraction is not modelled and a constant water level (ie. no tidal fluctuations) is assumed.

B2. Governing Equations

The numerical algorithm of 2GWAVE is based on the discretisation and solution of the Radiative Transfer Equation, which governs the evolution of directional wave spectra in both time and space (Young, 1987):

$$\frac{\partial}{\partial t}\left(cc_g E\right) + c_g \cos\theta \frac{\partial}{\partial x}\left(cc_g E\right) + c_g \sin\theta \frac{\partial}{\partial y}\left(cc_g E\right) + \frac{c_g}{c}\left(\sin\theta \frac{\partial c}{\partial x} - \cos\theta \frac{\partial c}{\partial y}\right)\frac{\partial}{\partial \theta}\left(cc_g E\right) = cc_g S$$

where, for a wave train of a particular frequency (*f*):

- c denotes the phase speed,
- c_g the group velocity,
- θ the direction of propagation,
- E the spectral energy of the wave motion, and
- S denoting sources and sinks of energy, with
- (x,y,t) representing the space and time domains to which the wave motion is referenced.

By assuming that the effect of mean currents on wave propagation is negligible, curved lines across the ocean's surface can be derived along which the wave frequency is constant and a simplified solution to the Radiative Transfer Equation is obtained (Young, 1987):

$$\frac{\partial}{\partial t}\left(cc_g E\right) = cc_g S$$

In the absence of forcing and energy losses, $S = 0$, and consequently the quantity cc_gE is conserved along wave rays.

B3. Sources and Sinks of Wave Energy

In the ocean a number of processes influence wave motion. Some act to generate or increase the energy of a wave train, for example the wind stress applied on the surface of the water, while others, such as frictional effects due to fluid viscosity and bottom roughness, remove energy from the wave motion. 2GWAVE accounts for the four main classes of sources and sinks known to have significant effects on ocean waves:

- atmospheric forcing,
- white-cap dissipation,
- bottom friction dissipation, and
- wave breaking (in both deep and shallow water).

B3.1 Atmospheric Forcing

In 2GWAVE this is accounted for using the exponential growth mechanism of Snyder et al (1981). Energy is transferred from the wind to the waves in a form proportional to ($U_{10}/c - 1$) where U_{10} is the wind speed measured at a reference height of 10 metres and c is the wave phase speed (ie. speed of wave propagation). Hence, wave components which propagate significantly slower than the wind receive a large energy input compared to components which propagate at, or near, the wind speed. As the growth mechanism is exponential, some initial energy is required for growth to occur. This is accomplished by the specification of an initial seed spectrum.

B3.2 White-Cap Dissipation

In real oceans, dissipation of wave energy by white-capping bounds the actively growing wind-sea portion of the wave spectrum. In 2GWAVE, white-cap dissipation is modelled by applying a saturation limit to the model spectrum for frequencies above 90% of the wind-sea peak frequency. This energy limit is of the form suggested by Phillips (1977), modified according to Kitaigorodskii et al (1975) to account for the local depth, and extended across direction space by the use of a cosine-squared spreading function (Young, 1987). The use of Phillips' formulation has the additional benefit that the saturation levels become lower as the sea becomes more mature, which models the observed transfer of energy away from moderate and high frequencies due to non-linear wave-wave interactions.

B3.3 Bottom Friction Dissipation

As the water depth becomes shallow in comparison to the wavelength, frictional effects of the ocean floor become important. The roughness of the sea bed acts to slow down the orbital currents at this interface, which in turn removes energy from the wave motion. The rougher the bottom and the shallower the water, the greater the energy losses due to bottom friction.

In 2GWAVE, the formulation proposed by Hasselmann and Collins (1968) is used to estimate bottom friction dissipation. This requires the specification of a bottom roughness friction factors over the entire model grid. Any number of friction factors can be used, however typically the following three bed types are important in the modelling of coastal waters:

- Sand,
- Seagrass, and
- Limestone or coral reefs.

