PORT KENNEDY

PORT KENNEDY JOINT VENTURE

PORT KENNEDY REGIONAL RECREATION CENTRE

ENVIRONMENTAL REVIEW AND MANAGEMENT PROGRAMME

Volume III: Appendices

DECEMBER 1988

Binnie & Partners Pty Ltd
CONSULTING ENGINEERS

PORT KENNEDY REGIONAL RECREATION CENTRE

ENVIRONMENTAL REVIEW AND MANAGEMENT PROGRAMME

VOLUME III: APPENDICES

Prepared for Port Kennedy Joint Venture

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December 1988

VOLUME III: INDEX OF TECHNICAL APPENDICES

APPENDIX A: COASTAL ENGINEERING STUDY
RIEDEL & BYRNE PTY LTD

APPENDIX B: MODELLING OF SHALLOW GROUNDWATER
MACKIE MARTIN & ASSOCIATES

APPENDIX C: TERRESTRIAL ENVIRONMENTAL INVESTIGATIONS
BOWMAN BISHAW & ASSOCIATES

APPENDIX D: VEGETATION SURVEY
FOR BOWMAN BISHAW BY MALCOLM TRUDGEN

APPENDIX E: MARINE ENVIRONMENTAL INVESTIGATIONS
BOWMAN BISHAW & ASSOCIATES

APPENDIX F: HARBOUR FLUSHING
CENTRE FOR WATER RESEARCH, UNIVERSITY OF WESTERN AUSTRALIA

APPENDIX G: GREENHOUSE EFFECT
COLIN PORTER

APPENDIX A: COASTAL ENGINEERING STUDY

RIEDEL & BYRNE PTY LTD

Report : Coastal Engineering Study
Project : Port Kennedy Regional Recreation Centre
Location : Warnbro Sound
Client : Binnie & Partners Pty. Ltd.
Status : Final
Date : 25 August 1988

396 Rokeby Road
Subiaco 6008
Western Australia

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TABLE OF CONTENTS

1. INTRODUCTION

2. WATER LEVELS
   2.1 Astronomical Tide
   2.2 Long Period Water Level Variations
   2.3 Extreme Events
   2.4 Summary

3. WINDS

4. WAVES
   4.1 Wave Hindcasts
       Sea Waves
       Swell Waves
       Storms
   4.2 Wave Transformation
       Refraction, Diffraction and Shoaling
       Seabed Friction

5. COASTAL PROCESSES
   5.1 Introduction
   5.2 Littoral Transport
       5.2.1 General
       5.2.2 Westport
       5.2.3 Bridport Point
       5.2.4 Measurement
   5.3 Harbour Impact and Management

6. CONCLUSIONS AND RECOMMENDATIONS

REFERENCES

APPENDIX AA : Wave Hindcast - Techniques
APPENDIX BB : Refraction, Diffraction & Shoaling
- Techniques
- Results
APPENDIX CC : Seabed Friction - Techniques

NOTE : The above Appendices are not included in this ERMP report. They can be inspected at the offices of Riedel & Byrne, 396 Rokeby Road, Subiaco, 6008, Western Australia.

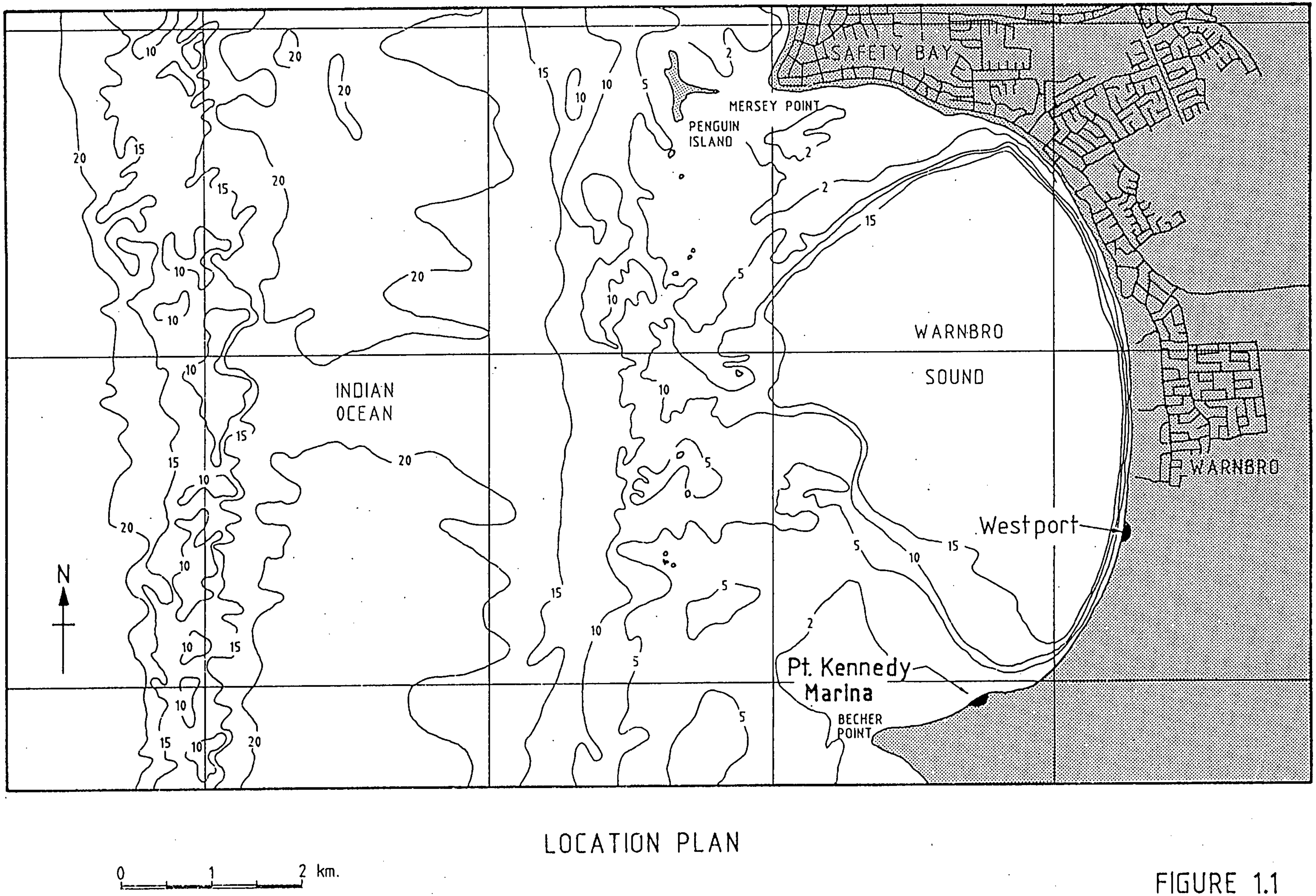
1. INTRODUCTION

The Port Kennedy Regional Recreation Centre is a proposed holiday and marina development located at Bridport Point on the southern shoreline of Warnbro Sound, as shown in Figure 1.1.

This report was commissioned to study the coastal engineering aspects of the project. Water levels, winds, waves and coastal processes were examined in order to:

- facilitate the design of breakwater profiles and entrances;
- estimate the impact of the marina on the coastline and bathymetry of the region;
- estimate the size of buffers and/or maintenance dredging required to enable continued serviceability of the marina and stability of the adjacent coastline.

Figure 1.2 shows the general layout and position of the proposed marina at Port Kennedy. Wherever possible existing data from the Westport site, Warnbro Sound and neighbouring region has been used in this study.



LOCATION PLAN

FIGURE 1.1

RIEDEL & BYRNE CONSULTING ENGINEERS P/L

2. WATER LEVELS

The chief factors influencing ocean water levels in Warnbro Sound are astronomical tide, long period water level variations and extreme storm surge events. These are discussed separately below.

2.1 Astronomical Tide

The astronomical tide along a considerable length of the Western Australian coastline including the Warnbro Sound region is very similar to that measured at Fremantle, some 35 km north of Port Kennedy. The astronomical tide data for the Port of Fremantle is summarised below.

Table 2.1 Astronomical Tides - Fremantle

Tide	Level (metres above Chart Datum)
Highest Astronomical Tide	1.1
Mean High High Water	0.9
Mean Sea Level	0.8
Mean Low Low Water	0.5
Lowest Astronomical Tide	0.2

The Fremantle tide is basically diurnal with a typical daily variation in tide levels of about 0.4 metres.

2.2 Long Period Water Level Variations

There is a continual slow variation in water level along the Western Australian coastline superimposed over the normal diurnal tides. The magnitude of this variation in water level can be the same as that of the diurnal variation. The change, however, takes from several days to weeks to occur.

A report by Provis and Radok (1979) on long period water level variations indicated that there were significant water level variations with periods in the range 1 to 20 days and 20 to 365 days.

The most significant factor responsible for these long period water level variations is the rise and fall of sea level in response, respectively, to falling and rising barometric pressure in the atmosphere above the ocean. The period of this type of variation is usually from 3 to 10 days.

Shelf waves are also significant in contributing to long period water level variations of periods from 1 to 5 days. They are a response to wind stress produced by large scale atmospheric disturbances, and mass energy movement of the deep oceans trapped on the relatively shallow continental shelf.

Large scale currents and eddies that travel down the Western Australian coastline and into the Great Australian Bight may cause water level variations of 0.1 to 0.2m with a period of several months.

2.3 Extreme Events

Extreme events such as Tropical Cyclone 'Alby' (1978) may cause a combined wave and wind set-up (or set down) as the storm system interacts with the coastline. This set-up (or set down) phenomenon may exist for one to five days.

Tropical Cyclone 'Alby' caused the water level at Fremantle to rise to 1.9 metres Chart Datum (1.15 AHD). This storm surge has been estimated to occur once in 100 years by the Public Works Department. (refer PWD 54411-2-1).

2.4 Summary

At Warnbro Sound we can expect:-

- diurnal tides with a daily range of 0.4 metres.
- long period variations with periods 3 to 20 days and a range of 0.4 metres.
- the possibility of storm event surges in water level; in extreme storm events up to 1.9 metres Chart Datum.

3. WINDS

The wind climate is of fundamental importance to coastal processes. The wind generates the waves which determine sediment transport direction and magnitude. Sediment transport may be onshore/offshore and/or alongshore in either direction.

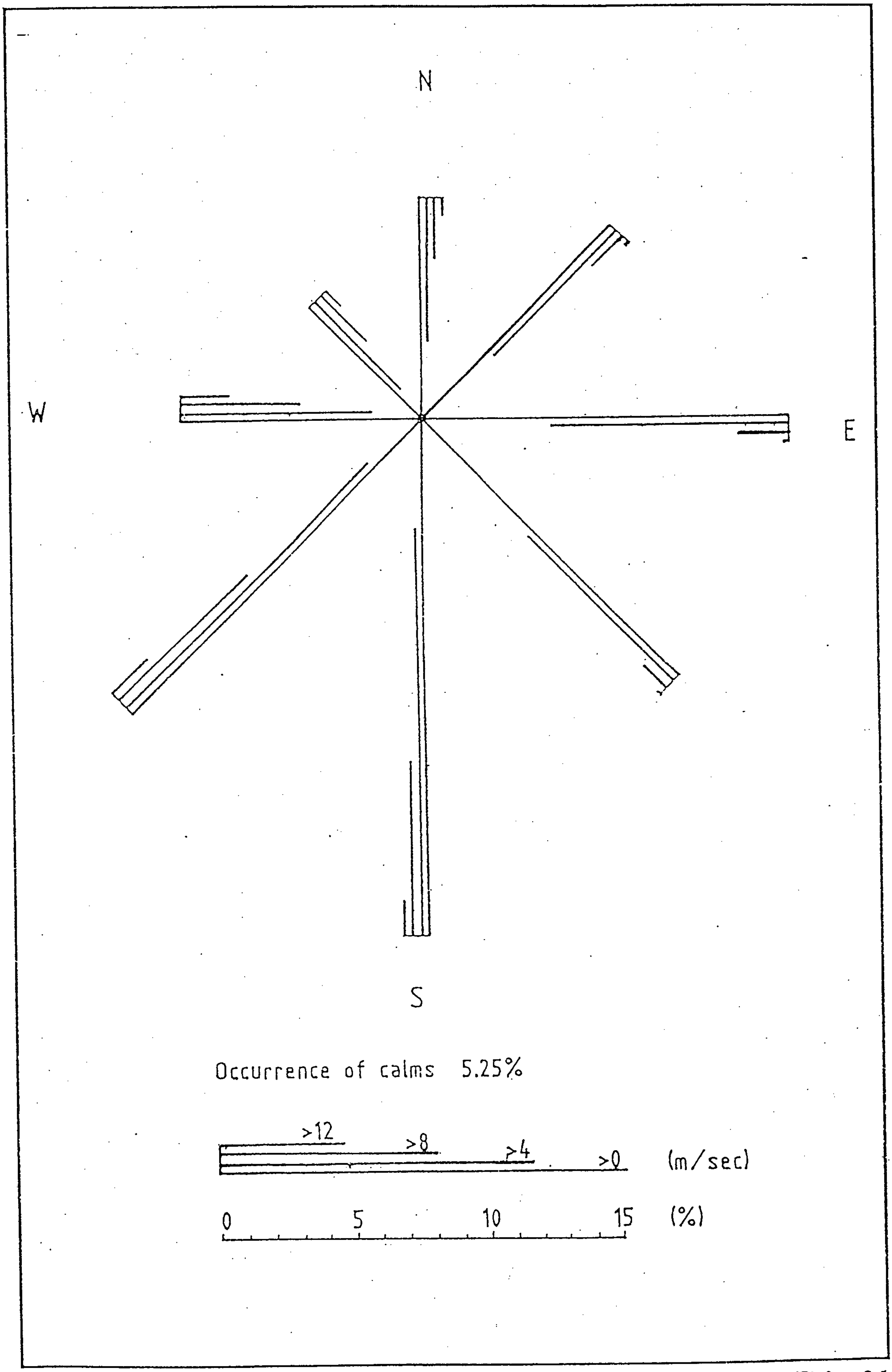
A report by Halpern and Glick (1983) found that for all practical purposes wind speed and direction are identical for Fremantle and Becher Point. Historical records and wind speed and direction for Fremantle can therefore be utilized for studies of Warnbro Sound.

The Table 3.1 below summarises the applicable wind data in numerical form while Figure 3.1 illustrates the wind data in the form of a wind rose. Winds from a southerly direction tend to dominate the overall wind spectrum.

Table 3.1 Wind speed-direction percentage occurrence matrix for Fremantle between 1.1.1979 and 31.12.1984

	Wind speed (m/second)								
Direction	0.1 to 2.0	2.1 to 4.0	4.1 to 6.0	6.1 to 8.0	8.1 to 10.0	10.1 to 12.0	12.1 to 14.0	14.1 and Over	Total
N	1.05	1.85	1.80	1.40	1.10	0.55	0.30	0.20	8.25
NE	1.20	2.50	2.70	2.20	1.10	0.30	0.10	0.00	10.10
E	1.65	3.25	4.05	2.85	1.45	0.35	0.05	0.00	13.65
SE	1.60	4.25	4.55	1.90	0.80	0.25	0.10	0.05	13.50
S	1.10	3.00	4.40	4.25	3.10	2.05	0.85	0.45	19.20
SW	0.80	1.90	2.85	3.25	2.90	1.90	1.00	0.75	15.35
W	0.65	1.20	1.40	1.35	1.40	1.20	0.80	0.85	8.85
NW	0.50	0.85	1.10	1.00	0.90	0.65	0.40	0.45	5.85
TOTALS	8.55	18.80	22.80	18.20	12.75	7.25	3.60	2.75	94.75

Occurrence of calms = 5.25%



WIND ROSE FOR FREMANTLE 1979-84

Figure 3.1

4. WAVES

A detailed knowledge of the nearshore, directional wave climate is required for the purposes of defining the coastal processes at Bridport Point. Measured data was not available for the Bridport Point site. A mathematical model was therefore developed using a hindcast deepwater, directional wave climate as the input and transformed to the site in shallow water, modifying the waves in accordance with the effects of refraction, diffraction, shoaling, attenuation due to seabed friction, and wave breaking.