The roughness of sand is usually determined by the height of the ripples it exhibits, as this is generally at least an order of magnitude greater than the grain size. Seagrasses generally offer more resistance to wave motion than sand as they add greater vertical relief to the seabed, for example by the formation of seagrass clumps, and their leaves act to dampen orbital currents in the benthic layer. In light of this, the frictional effects of seagrass areas are represented by a higher friction factor in 2GWAVE than those covered only by sand. Finally, reef can result in even rougher surfaces at the sea bed. Such areas are typically characterised by large variations in vertical relief, and voids and holes of various sizes, both of which significantly retard orbital wave motions near the ocean floor.

Obviously the inclusion of spatial variations of seabed roughness in 2GWAVE gives it the potential to more accurately model wave transformation in the study area, however it also introduces additional unknown parameters. The value of the extra friction factors must be tuned as part of the model calibration, making this procedure more complicated and time consuming. In regions characterised by an uneven distribution of bed types, the careful calibration of all three friction factors will produce directional spectra within the study area that are far more accurate than would otherwise be obtained using uniform bottom roughness over the entire grid.

B3.4 Wave Breaking

Waves can break in both deep and shallow water. As a wave approaches shallow water, its phase speed and wavelength decrease, while its amplitude and orbital currents increase. Eventually, a point is reached where the orbital current at the crest exceeds the wave phase speed, causing an instability and the breaking of the wave. Research has suggested that the ratio of wave height to water depth at the point of breaking depends on the wave period and the bottom slope, and can range between 0.6 to 1.3 (Goda, 1985). Despite this, a ratio of 0.78 is commonly used to estimate the onset of wave breaking.

In deep water, waves are observed to break when they become too steep. Wave steepness is measured as the ratio of height to length of the wave, with deepwater wave breaking occurring when this exceeds 0.142. At this point the crest angle is about 120º and the water particle velocity at the wave crest once again exceeds the phase velocity of the wave (CERC, 1977).

In 2GWAVE, both of these phenomena are modelled using the one algorithm. The formulation of Divoky et al (1970) representing the limiting wave steepness is expressed in terms of integral spectral properties, from which a limit on the total energy of the model spectrum is derived. If the total energy of the model spectrum exceeds this limit, the difference is removed. The manner in which this energy is removed from the wave spectrum can be performed in three different ways.

The original model, ADFA1, from which 2GWAVE was developed, accounted for energy loss due to wave breaking in a fairly simplistic fashion. The energy of the model spectrum was reduced, equally over all directions and beginning at the lower frequency limit, until its total energy was equal to that of the estimated breaking limit. The important characteristic of this algorithm is that the low frequency waves were completely removed, while higher frequencies left unaltered, which is akin to assuming that only swell waves break.

Of course, one would probably agree that this is rarely the case. For example, when swell waves break on offshore reefs during a strong sea-breeze, the area immediately following the breaking zone is generally quiescent, indicating that much of the energy of both the swell and the sea has been dissipated. Unfortunately, the hydrodynamics of wave breaking is still largely unknown, and a satisfactory empirical model of the spectral energy dissipation caused by this process is yet to be discovered.

In view of this, 2GWAVE offers two further algorithms by which the energy losses due to wave breaking are removed from the wave spectra. The first involves reducing the spectrum on a uniform pro-rata basis, over both frequency and direction domains, so that the total energy of the model spectrum is equal to the breaking limit.

The other technique incorporates the use of a transmittance function, which describes the attenuation due to wave breaking of the various wave components as a function of frequency. A value between zero and unity is specified for each of the frequency bands of the model spectrum - zero indicating complete dissipation of the wave energy and unity denoting no attenuation. This method of accounting for wave breaking may be particularly useful in situations involving extensive shallow reef systems where it is believed that wave breaking will play an important role in the transformation of the offshore wave climate to the nearshore conditions.

The transmittance function used by 2GWAVE can be easily modified by the user, and thus represents another set of parameters that could be tuned as part of the model's calibration.

B4. Wave Transformation Processes

The characteristics of the local wave climate are determined by two factors:

- the supply and dissipation of energy to the wave field, and
- hydrodynamic processes responsible for the redistribution of energy between different wave frequencies, the spatial redistribution and redirection of wave energy propagating across the ocean surface, and the transformation of energy between different energy forms associated with the wave motion.

The supply and dissipation of wave energy has been discussed in detail in the previous section. The main hydrodynamic processes responsible for the redistribution, redirection, and transformation of wave energy are outlined below:

- refraction - the redirection of energy in space due to the interaction of the wave motion with the seabed topography,
- shoaling - the transformation of energy between its potential and kinetic forms as the phase and group velocities of a wave change in reaction to variations in the local depth,
- non-linear wave-wave interaction - the redistribution of energy between different frequency and direction bands within the wave spectrum, and
- diffraction - the redistribution of wave energy in space due to gradients in the wave height in the local direction of the wave crest.

The process of diffraction is only significant in situations in which there is a substantial gradient in wave height along the local direction of the wave crest, and only over scales in the order of the dominant wave length or smaller. In view of the scale adopted for the numerical modelling of most coastal waters, such situations are unlikely to occur. Therefore the fact that 2GWAVE does not model diffraction processes is unlikely to have any significant effects on the accuracy of its results for such applications.

The remaining three hydrodynamic processes, however, are believed to be significant, and are explicitly modelled by 2GWAVE. These are discussed in greater detail below.

B4.1 Refraction

Refraction is the process responsible for the bending of wave crests, and the redirection of wave energy paths (rays), as the wave propagates through water in which the depth contours of the seabed are not parallel to the wave crests above them. In other words, refraction occurs when the water depth is not the same under all points along a given wave crest.

The refraction of a surface wave of a particular frequency is brought about by the fact that its phase speed decreases as the water depth becomes shallower. Therefore, if a wave is travelling such that the depth varies along its crest, those areas of the wave over relatively deep water will travel faster, causing the wave crest to bend. This behaviour is responsible for the energy of swell waves typically concentrating on headlands and becoming weaker in embayments.

It is important to note that refraction effects only occur in waters which are shallow enough for the wave to "feel" the effects of the bottom. Generally this occurs in water depths less than one half to one quarter of a wavelength. In areas deeper than this, the wave behaves as a "deepwater wave" and the depth has little or no effect on its propagation.

The wavelength of deepwater waves is proportional to the square of the period. Consequently, long period waves (eg. swell) have much longer wavelengths than waves of shorter period (eg. sea). In light of this, for waves travelling towards the coast, encountering progressively shallower water, those of longer period will start to feel the bottom and exhibit the signs of refraction earlier (ie. in deeper water) than waves of shorter period. In general, refraction processes are more important to the lower frequency components of the wave spectrum.

Refraction is modelled in 2GWAVE by applying the laws of ray theory, as represented by the equations below, across the entire domain of each model grid.

$$\frac{\partial x}{\partial t} = c_g \cos\theta$$

$$\frac{\partial y}{\partial t} = c_g \sin\theta$$

$$\frac{\partial \theta}{\partial t} = \frac{c_g}{c}\left(\sin\theta \frac{\partial c}{\partial x} - \cos\theta \frac{\partial c}{\partial y}\right)$$

These equations are discretised and then solved at each grid point, for each discrete frequency and direction combination, to determine the starting points of the wave rays along which energy travels to reach the grid point at the end of one time step of the model run. This information allows 2GWAVE to completely model the refractive effects associated with waves of different frequencies travelling in different directions.

As the wave energy paths depend only on the wave frequency and direction, and the local bathymetry, the set of rays for all grid points for all frequencies and directions need only be calculated once prior to the simulation proper. Furthermore, the same set can be used for subsequent simulations using the same horizontal grid and bathymetry. For grids dominated by large areas of slowly varying seabed topography, the same spatial resolution can be used for the calculation of wave rays as is used by the model in the remainder of the simulation. However, for areas of complex bathymetry, a finer grid resolution can and should be used to better model the effects of refraction.