This nearshore directional wave climate was then used for the preliminary design of breakwater profiles and entrances, and also, for comparison with Westport wave data in the evaluation of sediment transport at the site.

4.1 Wave Hindcasts

Waves are broken into two broad categories for wave hindcasting:

* Sea waves which are locally generated and generally short period waves.

* Swell waves which are generated from distant fetches and have left their generation area. Swell waves are generally longer period waves.

The hindcast techniques used have been verified at other sites where measured data was available and the highest wave height estimates were within 10% of the measured wave heights, McCormack, et al (1985).

Wave activity varies seasonally and so for reliable results a full year of hindcast must be obtained. The year chosen, from November 1984 to October 1985 was reasonably typical although a little on the severe side as a result of a significant southwest storm in the August of that year.

A full years data is seen as the minimum required to allow for the seasonal variation in wave climate.

Sea Waves

Warnbro Sound is protected from offshore waves via the Murray Reefs system (aligned north/south offshore of Warnbro Sound), Becher Point, and Penguin Island/Mersey Point. Sea waves may be generated offshore in the ocean neighbouring the Sound or may be generated totally within the Sound. Sea waves generated offshore are affected by refraction, diffraction, shoaling, breaking and seabed friction as the waves follow their paths from the ocean through the reef, to the shore.

Hindcast sea waves were therefore split into two groups; offshore, and that locally generated within Warnbro Sound to ensure all locally generated waves are accounted for. It is possible that the effects of some winds may be included in both hindcasts giving a slightly conservative estimate of the sea wave climate. This effect is not considered to be significant and it is considered that the hindcasts are a reasonably accurate assessment of the sea wave climate.

Techniques outlined in CERC 1984 and the local wind data were used to hindcast waves generated within Warnbro Sound. These inshore generated waves were found to be dominant in determining significant wave heights for the Bridport Point site. Table 4.1 shows a summary of the results for a Typical Year (1984/85); a severe Westerly Storm (1983); and Tropical Cyclone 'Alby' (1978).

Table 4.1 Hindcast Waves within Warnbro Sound

ANGLE DIRECTION	TYPICAL YEAR (1984/85)	WESTERLY STORM (1983)	TROPICAL CYCLONE ALBY (1978)
250	1.2	1.3	1.0
260	1.2	1.1	
270	1.2	0.6	0.6
280	1.0	0.5	
290	1.0	0.6	0.6
300	1.0	1.0	
310	1.4	0.7	0.6
320	1.5	1.3	
330	1.5	0.8	2.0
340	1.5	0.4	
350	1.5	1.0	
0	1.2	0.5	1.2
10	1.2	0.4	
20	1.2	0.3	
30	1.2		0.3
40	0.8		
50	0.5		
60	0.5		

The offshore sea waves generated in the nearby ocean were hindcast by Oceanroutes (Australia) Pty. Ltd. for a site in 20 metres of water west of the line of reef offshore from Warnbro Sound. The hindcast was for 6-hourly intervals for the year from November 1984 to October 1985 being based on the wind data for 6-hourly synoptic charts.

Swell Waves

Information on wind fields was collated from synoptic charts, ship reports, satellite imagery and wind records to produce a hindcast for every 6 hours for swell waves. Full details of the methods used are found in Appendix AA.

A point in approximately 100 metres depth of water, west of Warnbro Sound was selected as the swell wave hindcast site. Waves here have not been significantly altered by refraction, shoaling or seabed friction and thus the hindcast produced represents the deepwater wave climate.

The swell hindcast was broken down into three basic groups covering the swell from the:

- south-western sector
- western sector
- north-western sector

This breakdown was required in order to keep the waves arriving from separate storms, distinct, and thus avoid the errors resulting from combining waves from different directions.

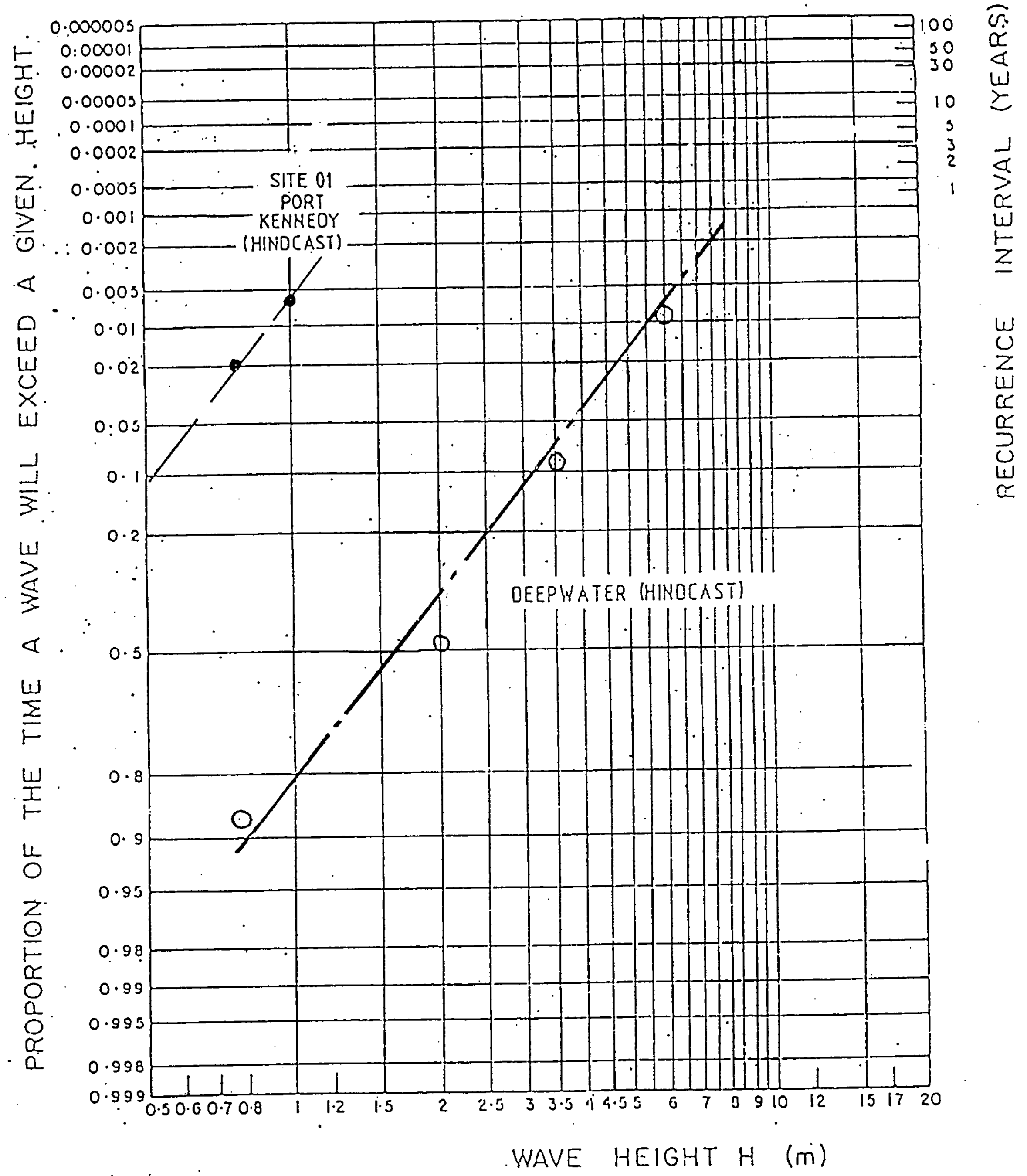
The wave height exceedance curves for the deepwater wave hindcast and the shallow water wave climate resulting from this hindcast at Port Kennedy refraction Site 01 have been plotted on Figure 4.1. The curves illustrate the effects of refraction, diffraction, shoaling and seabed friction, and wave breaking on wave heights during their transformation from deep water offshore to shallow water inshore.

Storms

Extreme storms can affect the breakwater design and sediment transport at a site. A series of three storms were hindcast to evaluate their effect on Warnbro Sound. A severe winter south-westerly storm (1985), winter westerly storm (1983) and Tropical Cyclone 'Alby' (1978) (predominantly from the north-west) were the storms hindcast. They were chosen from meteorological data spanning 10 years from 1975 to 1985. A brief summary of each event appears below in Table 4.2

Table 4.2 Extreme Storm Events

Date	Direction	Deepwater Wave Ht Hs (m)	Period T (Sec)	Comments
April 1967	NW	6.0	10	Cyclone Alby
August 1983	W	8.5	10	Key Biscayne Sinking
August 1985	SW	7.9	11	S.W. Storm



WAVE HEIGHT EXCEEDENCE CURVES

Figure 4.1

4.2 Wave Transformation

Refraction, Diffraction and Shoaling

As waves move from deep water to shallower water they are altered by refraction and shoaling and in some cases by diffraction. A mathematical model scheme based on that developed by Abernathy and Gilbert (1975) and Treloar and Abernathy (1977) was used.

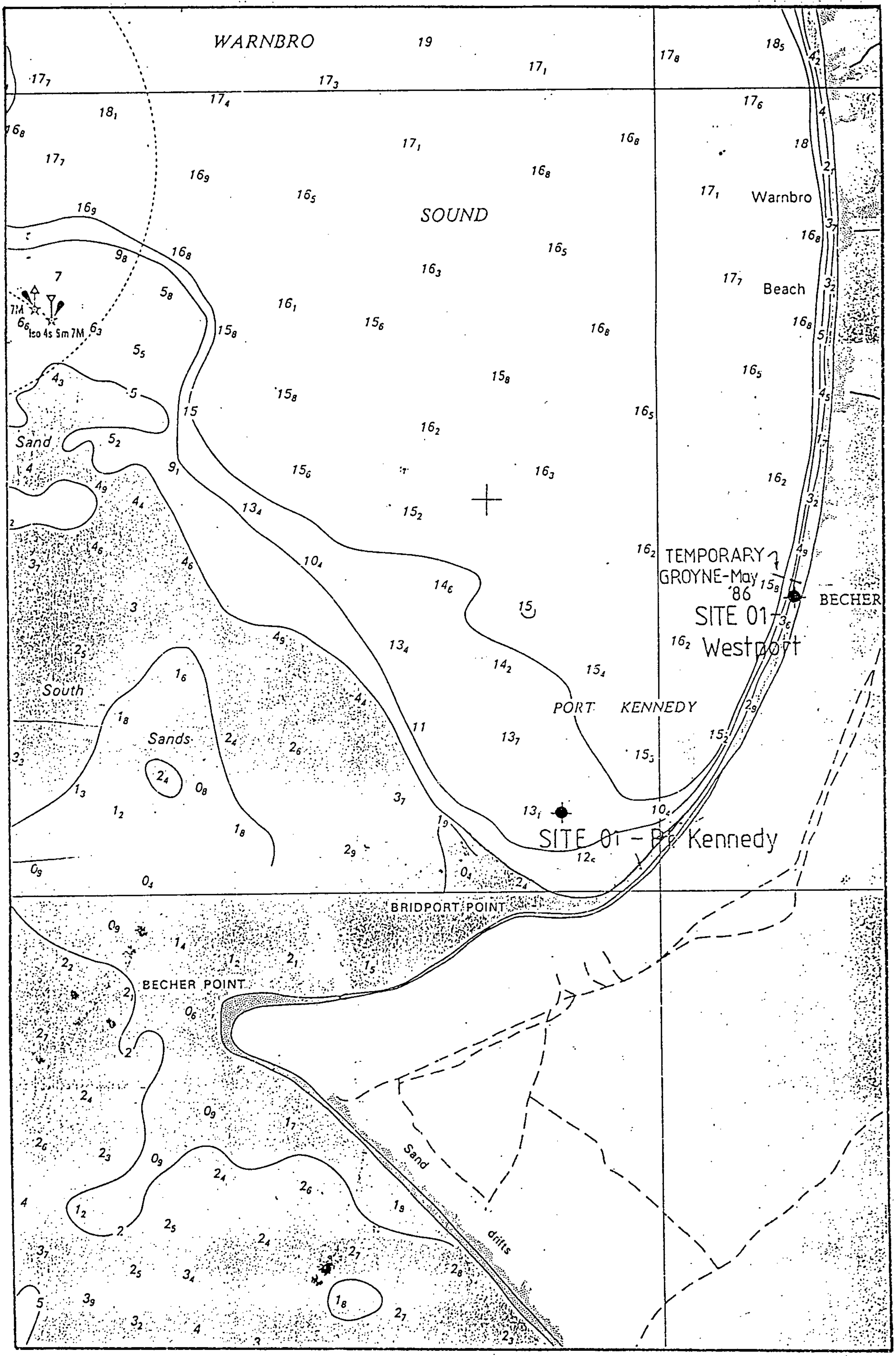
The program uses a reverse ray technique with a spectral basis to allow for the natural spread in wave periods and directions. The input allows variable grid sizes to cater for complex seabed bathymetry.

The refraction technique used, is described in detail in Appendix BB together with details of the mathematical schematization.

Site 01 at Port Kennedy, Figure 4.2, was chosen as the refraction origin for significant wave height analysis. The results from the mathematical modelling were combined with the hindcasts of waves generated within Warnbro Sound to produce the significant wave height roses shown in Figure 4.3.for:

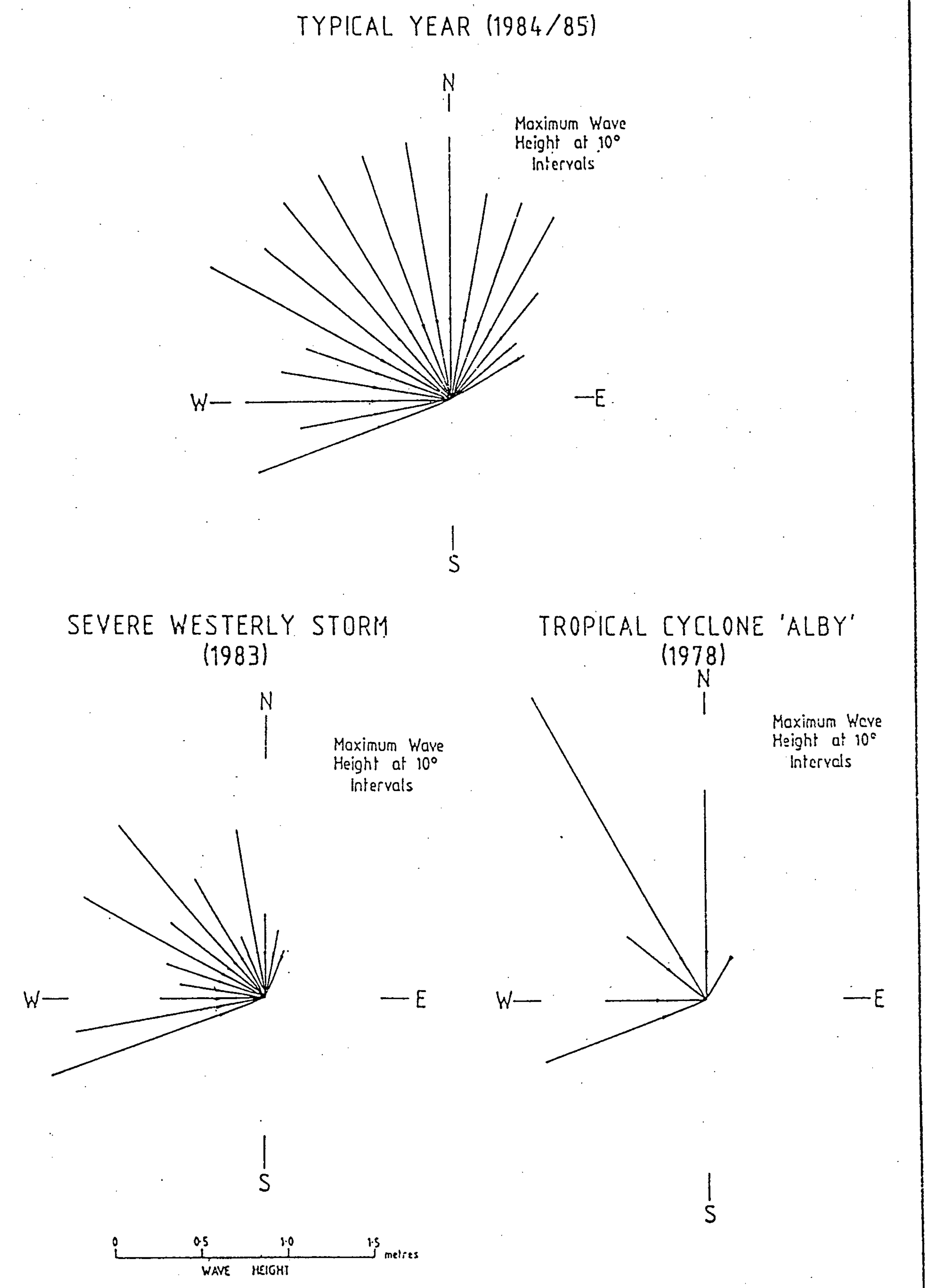
- the typical year (1984/85) (which includes the severe winter south-westerly storm)
- a severe westerly storm (1983)
- tropical cyclone 'Alby (1978)

Wave coefficient and inshore direction tables for the 1984/85 typical year for sea and swell waves are to be found in Appendix BB. Table 4.3 shows the results for swell waves. The coefficient shown in the table shows the factor by which the offshore wave is multiplied to obtain the inshore wave. That is, a 12 second, 1 metre high deepwater swell wave coming from the south-southwest (approximately 200°) would be modified by refraction, diffraction and shoaling (attenuation due to seabed friction not included here) to become an 0.27m high wave with a nearshore direction of 296°.



REFRACTION ORIGINS

Figure 4.2



SIGNIFICANT WAVES - SITE 01 PT KENNEDY

Figure 4.3

Table 4.3 Port Kennedy refraction, diffraction and shoaling coefficients

Inshore Location : Port Kennedy
Water depth at Site : 14.4m
Wave type : Swell Waves

Offshore direction (degrees)	Peak period (seconds)				
	6	8	10	12	14
Wave Coefficients					
180	.12	.16	.18	.20	.22
190	.18	.22	.23	.24	.25
200	.25	.28	.27	.27	.28
210	.33	.33	.31	.29	.29
220	.40	.37	.33	.31	.31
230	.46	.40	.36	.33	.33
240	.52	.43	.38	.35	.35
250	.56	.45	.40	.38	.38
260	.60	.48	.42	.40	.41
270	.62	.49	.44	.43	.44
280	.62	.49	.45	.45	.46
290	.60	.49	.45	.46	.47
300	.56	.47	.44	.45	.46
310	.51	.43	.41	.42	.43
320	.44	.38	.36	.37	.38
330	.36	.32	.30	.30	.31
340	.28	.26	.24	.24	.24
Inshore Directions (degrees)					
180	297	296	296	297	299
190	296	295	295	297	299
200	294	299	294	296	298
210	293	294	294	295	297
220	291	293	294	295	297
230	289	293	294	296	298
240	288	292	295	298	300
250	288	292	296	300	302
260	290	294	298	302	304
270	292	296	300	304	306
280	295	299	303	306	307
290	298	302	305	307	308
300	301	304	307	308	309
310	304	306	308	309	309
320	306	307	309	309	309
330	308	308	309	310	309
340	309	309	311	311	310

Table 4.3 and inspection of detailed results (full tables in Appendix BB.3) reveal that the common swell events from all directions in deepwater have inshore directions between 290° and 310°. That is, to

say, that the swell wave orthogonals approach the shore from the same narrow band of direction irrespective of the deepwater direction.

Seabed Friction

Wave attenuation by seabed friction is often overlooked whereas its effect can be quite significant, particularly where there are reefs or seagrass meadows or where the sand bed may be rippled. The existence of ripples depends on the sand grain size, wave characteristics and water depth.

The methods used to calculate the attenuation due to friction have been adopted from Riedel, Kamphuis and Brebner (1972), Kamphuis (1975), Nielsen (1977) and Hsiao and Shemdin (1978). The method treats seabed friction in detail and is described in Appendix CC. In brief, the seabed is schematized in segments to which are assigned:

- water depth
- sand grain size
- seagrass roughness if seagrass is present
- reef roughness where reef is present.

For every possible combination of wave direction, height and period calculations are performed to determine:

- whether ripples are likely to exist
- the effective roughness of the seabed
- the wave height attenuation
- whether wave breaking would occur and if so assigns a reformed wave height.

The wave height attenuation by seabed friction depends upon many variables:

- wave travel path
- nature of seabed
- wave height over the individual segments used in the calculations; the variations due to refraction and shoaling are taken into account
- wave period
- wave depth
- wave regeneration by a following wind.

Consequently, it is not possible to present the results in a simple format. The values were stored in a computer for later application when breaking heights were calculated for sediment transport calculations.

The deepwater waves which approach the site from the South-west and have to pass over the large shallow sand bank are naturally most affected by seabed friction. Typically such waves would have friction coefficients of between 0.1 and 0.2. Waves approaching from the North-west and passing through the entrance to Warnbro Sound are less affected and typically have friction coefficients of 0.5 to 0.7.

Summary

The combined transformation coefficient for swell waves from the South-west would be in the order of 0.05, that is 5% of their deepwater height.

Swell waves from the north-west are slightly less affected being reduced to about 25% of their deepwater height.

It is not surprising therefore that the wave climate at the site is dominated by the locally generated sea. In particular the waves from the northern quadrant where the available fetch lengths are greater.

5. COASTAL PROCESSES

5.1 Introduction

As discussed in Section 4, Warnbro Sound is a deep well protected embayment bounded on the south by Becher Point and to the north by Mersey Point

The wave climate within the sound is mild as a result of the protection afforded by the large expanses of sand flats and the system of reefs and ridges at the sound entrance.

As a consequence the sediment transport within the sound both longshore and onshore/offshore, is significantly less than on the open coast.

5.2 Littoral Transport

5.2.1 General

The general net movement of littoral transport in the region is to the north as a result of the predominant south-westerly swells.

Assessments of the rate of sand movement into the Becher area from the south vary, but are generally estimated to be in the 50,000 to 100,000 m3/year range (Foster, Wallace 1983). Available historical surveys from the mid to late 1880's indicate that the sand flats between the reef and Becher Point have been accreting at much the same rate.

The majority of sand entering the area from the south is deposited on the sand flats, although there is some leakage of sand around Becher Point and into Warnbro Sound.

5.2.2 Westport

A major coastal processes study as part of an ERMP was undertaken at the Westport site approximately 2.5 kilometres to the north of Bridport Point.

That study included mathematical modelling of sediment transport and the construction of a temporary groyne to trap and measure littoral drift.

That study indicated that the net direction of sediment transport within the sound is cyclic, being generally to the south in the winter months between May and September, and to the north between October and February and quiescent for the remainder of the year.

The total gross movement of sand is small being less than 20,000 m3 in a year and the net movement in any one direction probably less than 5,000 m3/a.

As can be seen from the sediment transport graphs shown in Figure 5.1 the north and west swells tend to move sand to the south, and the south-westerly swells move sand in the opposite direction. The south-westerly swell waves are a regular occurrence whereas the swell from the north and west tend to move sand during discrete storm events.

The locally generated sea tends to have a cyclic effect moving sand to the north in summer and south in the winter.

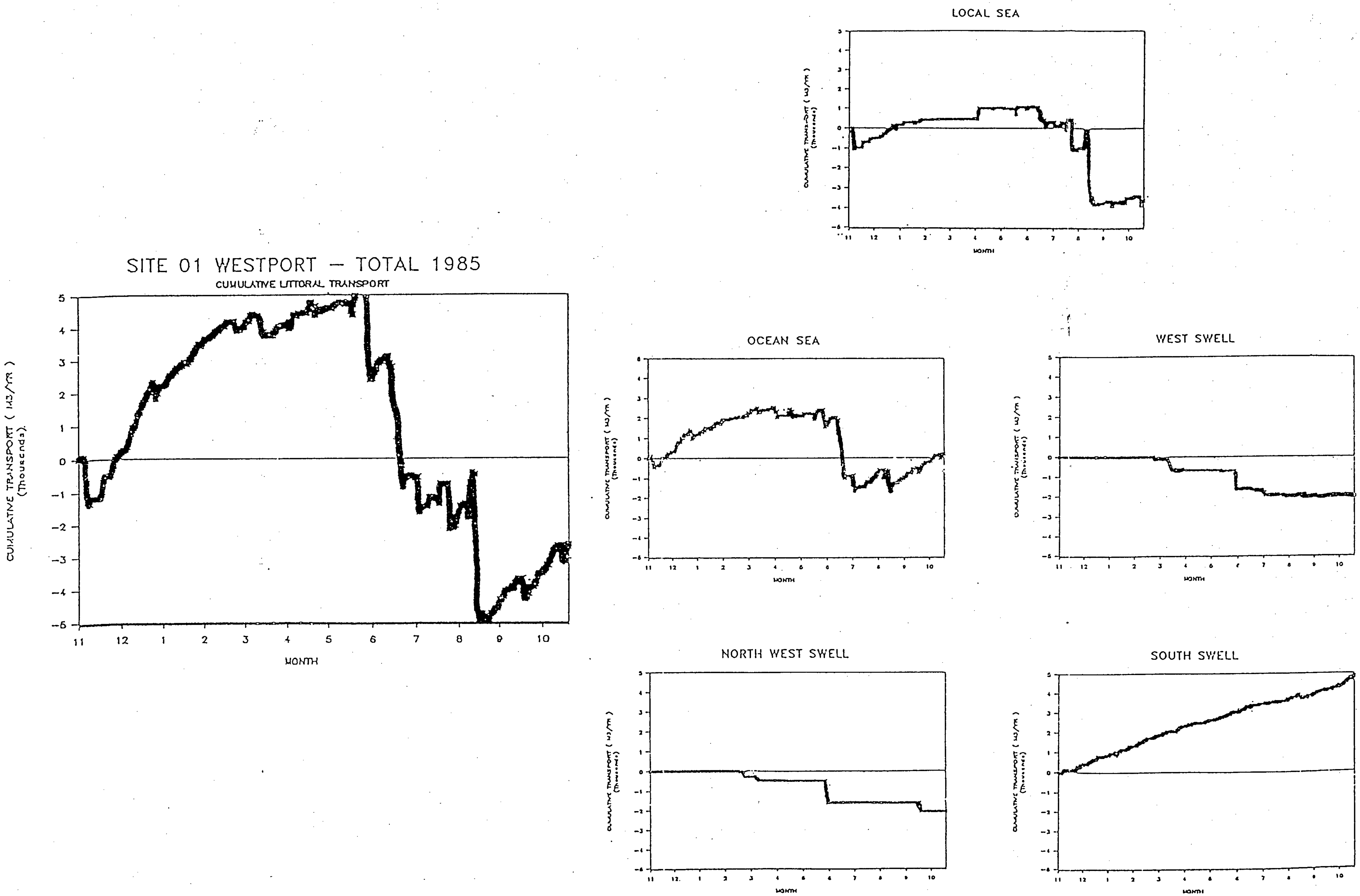
The direction of net movement at Westport is likely to vary from year to year depending on the synoptic patterns.

5.2.3 Bridport Point

The magnitude of littoral transport at the Bridport Point site is somewhere between that occurring on the open coast south of Becher and the protected site at Westport.

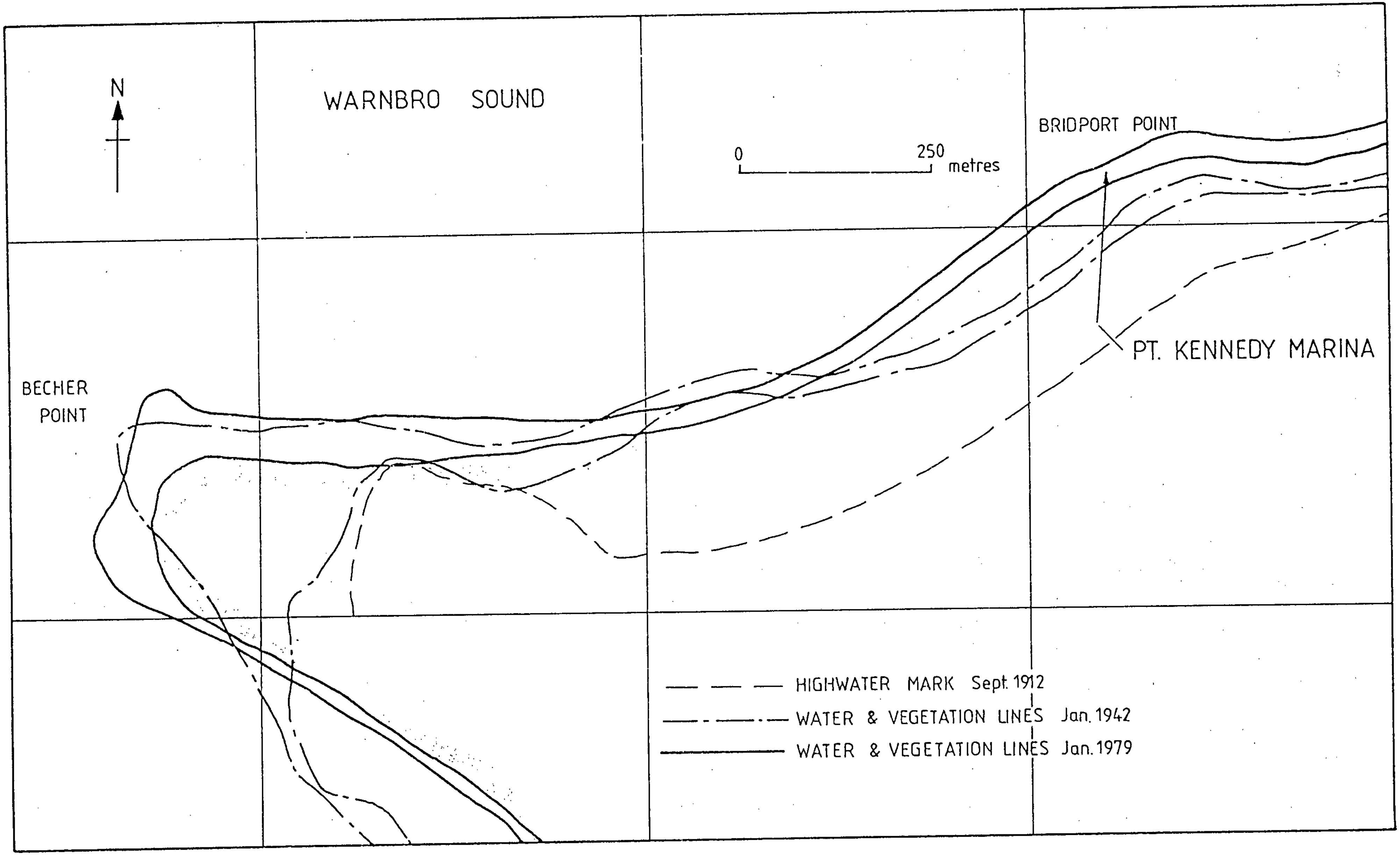
The site at Bridport Point has a mild wave climate as a result of the protection of the reefs and sand flats, however it is influenced by the leakage of sand around Becher Point

Shoreline movement plans have been prepared by the Department of Marine & Harbours for the period between 1942 and 1979, these have been combined with survey information dating back to 1912. The results are shown in Figure 5.2.