B4.2 Shoaling

Shoaling is the process by which some of the kinetic energy of a wave is transformed into potential energy. Shoaling occurs when waves travels into shallower water. This causes the phase speed to slow down and the wave height to increase. The reverse effect occurs when a wave travels into progressively deeper water.

The reason for these observed phenomena is centred on energy conservation. As a deepwater wave encounters progressively shallower water, its phase speed decreases, and its group velocity (the velocity with which energy is propagated by the wave motion), after initially increasing slightly, steadily decreases. A result of this is that the kinetic energy of the wave decreases. In the absence of frictional losses (viscosity, bottom friction, wave breaking etc.), which are usually negligible over the time scales in which shoaling occurs, the total energy of the wave must be conserved. This is satisfied by an increase in the potential energy of the wave, which is reflected by an increase in its height. Thus the process of shoaling accounts for why waves become bigger as they encounter shallower water, usually prior to breaking.

Similar to refraction, shoaling effects only become significant when waves begin to "feel" the bottom. Once again, this occurs at depths less than one-half to one-quarter of a wavelength, and consequently low frequency waves exhibit the effects of shoaling in deeper water (ie. earlier as waves approach the shore) than their higher frequency counterparts.

Shoaling is modelled in 2GWAVE by the inclusion of the appropriate terms in the governing equation. Therefore by numerically solving this equation 2GWAVE implicitly accounts for shoaling processes and their effects on the wave climate.

B4.3 Non-linear Wave-Wave Interaction

Non-linear wave-wave interactions are responsible for energy being transferred between different regions of the spectrum, causing it to evolve over time. A non-linear transfer function has been established in frequency space (Hasselmann and Hasselmann, 1981) which approximates the energy exchange that has been observed between ocean waves of different frequencies (see Figure 3.1). This transfer function is dominated by a positive (forward) lobe at low frequencies, and a negative lobe at moderate to high frequencies. A much smaller positive lobe occurs at very high frequencies. The shape of the transfer function implies that the net effect of non-linear wave-wave interactions is the exchange of energy from moderate and high frequencies to waves of relatively low and also very high frequencies. The latter generally contain a negligible amount of energy and are not modelled by 2GWAVE.

Of greater significance are the forward lobe at low frequencies, and the negative lobe at moderate to high frequencies. The former represents a source of energy for long period waves, and is modelled using a piece-wise linear approximation. Both the magnitude and the position in frequency space of this approximation of the forward lobe are estimated from the parameters of the JONSWAP spectrum that best fits the model spectrum. For model spectra which have only one peak, the determination of the best fitting JONSWAP parameters is straight forward, since it too is characterised by a single energy peak. In the case of multiple peaked spectra (eg. swell together with sea) 2GWAVE assumes that the significant non-linear interactions are associated with the wind-sea spectrum, and hence assigns the mean direction and peak frequency of the JONSWAP approximation to the local wind direction and wind-sea peak respectively. The remaining JONSWAP parameters required are estimated from the total energy of the whole model spectrum and the magnitude of the local winds. The approximation of the forward lobe is then extended to direction space by scaling the magnitude of the lobe's peak according to the angle from the mean direction of the model spectrum.

The negative lobe of the non-linear transfer function plays a far less significant role in the evolution of ocean wave spectra (Young, 1987). It represents a drain of energy away from moderate and high frequency waves, and is accounted for in 2GWAVE by the application of a spectral saturation level over this frequency range. The role and utilisation of saturation limits in ADFA1 has already been described under the subsection titled White-Cap Dissipation.