NETT SEDIMENT TRANSPORT - WESTPORT
TYPICAL YEAR (1984/85).

FIGURE 5.1



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PUBLIC WORKS DEPARTMENT (W.A.)
DWG. N° 52624-6-1

SHORELINE MOVEMENTS
AT
POINT KENNEDY

FIGURE 5.2

It can be seen that the shoreline adjacent to Bridport Point has accreted by approximately 200 metres in the 65 years between 1912 and 1979. If that accretion is assumed to have occurred between the RL +2.0 contour and the RL -1.0 to RL -2.0 contour then it represents a total accumulation of about 750,000 m3 of sand or 10,000 - 15,000 m3/a.

The accretion of sand in this area results from a combination of factors.

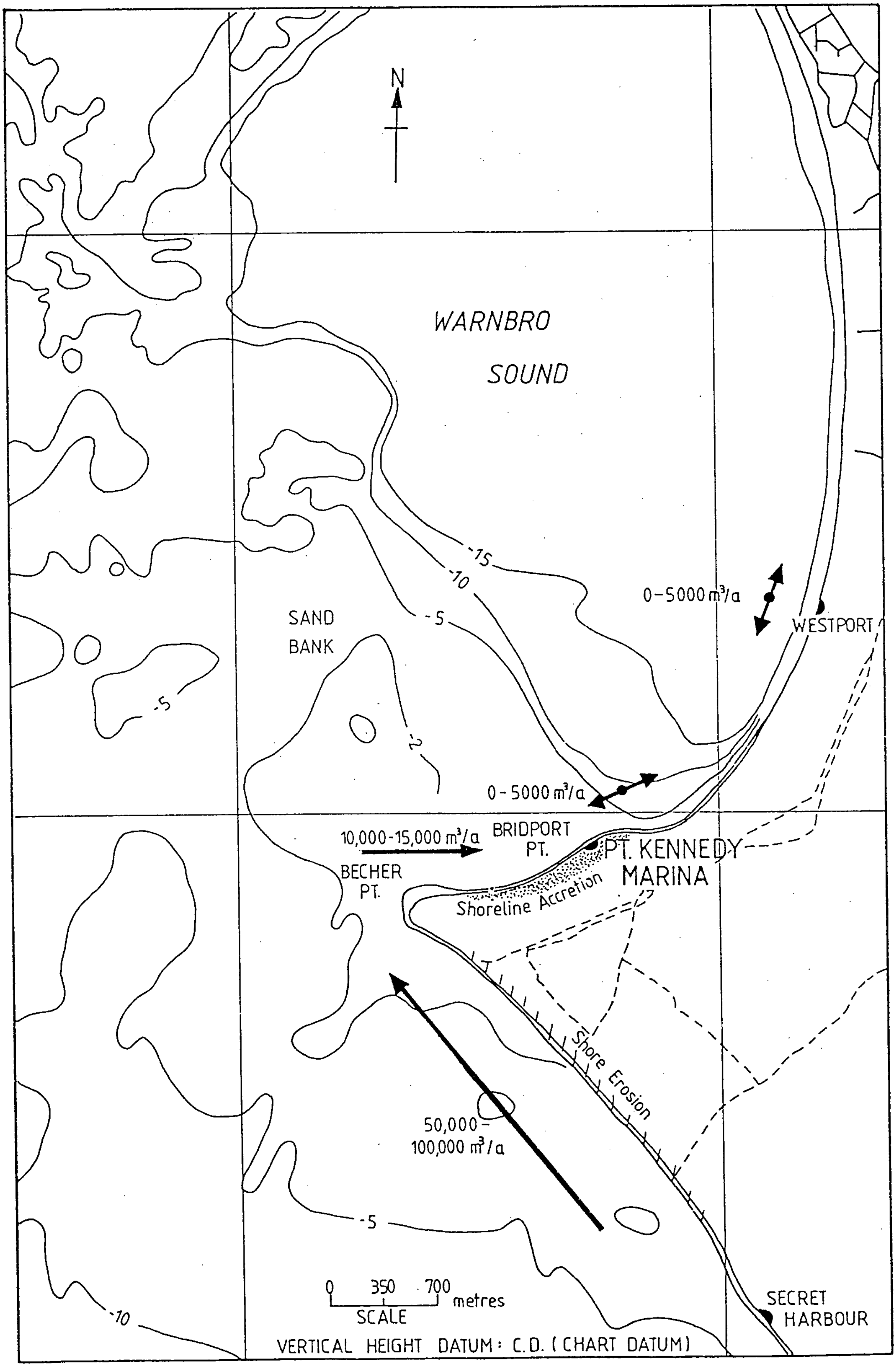
As the waves propagate across the sand flats they lose energy due to friction with the seabed. The waves therefore become progressively smaller as they move past Becher Point and are less able to move sediment, and sand accretes.

As the waves approach the deep water of Warnbro Sound there is a confluence with the waves coming in through the entrance to the sound and tending to move sediment in the opposite direction. This area is characterised by a bump in the coastline indicating a deposition of sand.

A conceptual model of the sediment transport in this region is illustrated on Figure 5.3.

There is a net transport from the south of 50,000 - 100,000 m3/a approaching Becher Point A large percentage of this material is deposited on the sand flats at the point although some does leak around towards the Bridport Point area.

Between 10,000 and 15,000 m3/a is deposited between Becher and Bridport Points resulting in quite significant shoreline accretion. The net amount of sand passing Bridport Point and moving along the narrow coastal margins of the sound varies in magnitude and direction from year to year as a result of slightly changing meteorological conditions. The net littoral transport in this area is expected to be less than 5,000 m3/a.



CONCEPTUAL SEDIMENT TRANSPORT MODEL **Figure 5.3**

5.3 Harbour Impact and Management

The construction of a harbour at Bridport Point is likely to have little significant impact on the coastal processes of the region.

The 10,000 - 15,000 m3 of sand which currently deposits annually in the area will continue to do so. The shoreline will continue to move seaward, at a reduced rate as it enters deeper water.

There will therefore be significant sand accretion against the harbour's western breakwater. The amount of storage in this area is however sufficient to cater for sand accumulation for the next 50 years or so without bypassing or silting of the harbour entrance.

Construction of a relatively inexpensive spur groyne off the western breakwater could extend the sand storage for a further 20 - 30 years if required.

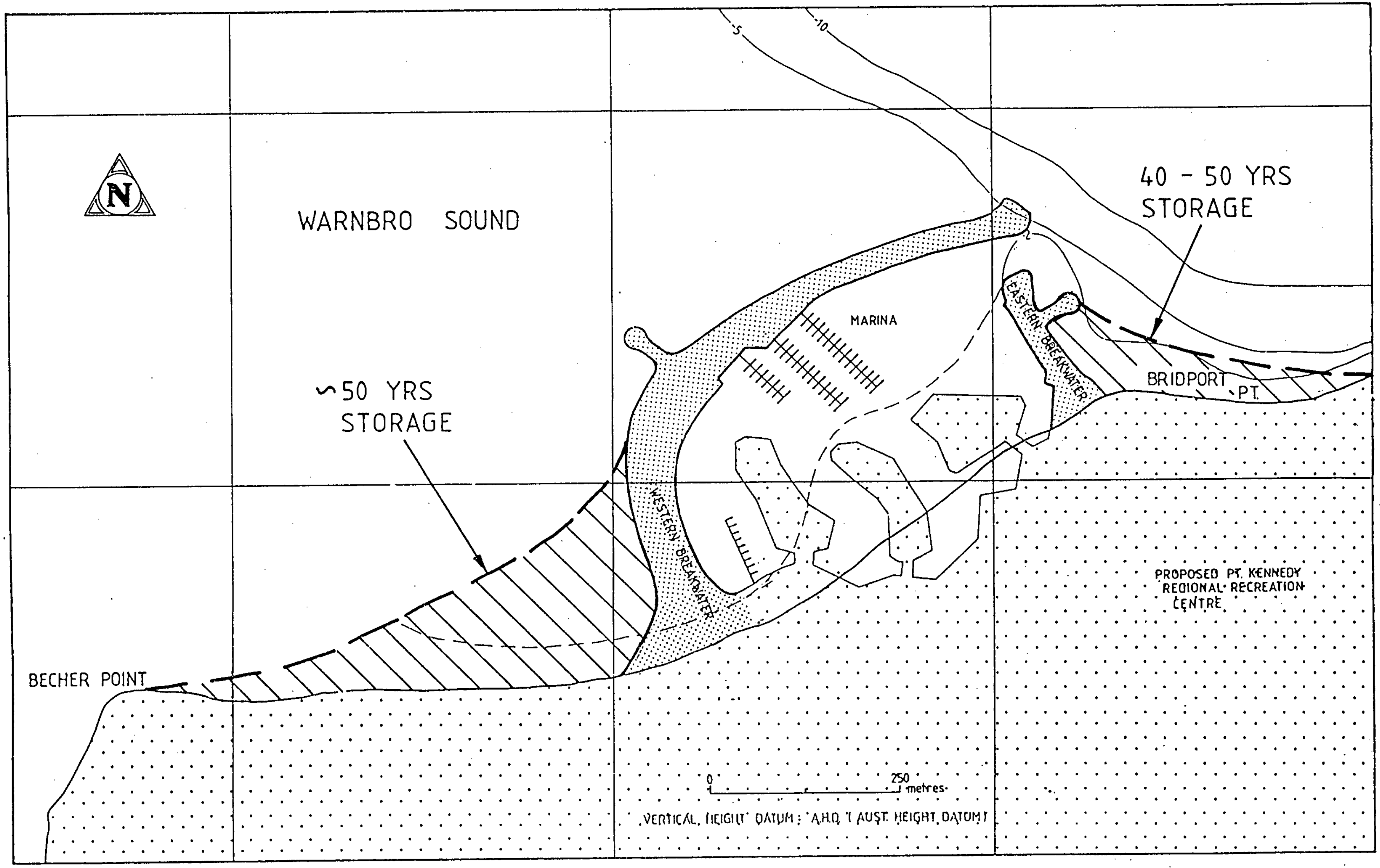
It is possible that in some years the wave conditions will be such that up to 5,000 m3 of sand would wish to bypass the development and be transported along the coastal margin of the sound. The construction of the harbour would prevent such bypass.

It will be necessary to monitor the coastline movements to the north of the harbour and mechanically bypass sand if necessary to prevent coastal erosion.

The extent of such bypassing on average is expected to be very small and in any one year should be less than 5,000 m3.

It is possible that there will be accretion of sand on the Eastern breakwater as a result of occasional net movement of sand from the north. The breakwater length has been designed to provide a storage sink for sand from this source for 40 to 50 years. Once again relatively inexpensive spur groynes could be constructed to increase that storage some time in the future if required.

The sand storage areas are illustrated in Figure 5.4.



SEDIMENT BUFFER ZONES

FIGURE 5.4

6. CONCLUSIONS AND RECOMMENDATIONS

Water Levels

- There are three main factors affecting water level in the Warnbro Sound, astronomical tide, long period water level variations and extreme storm surge events.
- Astronomical tides typically have a daily variation of about 0.4 metres.
- Long Period Water Level Variations generally have periods ranging from 3 to 20 days and have a range of about 0.4 metres.
- Storm Surges are the most significant influence of peak water levels resulting in levels up to 1.9 metres above Chart Datum for extreme events such as Cyclone Alby.

Winds

- The wind climate at Bridport Point is very similar to that at Fremantle with winds from the southerly quarter being dominant.

Wave Climate

- The wave climate at Bridport Point is mild, the offshore swells being significantly attenuated by the fringing reefs and large expanses of shallow sand banks.
- Waves at the site are dominated by those locally generated from within the Sound. Except for quite severe storm events, significant waves heights tend to be less than about 1.2 metres.
- Extreme offshore storm waves from the west to north-west can result in wave heights at the Bridport Point site up to 2.0 metres in amplitude.

Coastal Processes

- The predominant south-westerly swells result in a net northerly movement of sediment of 50,000 - 100,000 m3/year approaching the region along the open coast.

- The vast majority of this sediment is deposited on the large shallow sand banks which fringe Warnbro Sound.

- There is some leakage of this sediment, 10,000 - 15,000 m3/a, around Becher Point and into the Sound. Most of this material is deposited on the coast between Becher and Bridport Points resulting historically in quite significant shoreline accretion in this area.

- Within the Sound itself there is very little net littoral drift, probably less than 5,000 m3/a on average. The direction of sand movement is cyclic being to the north in summer and south in winter. The direction of net movement is likely to vary from year to year depending on climatic conditions.

Development Impact

- The impact of the harbour construction on the coastal processes is not expected to be significant.

- The sand which currently accretes between Becher and Bridport Points will continue to do so resulting in further shoreline accretion.

- Depending on the direction of net sediment movement within the Sound there may be some tendency to small erosion of the coast to the north of the development. From time to time some bypassing of sand may be needed to replenish the sand so lost.

- A very pleasant well protected beach will be created on the eastern side of the development. This should more than compensate for the beach lost by the harbour construction.

Monitoring and Management

- The shoreline on both sides of the harbour will need to be surveyed on a regular basis, bi-annually for the first two or three years and then possibly annually.

- Some bypassing of sand may be required from time to time to replenish beaches to the north of the development. The extent and frequency will be small and of little economic consequence.

- There is adequate sediment storage against the breakwaters on the East and West sides of the development to cater for expected accretion over the next 40 to 50 years. There should be no significant sedimentation of the harbour entrance in that time. The entrance bathymetry should be monitored on an annual basis.

- Construction of spur groynes could be undertaken at any time in the future to increase sediment storage capacity if required, or to prevent leakage of small quantities of sand along the breakwater should that occur.

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APPENDIX B: MODELLING OF SHALLOW GROUNDWATER

MACKIE MARTIN & ASSOCIATES

BINNIE & PARTNERS PTY. LTD.