B5. Grid Size and Resolution

To simulate the transformation of ocean waves as they pass through the study area, 2GWAVE applies directional wave spectra at the open boundaries of a two-dimensional spatial grid that contains the area of interest. As time progresses, these boundary spectra propagate through the grid and are modified by a variety of physical processes to create different directional wave spectra at interior grid points. As a result of this process, a complete directional wave spectrum is computed for every wet grid point (ie. those on the ocean surface, not land) at every point in time throughout the duration of the model simulation.

The extent of the grid therefore needs to be not only large enough to cover the study area, but it should also encompass nearby regions of the ocean in which significant spectral transformation occurs, and is desired to be modelled, prior to the waves entering the area of greatest interest.

The elements of the 2GWAVE grid must be square, with the resolution determining both the accuracy and the actual duration of the simulations. A finer grid enables a more accurate representation of the wave field and transformation processes, particularly refraction in areas of sharply varying bottom topography, however it significantly lengthens the computational time since the number of grid points is increased and the time step must be decreased. In practice, a doubling of the spatial resolution of the model in both horizontal directions leads to an eight fold increase in computational duration.

An important feature of 2GWAVE is its ability to utilise nested grids of progressively smaller horizontal extent and greater resolution. This enables a rapid simulation of the transformation of waves over large areas where the bathymetry and atmospheric conditions do not vary much, and more of the computational effort can be focussed on the region of primary interest and areas characterised by rapid changes in bottom topography. The output for a simulation on a parent grid is used to form the initial and boundary conditions of a subsequent simulation on the nested grid. Each nested grid must be wholly contained within its parent, and have higher resolution which is an integer multiple of that of its parent.

B6. Time Step and Numerical Stability

2GWAVE steps through time in uniform increments, and is unconditionally stable irrespective of the length of the time step in comparison to the spatial resolution. Despite this, the accuracy of the solution is dependent on size of both the grid elements and the time step. In both cases, smaller sizes produce more accurate results. In general, for a grid of resolution Δx, the time step (Δt) should be chosen so that the relationship:

$$\frac{c_g \Delta t}{\Delta x} < 1$$

is satisfied, with the group velocity (c_g) calculated from the peak frequency of a representative spectrum of the study area. In many applications, larger time steps can be chosen, however these should be subject to a sensitivity analysis to ensure that accuracy is not significantly affected.

B7. Initial and Boundary Conditions

The initial sea state assumed by 2GWAVE for the largest grid is that of an essentially calm ocean, with only the seed spectrum present at each interior grid point. At wet points along the boundary of this grid, a directional wave spectra must be specified for each time step of the model run. Wave energy is reduced to zero by shallow water breaking prior to reaching dry grid points, and so land boundaries act as an energy flux barrier. For simulations performed on nested grids, both the initial and boundary wave energy states are interpolated, in both space and time, from the results of the parent grid run.

Both parent and nested grid simulations require the specification of the bottom topography and roughness over the entire horizontal domain. For the generation of the wave rays for each point, the bathymetry should be specified at least at every grid point. Increased resolution is desirable as this improves the accuracy of the curves, particularly in areas exhibiting complex bottom topography.

Finally, all simulations require the specification of the bottom roughness at every grid point in terms of a friction factor for use in the calculation of energy loss due to bottom friction. ADFA1 assumed this to be constant over the entire grid. However, as already discussed, this has been improved in 2GWAVE to allow the specification of spatial variations in this friction factor, which offers significant advantages for the modelling of directional wave spectra.

B8. Model Output

2GWAVE calculates the full directional spectrum and summary parameters (eg. significant wave height, peak spectral frequency, and mean spectral direction) at every grid point at every time step, however due to storage limitations, not all of this information is saved. Typically the entire spatial array of summary parameters is stored for every time step and the full directional spectra at particular points of interest are saved at uniform time intervals as specified by the user. In addition to this, directional spectra for every point on the grid are saved at the end of the simulation and at any time specified by the user to enable a hot start or nested grid simulation.

The output files produced from a 2GWAVE run can then be accessed through graphics software to display the results in a form appropriate to the user's needs.

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