PORT KENNEDY REGIONAL RECREATION CENTRE

NUMERICAL MODELLING OF SHALLOW GROUNDWATER SYSTEM

MAY 1988

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West Perth 6005

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TABLE OF CONTENTS

PAGE

1.0 INTRODUCTION B3

2.0 BACKGROUND DATA B3

3.0 LOCAL GEOLOGY B3

4.0 GROUNDWATER OCCURRENCE B4

5.0 RESOURCE MEASUREMENT B5

6.0 DISTRIBUTED PARAMETER NUMERICAL MODEL B6

7.0 IMPACT OF ABSTRACTION B8

8.0 GENERAL DISCUSSION B9

REFERENCES B11

APPENDIX 1: Hydrographic Data for the Area

APPENDIX 2: Results of Model Calibration
- Westport Hydrographs

LIST OF FIGURES

Figure 1: Locality and geology map B12

Figure 2: Comparison of hydrographs B13

Figure 3: Comparison of rainfall and water table oscillations B14

Figure 4: Model grid geometry B15

Figure 5: Base of aquifer B16

Figure 6: Average Summer Mounding B17

Figure 6: Average Winter Mounding B18

Figure 7: Impact of Pumping at 4000 kl/day B19

Figure 8: Impact of Pumping at 3500 kl/day with Wesport Stages I & II B20

1.0 INTRODUCTION

Development of the Port Kennedy Regional Recreation Centre is proposed for the Becher Point area south of Safety Bay. As part of this development it is intended to exploit groundwater resources contained within shallow sand aquifers. In accordance with ERMP guidelines the expected impact of development upon these water resources has been investigated to a level commensurate with existing data.

Mackie Martin & Associates Pty. Ltd. (groundwater engineers and earth scientists) have been commissioned by Binnie & Partners Pty. Ltd. on behalf of the Port Kennedy Joint Venture to provide an assessment of impact. Contained within this document are results of recently completed desk top studies including generalised aquifer mapping, analysis of regional hydraulics and results of computer based numerical modelling of the shallow aquifer system under proposed water abstraction scenarios.

2.0 BACKGROUND DATA

Sources of information to conduct desk top studies have included the following:

* various Geological Survey reports and maps;
* Water Authority of Western Australia reports and hydrographic data;
* various reports relating to the hydrogeology of the Secret Harbour Development (Rockwater Pty. Ltd.):
* hydrogeology relating to the Westport project (ERMP-Delta Holdings Pty. Ltd.):
* rainfall data for Mandurah and Rockingham from the Dept. of Meteorology.

3.0 LOCAL GEOLOGY

The geology and hydrogeology of the area around Becher Point have been described by numerous workers (Allen, A.D.,1978,1981; Davidson, W.A.; Passmore, J.R.,1970) as well as various government, consulting and development organisations.

Geologically, the area is part of the Swan Coastal Plain lying within the extensive Perth Basin - a thick succession of sediments ranging in age from Palaeozoic to Recent. Sands occur over most of the proposed development area and extend to the north, south and east. These sands are termed superficial sediments and also include calcarenites, limestones and clays of variable thickness.

Two principal aquifer systems are recognized; the surficial Safety Bay Sand aquifer (and Coastal Limestone unit) and the underlying Rockingham Sand aquifer.

The Safety Bay sand unit is the main aquifer considered in the current study. It comprises fine to medium to coarse grained unconsolidated quartzose and calcareous sands with variable degrees of sorting and cementation. The unit attains a thickness of about 20 metres along the coastline and thins to the east, eventually pinching out against (Coastal) limestones in the vicinity of Lake Walyungup and Anstey Swamp to the south. At the contact between the Safety Bay sands and the Coastal Limestones, a thin sequence of intercalated clays and sandy clays is often noted. Figure 1 indicates regional geology.t

Coastal limestones form the pronounced ridges in the eastern part of the area near the Old Mandurah Road. These limestones dominate much of the coastal plain and comprise calcareous shell fragments and cemented sands. The unit attains thicknesses in excess of 20 metres and weathering produces the distinctive honeycombing texture. Marls and clays often dominate the lower zone

Underlying the surficial aquifers is a succession of sands known as the Rockingham Sand unit. Sands are medium to coarse grained, moderate to poorly sorted quartzose with occasional clay zones. The sequence may attain thicknesses greater than 100 metres. Beneath the sands occur the older slightly more consolidated materials of the Leederville and Yarragadee Formations. These have not been considered in this modelling exercise.

4.0 GROUNDWATER OCCURRENCE

Groundwater occurs within the shallow Safety Bay sands as intergranular or intrinsic storage, the upper surface of which is a free standing or phreatic water table. The main source of recharge is rainfall and contained water is generally of good quality with total dissolved solids (TDS) mostly less than 1000 mg/litre and often potable.

Although mapping of the water table south of Rockingham is incomplete it is known that a groundwater mounding occurs in the zone between the coastline and the chain of swamps and lakes to the east. This mounding is a relatively normal hydrogeologic phenomenon developed through rainfall recharge. It maintains hydraulic heads which induce flows to the east and to the west. The geometry is directly related to the volume and extent of rainfall as well as the geometry of permeable sands at depth and the distribution of aquifer hydraulic properties.

To the west of this mound groundwater discharges to the ocean, at a rate controlled by the rainfall recharge and subsequent increase in hydraulic head across the mound. At the coast, a dynamic balance between the fresh groundwaters and more dense sea water establishes a salt water wedge underlying the outflowing groundwater. The position of this wedge is governed by the local hydraulic gradients. It is essential to maintain a positive gradient towards the coast to ensure inland encroachment of this wedge does not occur.

Vertically downward leakage is believed to occur from the Safety Bay sands into the limestones and possibly into the Rockingham sands. The extent of this leakage is determined by the distribution of clays between the surface sands and the underlying limestone. In the Safety Bay area reported clays at depths of about 22 metres are likely to prevent significant leakage while around Becher Point and to the east, little is known about leakage potential. For the purposes of the current study leakage is assumed to be minimal and accounted for in the calibration of the model to measured water table fluctuations.

Numerous observation bores have been constructed throughout the area and data from these bores relating to geology, water table elevation and seasonal oscillation of the phreatic surface, have been utilised in estimating the groundwater resources of the region.

In particular, data from Water Authority bores T330, T380, T430 and T480 has been reviewed together with hydrographic data from shallow bores relating to proposed developments at Westport (Delta Holdings Pty. Ltd.). Swamp and lake hydrographic data has also been examined.

All hydrographic information clearly shows a seasonal oscillation related to rainfall recharge. However phase relationships appear complex in some cases. Amplitudes of more than 1 metre are typical with mean and absolute levels indicating a groundwater mounding as expected. Hydrographic data are represented in Appendix 1 for reference. It is interesting to note the phase relationship between the deeper bore T380 and nearby shallow bores N1,N2 and N3. Figure 1 indicates bore positions while Figure 2 shows a comparison of hydrographs. Clearly bore T380 is almost 6 months out of phase or lagging the response shown at shallow bores. Similar relationships are observed at other T series deeper bores suggesting a delay in downward leakage to the horizons monitored by those bores. In view of this relationship data from T series observation bores has not been used in assessing shallow aquifer hydraulics in the current study.

The relationship between rainfall and water table response is shown by reference to Figure 3. Historical rainfall for Rockingham is plotted for the period 1974 to present together with hydrographic data for Lake Walyungup. A lag of between 1 and 2 months is noted in peaks between rainfall and water table rise. The period of low water levels during 1977-1978 is easily correlated to a similar period of low rainfall.

5.0 RESOURCE MEASUREMENT

It is possible to assess the resource using generalised one dimensional analysis to estimate storage, recharge and impact of abstraction however such analysis does not permit a realization of spatially variable aquifer properties. Nor does it permit reasonable prediction of impact under transient (changing) conditions relating to seasonal rainfall and water table movements.

The most appropriate means of assessing these parameters and various abstraction strategies is by a numerical computer model. Using such a model, regional properties may also be reasonably estimated and the final layout may be progressively updated in time as further information becomes available. Additionally a model may also be used as a management tool to optimise resource usage and to predict performance under changing climatic conditions, eg. droughts.

By developing a numerical model at an early stage of resource measurement it is also possible to undertake sensitivity analyses if required to determine where further data should be sought in the course of development of the area.

6.0 DISTRIBUTED PARAMETER NUMERICAL MODEL

A two dimensional finite element distributed parameter numerical model has been designed and tested for the Regional Recreation Centre. With this technique the aquifer is simulated by a number of discrete elements each having representative aquifer properties, head conditions, rainfall recharge, etc. Parameters are 'tuned' against known conditions until an acceptable fit is obtained between field data and model output. Various abstractions may then be imposed and impact assessed by reference to model water table contours.

Under the development proposal it is planned to abstract at a rate of 5500 kl/day declining steadily to 4000 kl/day over the first 5 years as grasses and trees become established.

A finite element model (AQUIFEM) comprising 686 triangular elements described by 384 nodes has been developed to accommodate the most important regional and localised hydrogeologic conditions. These include:

* the base of the shallow Safety Bay sands obtained from an assimilation of reports for the Westport and Secret Harbour projects;

* the water table mounding geometry as measured for the Westport development;

* aquifer properties as variously reported;

* rainfall infiltration as reported in the Perth Urban Water Balance Study.

Model geometry is illustrated on Figure 4. The following model design parameters and boundary conditions have been incorporated:

* the Indian Ocean has been treated as a constant zero head and thus acts as a line sink for groundwater flows towards the ocean;

* the northern and southern boundaries of the model have been aligned with expected flow lines and are therefore regarded as no flow boundaries;

* in the absence of detailed flux information the eastern perimeter of the model has been located along the lake and swamp system and treated as a time varying constant head boundary the head variation being determined from known hydrographic data;

* a tuning period from December 1982 to November 1984 has been applied. This period equates to the period of observation of 11 shallow piezometers installed as part of the Westport project;

* rainfall recharge to the aquifer was initially set at 22% of annual rainfall distributed quarterly by a step function representative of Rockingham and Mandurah rainfall during the tuning period;

* aquifer properties were initially set at 25 m/day for hydraulic conductivity, 15% drainable porosity and zero leakage to the underlying limestone and Rockingham sands.

The tuning process involved calculation of distributed heads across the model for defined properties and rainfall over the 2 year tuning period and comparison of model response to hydrographic data. As noted previously, only 11 hydrographs relating to the Westport project have been used due to complex phase relationships evident in the deeper T series observation bores monitored by Water Authority.

Results of calibration are presented as hydrographs in Appendix B. For these hydrographs the mean rainfall level (average of oscillations) is directly related to prevailing regional hydraulic conductivities, porosities (specific yield) and percentage of rainfall infiltrated to the aquifer. Amplitude of seasonal oscillations is more sensitive to porosity and less sensitive to the parameters noted above.

Calibration parameters for an aquifer base as shown at Figure 5 are:

hydraulic conductivity = 16 m/day (Safety Bay area)
hydraulic conductivity = 48 m/day (remainder of the area)
drainable porosity = 11%
leakage = nil
rainfall recharge = 34.5% of annual rainfall

These parameters are reasonable estimates and generally consistent with previous studies. Table 1 summarizes other estimates.

The following general points are noted in respect of calibration.

The aquifer base (and thickness) has been interpolated over much of the model area and discounts any hydraulic connection to underlying limestones or the Rockingham sands. Hydraulic conductivity has been adjusted during calibration however the important parameter to consider is the transmissivity or product of conductivity and saturated aquifer thickness. Thus, given a reasonable state of calibration, either the hydraulic conductivity or the thickness may be adjusted slightly (assuming some model interpolation error) so long as the product remains the same as the calibrated model transmissivity.

		Hydraulic Conductivity (m/day)	Spec. Yield % pore	Rainfall Infiltration (% annual)
Passmore (1970)		40.0	11 - 20	
Allen (1981)		30.0	30.0	>11.5
Davidson		17.5		8.0
Secret Harbour Rpts		20.0	10 - 20	
Westport	*	25.0	20.0	20.0
Jandakot Mound	**			16.0
Gnangara Mound	**			22.0
Stakehill Mound	***			20.0
Current Model		16-48	11.0	34.5

Table 1: Comparison of hydraulic properties and rainfall estimates.
* Estimate from previous workers;
** Derived from numerical modelling (Urban Water Balance Model);
*** Inferred from modelling in other areas (Water Authority).

Leakage has been assigned a zero value however, if it occurs then rainfall infiltration must be increased in the area of leakage by an amount equivalent to the deeper leakage rate to ensure a net volume of 34.5% is sustained to the shallow aquifer system.

Model parameters may be updated as further information becomes available.

Geometry of the mounding of the water table for average summer and winter rainfall conditions is shown in Figures 6 and 7, respectively. A variation between these figures of approximately 0.4 metres is noted at the centre of the mound, with little variation in hydraulic gradients at the coastline. Groundwater levels resulting from such average recharge (rainfall) patterns have been used as a base for estimating the impact of groundwater abstraction discussed in Section 7.

7.0 IMPACT OF ABSTRACTION

Design of pumpage within a coastal aquifer system should ensure that the water table along the coastline is maintained above sea level with a positive head located along the shore in order to mitigate the encroachment of sea water into the aquifer (resulting in saline upconing at bores and a deterioration of water quality).

Given that the calibrated numerical model is a fair and reasonable representation of prevailing hydrogeologic conditions within the study area, the maximum steady state abstraction rate can be determined by reference to model fluxes (or subsurface throughflow) away from the groundwater mound and towards the coast. Such abstractions are however generally impractical as fluxes equate to rainfall received and large areas are therefore required to harvest water in a steady state condition.

Instead, design usually relies upon aquifer storage and by exploiting such storage, the groundwater table is depressed more regionally. Often under these conditions, infiltrating recharge may ultimately be increased due to the development of widespread regional differential heads leading to long term steady state conditions. Monitoring of abstraction generally provides sufficient data to determine the onset of steady state.

A typical abstraction network might comprise 5 to 10 bores each pumping at the same rate to provide the total yield required. In order to demonstrate viability of such a scheme the calibrated model has been used with a conceptual wellfield located as shown on Figure 8. Bore abstractions have been assigned to nodes located along the axis shown and an average yield of 800 kl/day applied. The total abstraction of 4000 kl/day is expected to induce a local drawdown to approximately 0.5 mAHD in the vicinity of the borefield (Figure 8).

A second scenario incorporating the Stage II development at Wesport is presented in Figure 9. This illustrates the reduced yield available (3500 kl/day) to maintain an appropriate hydraulic gradient towards the ocean in the vicinity of the Recreation Centre.

8.0 GENERAL DISCUSSION

Modelling indicates a water supply for the Port Kennedy Regional Recreation Centre can be met over the first 5 years by harvesting groundwater resources from the shallow sand aquifer system with some augmentation from deeper aquifer sources.

During this period, depression of the water table is likely to occur in areas to the west of the proposed borefield locations and over parts of Becher Point. In these areas, water table gradients are reduced but a positive head is retained along the coastline. Elsewhere, water table conditions remain relatively unaffected and in particular, the Stakehill groundwater mound to the north-west remains intact.

The augmentation of the shallow groundwater supply may be derived from either the Leederville aquifer system or the Yarragadee system. Limited supply is available (a maximum of 300 kl/day) from the Leederville aquifer. Although a significant resource is contained within the Yarragadee aquifer the total volume of water drawn from this deeper aquifer will be limited by the water quality, and the available shallow sources to dilute the Yarragadee water to an acceptable quality.

It is noted however that water resources contained within the underlying Rockingham Sands have not been modelled in this present simulation. As a consequence, upward leakage from this formation has not been included in the assessment of shallow aquifer response. Significant water contributions from the Rockingham Sands are to be expected and as a result, the shallow gradients are not expected to be impacted to the extent so far predicted. Only a longer term monitoring of abstractions and regional water table movements will resolve contributions from other sources.

In addition, should the Westport development fail to proceed, additional shallow groundwaters may be harvested via an extension of the abstraction network to the north. An assessment of the additional supply available from such an extension was beyond the scope of this study.

The final design of a satisfactory abstraction network from the shallow groundwater system will require a suitable monitoring network to ensure hydraulic gradients are maintained towards the coast. The long term management of the borefield would be derived from a more comprehensive cause-effect numerical model based upon the results of local hydraulic testing (from initial production bores) and monitoring of the medium term response of the aquifer to stressing.

Monitoring of the aquifer will include a line of five monitoring bores recording groundwater levels between the coast and Ennis Avenue, located at appropriate sites to monitor the movement of the saline interface. Each observation bore and pumping bore will be fitted with a transducer to automatically record water level and will periodically be sample for water quality analysis. Discharge recorders will be fitted to each pumping bore to record the total volume of water abstracted. Climatic data will be obtained from a rain gauge and evaporation pan on site.

Long term monitoring requirements will be established in conjunction with the Water Authority.

Mackie Martin & Associates Pty. Ltd.
May 1988

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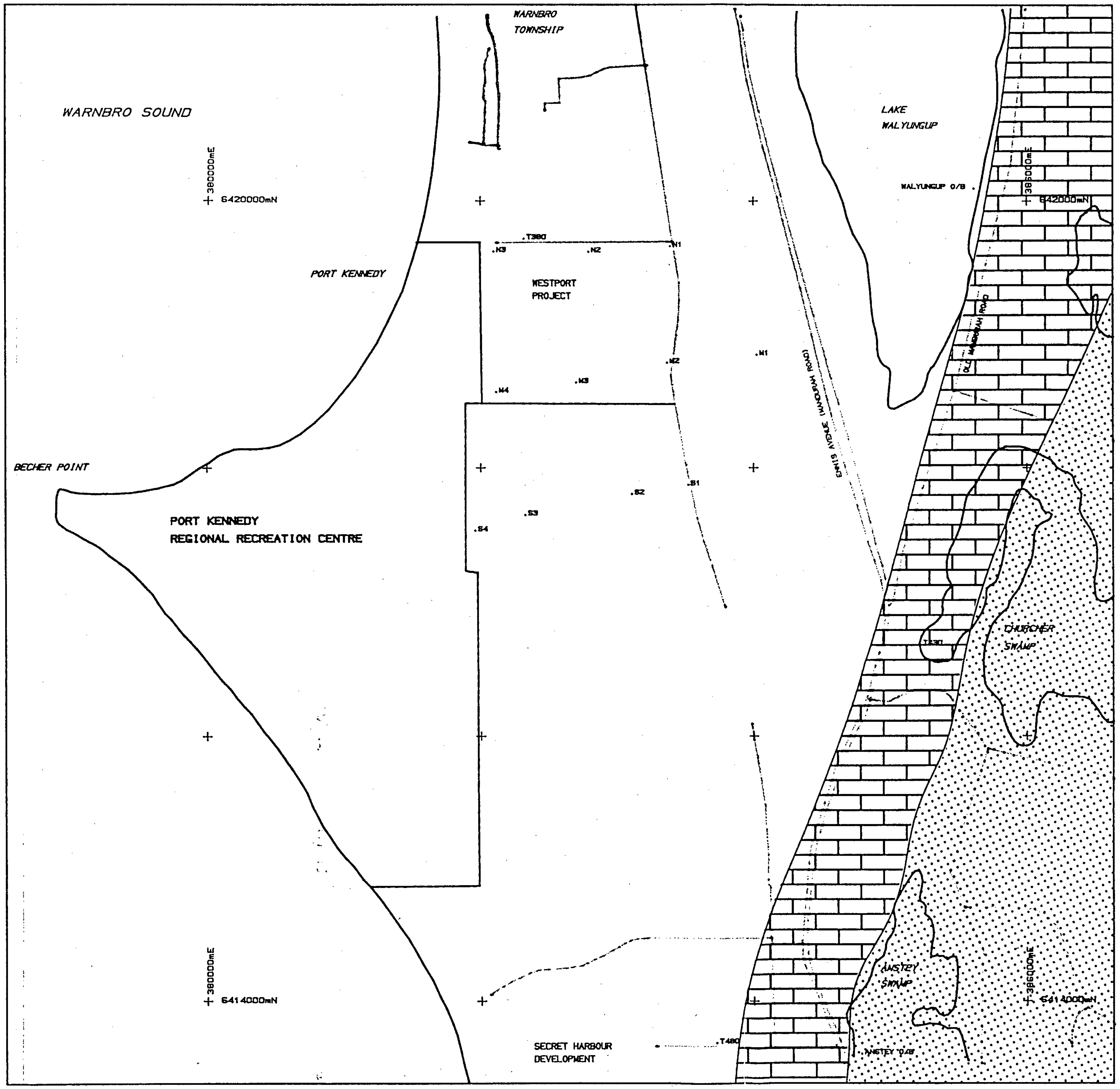

0 400 800 1200 1600 2000m

SCALE 1 : 30000

. LOCATION OF EXISTING BORE

Safety Bay Sand

Tamala Limestone

Bassendean Sand

PORT KENNEDY
REGIONAL RECREATIONAL CENTRE

BORE LOCALITY PLAN AND
REGIONAL GEOLOGY

Figure 1

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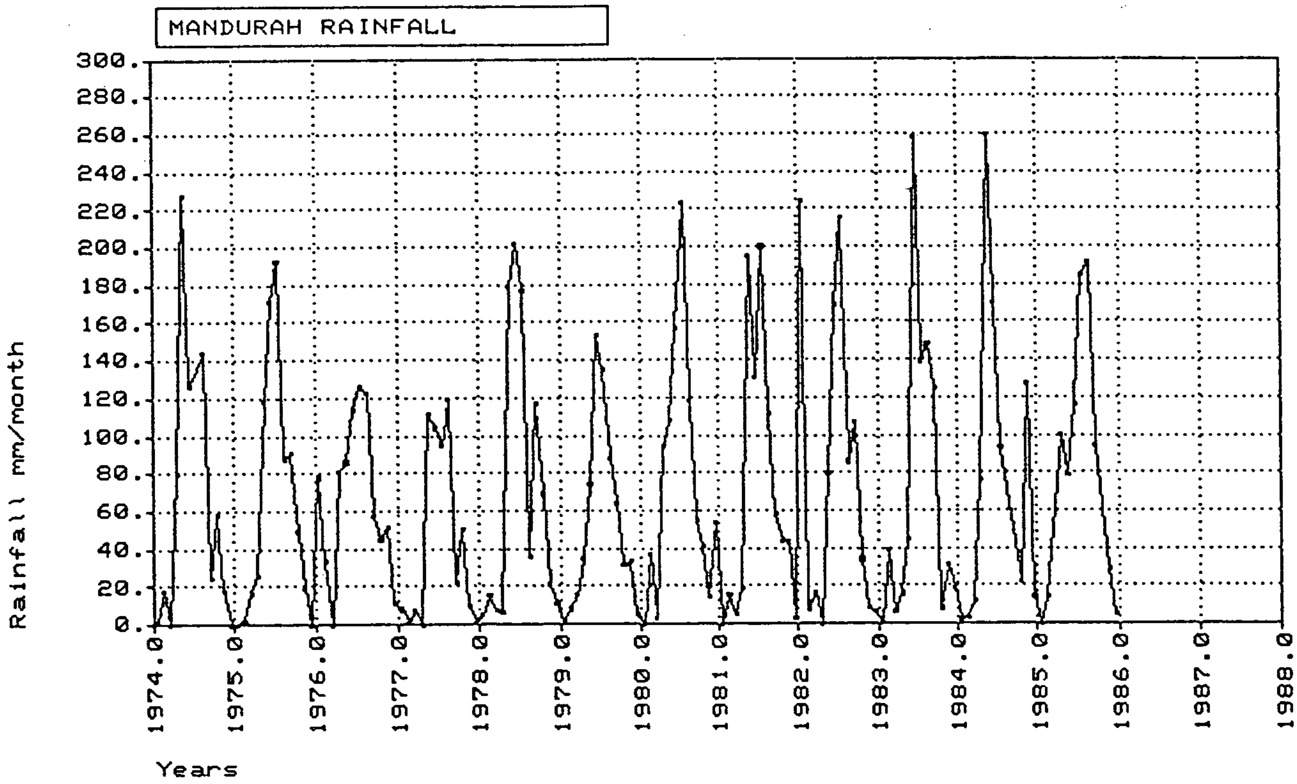

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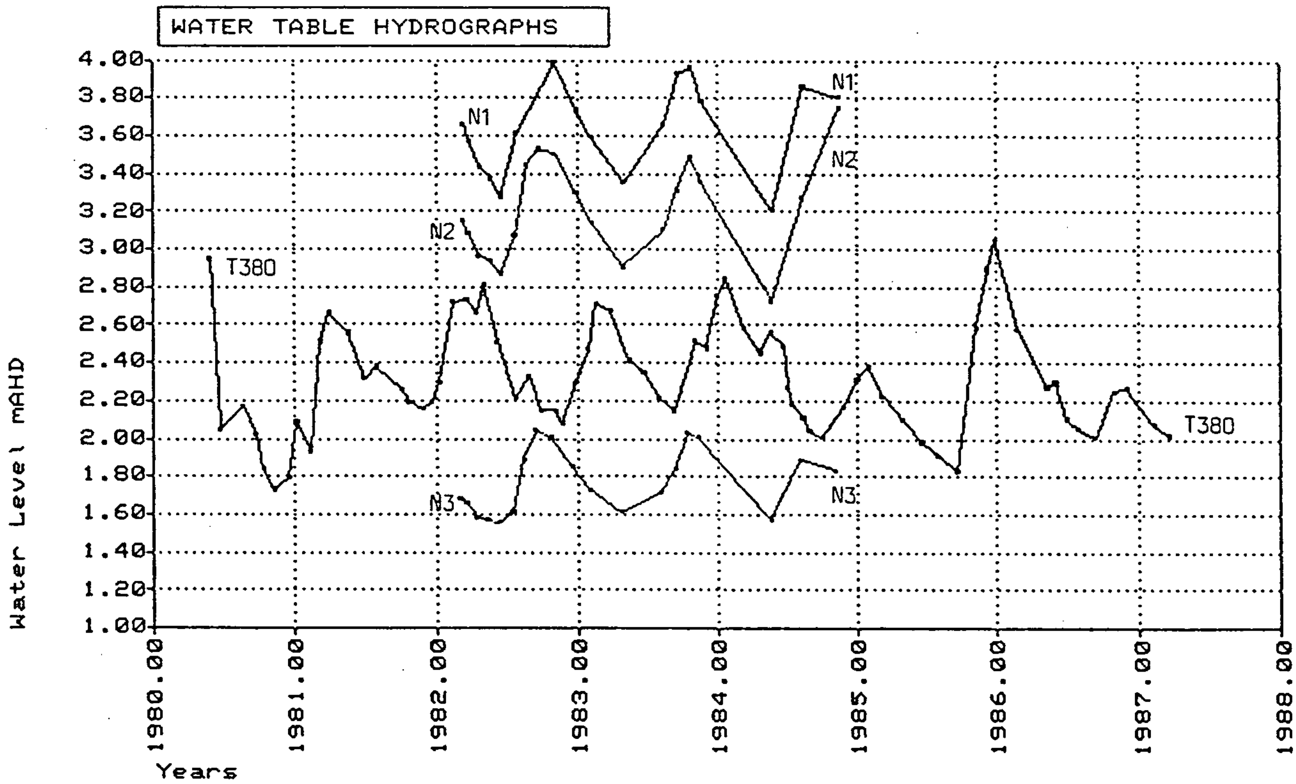

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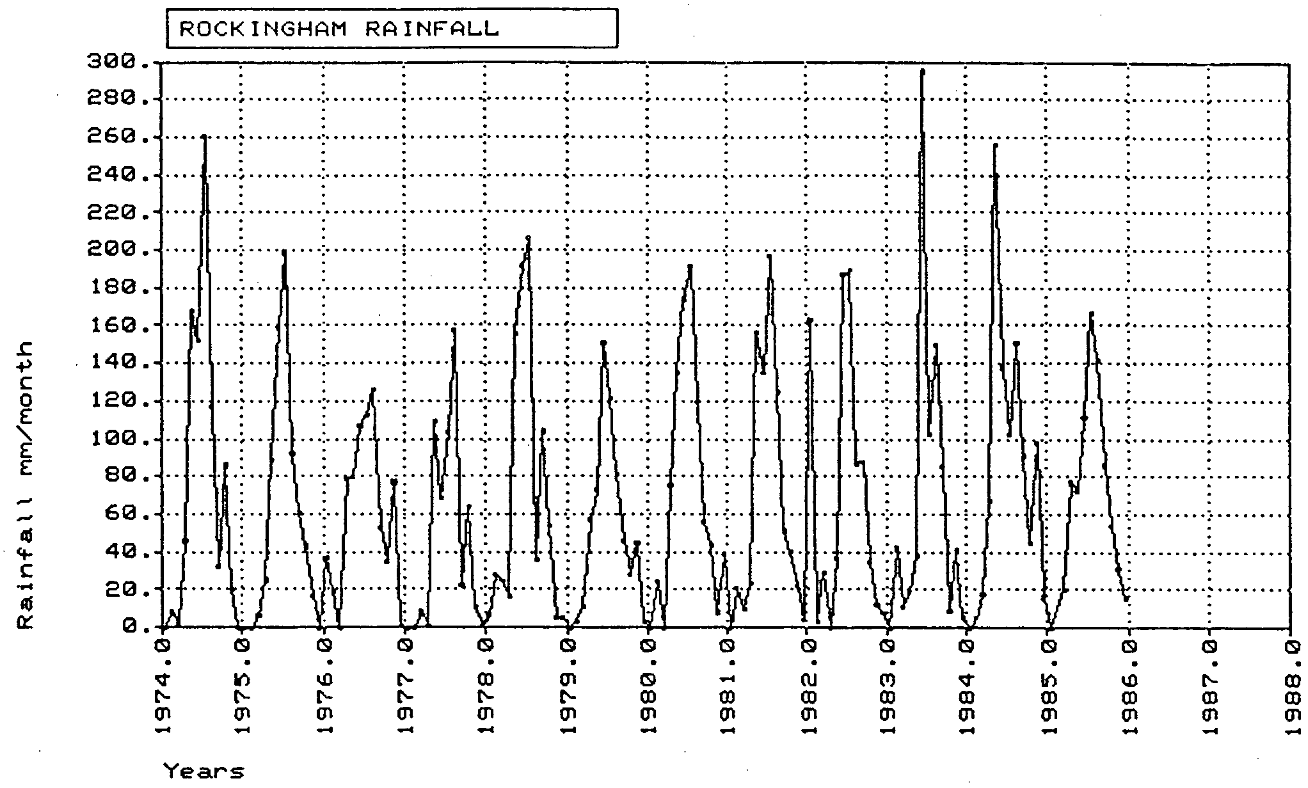
Figure 2



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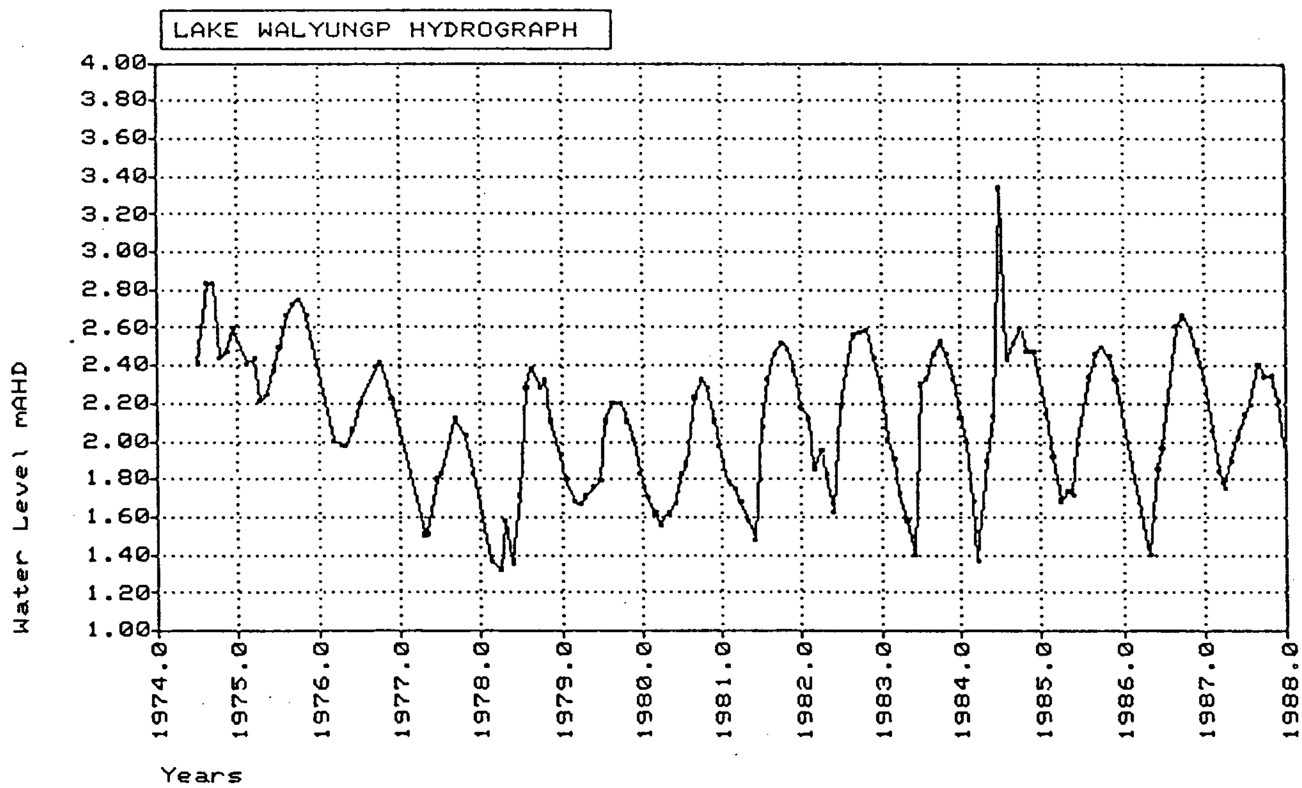

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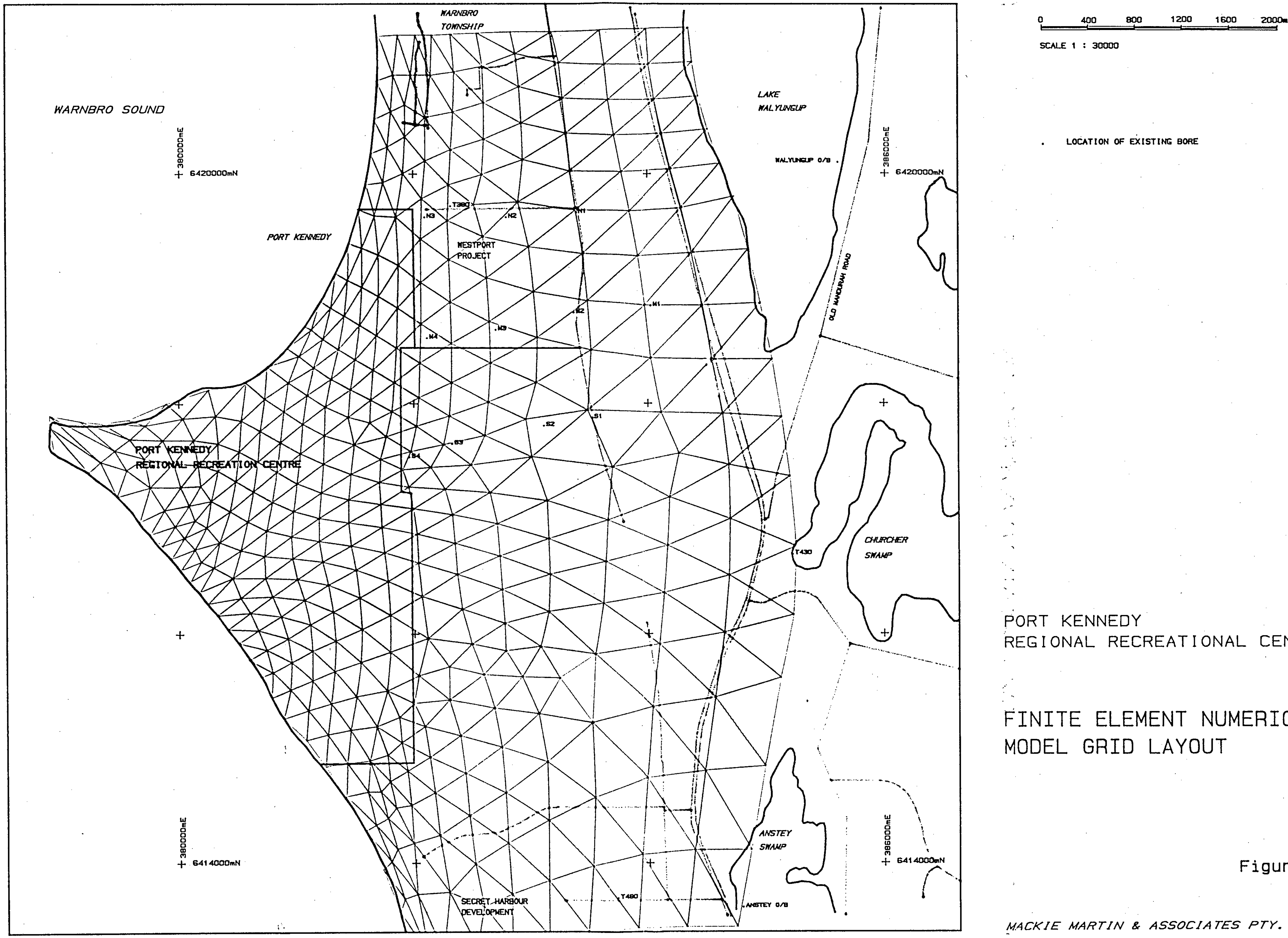
Figure 3

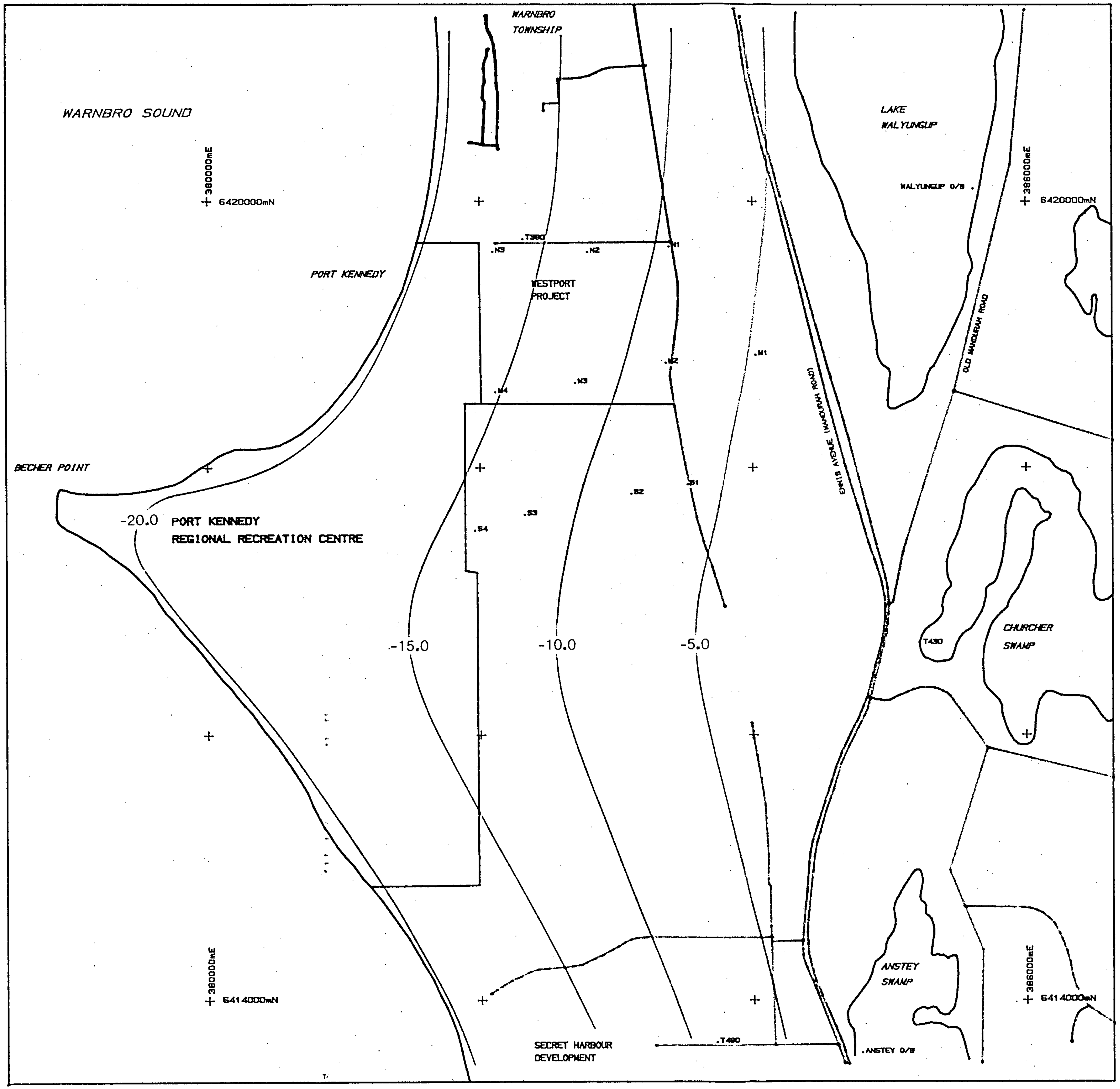


PORT KENNEDY
REGIONAL RECREATIONAL CENTRE

FINITE ELEMENT NUMERICAL
MODEL GRID LAYOUT

Figure 4

MACKIE MARTIN & ASSOCIATES PTY. LTD.



0 400 800 1200 1600 2000m

SCALE 1 : 30000

ALL CONTOURS IN m (AHD)

. LOCATION OF EXISTING BORE

PORT KENNEDY
REGIONAL RECREATIONAL CENTRE

BASE OF SHALLOW PHREATIC SAND AQUIFER

Figure 5

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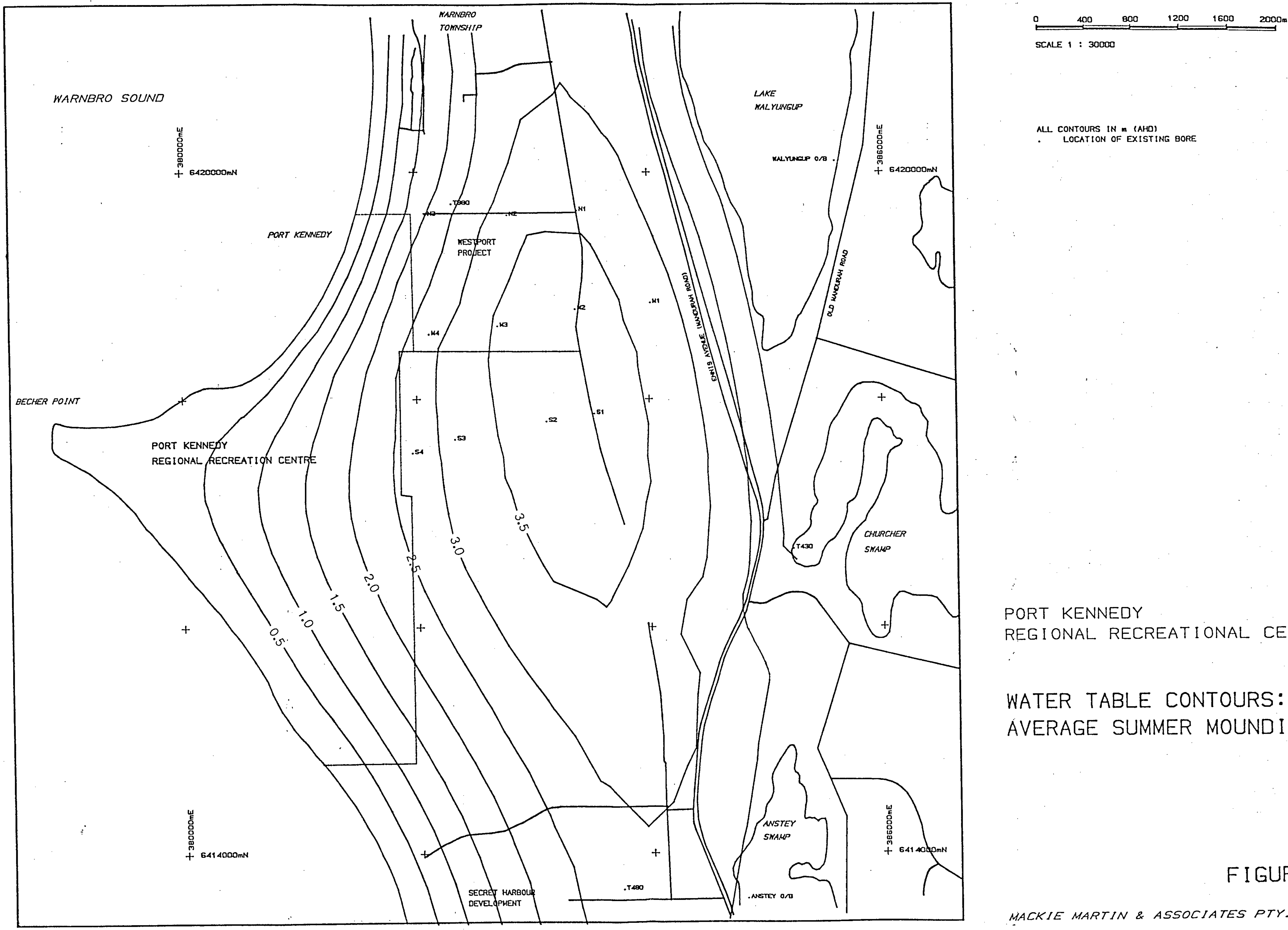

PORT KENNEDY
REGIONAL RECREATIONAL CENTRE

WATER TABLE CONTOURS:
AVERAGE SUMMER MOUNDING

FIGURE 6

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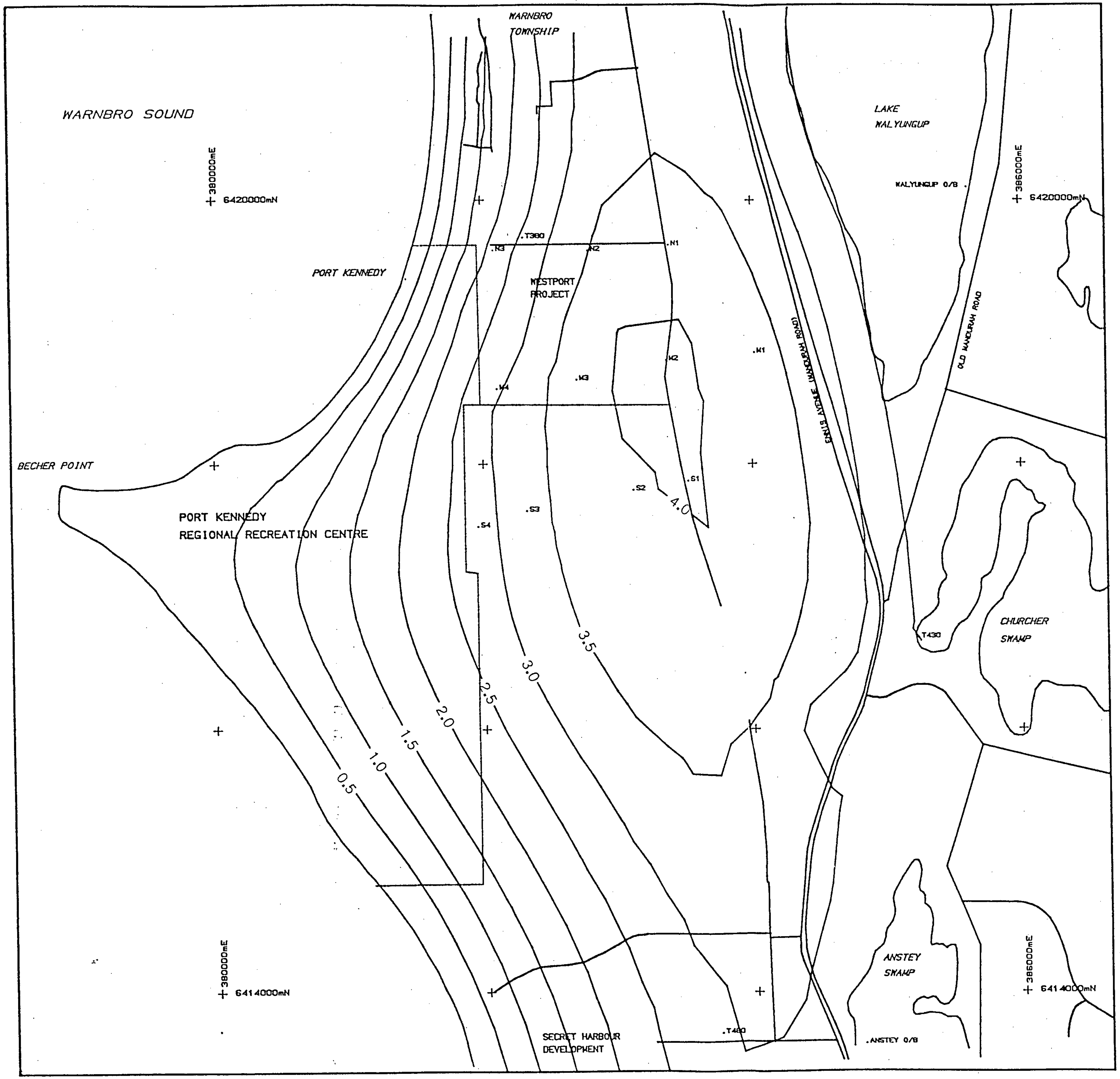
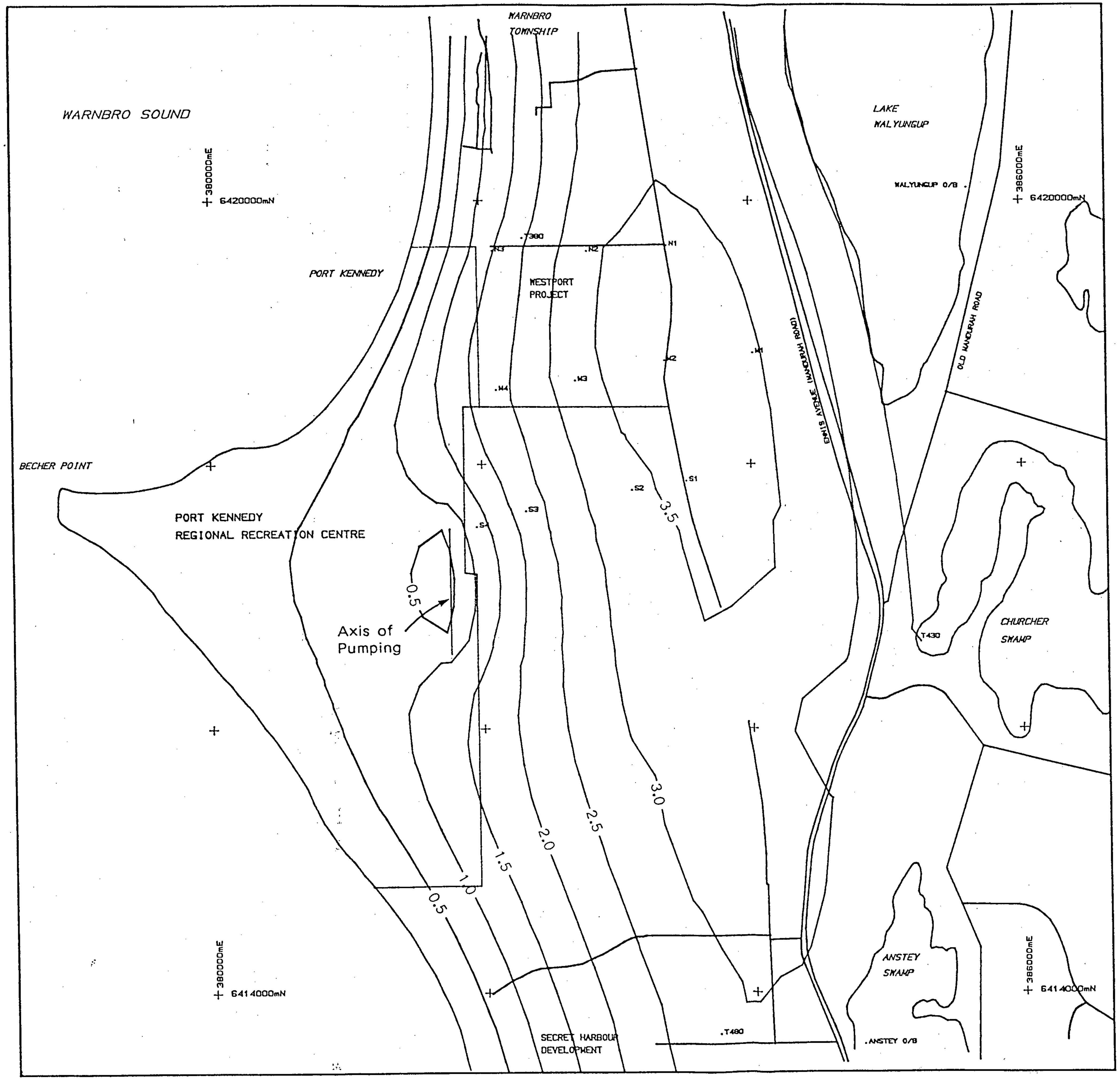


PORT KENNEDY
REGIONAL RECREATIONAL CENTRE

WATER TABLE CONTOURS:
AVERAGE WINTER MOUNDING

FIGURE 7

MACKIE MARTIN & ASSOCIATES PTY. LTD.

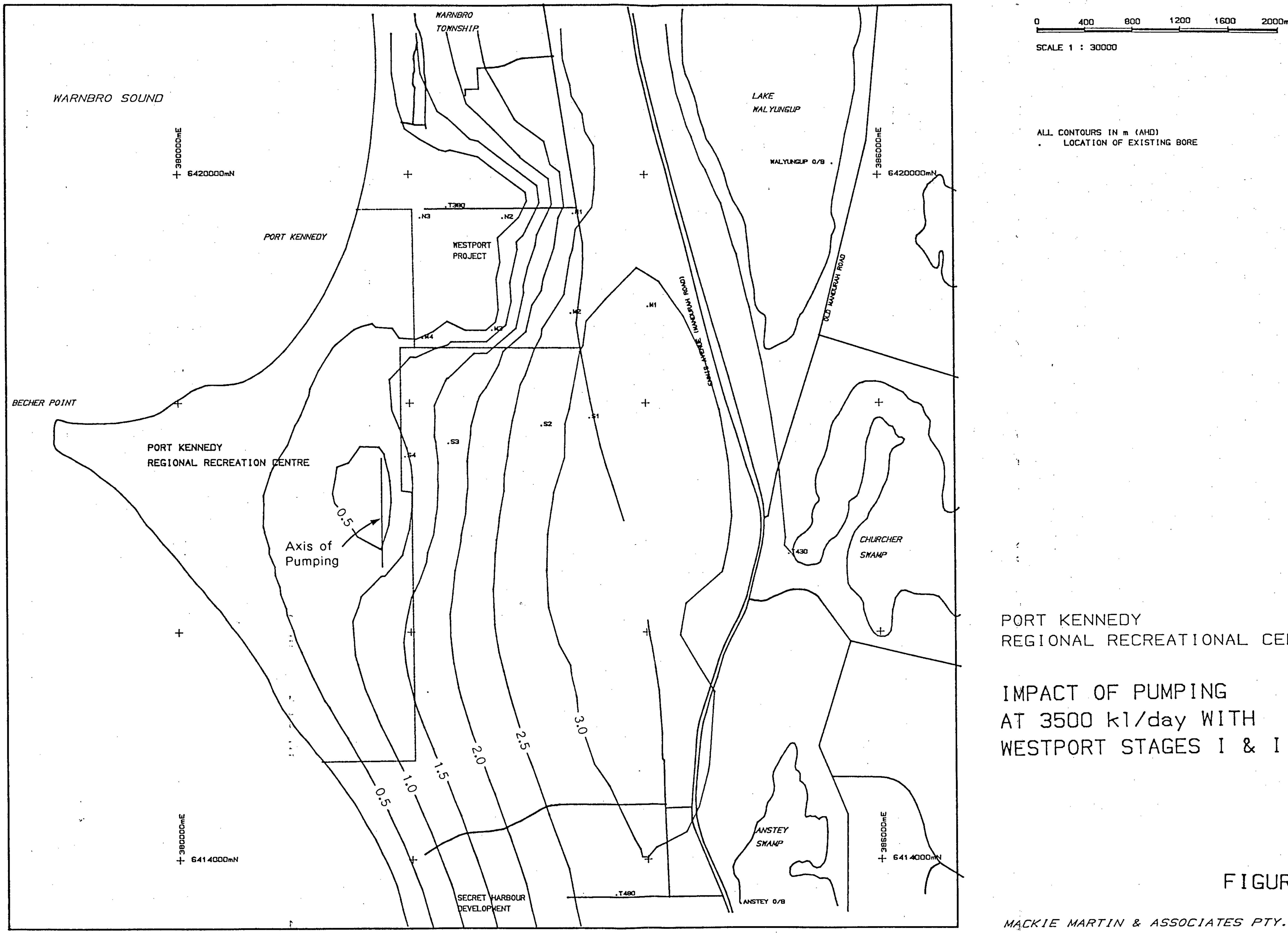


PORT KENNEDY
REGIONAL RECREATIONAL CENTRE

IMPACT OF PUMPING
AT 4000 kl/day

FIGURE 8

MACKIE MARTIN & ASSOCIATES PTY. LTD.



PORT KENNEDY
REGIONAL RECREATIONAL CENTRE

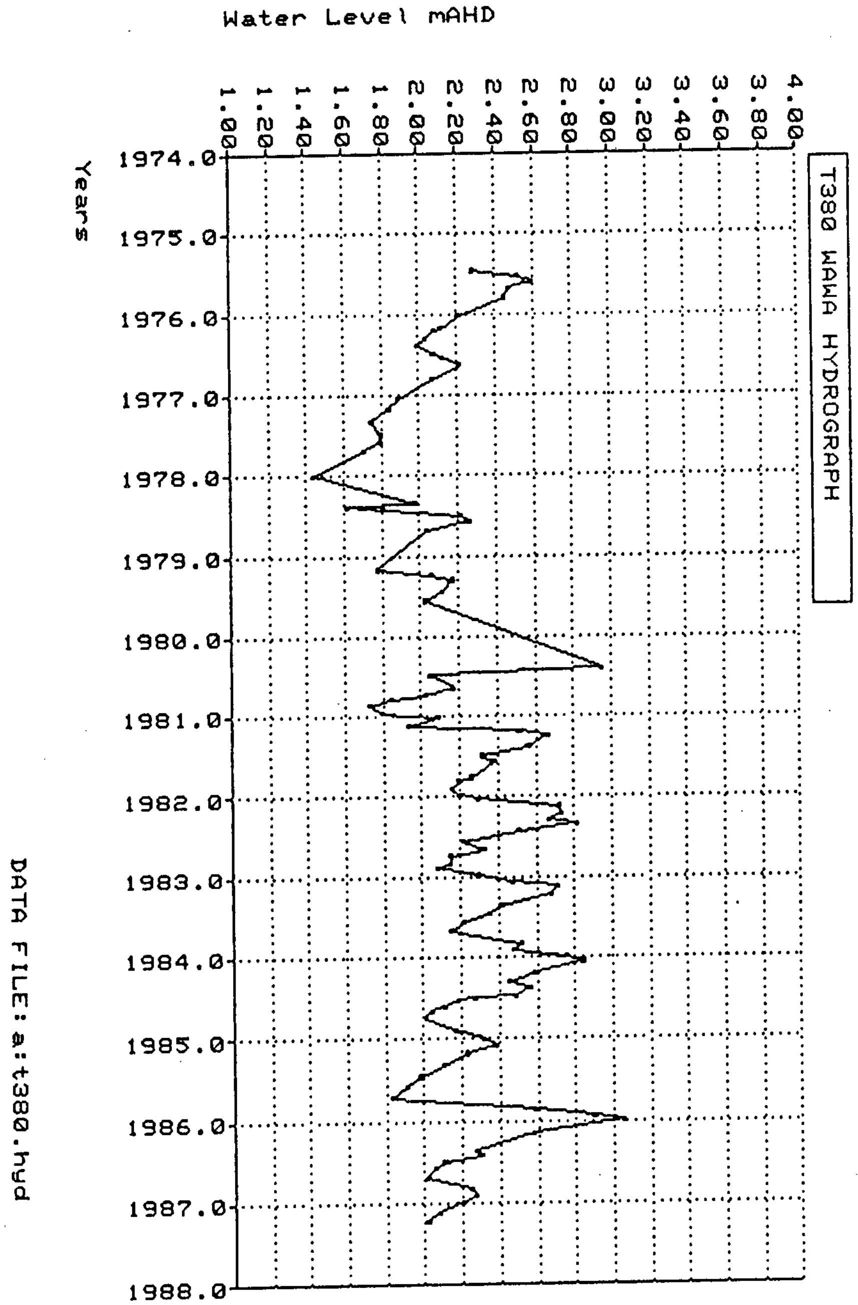
IMPACT OF PUMPING
AT 3500 kl/day WITH
WESTPORT STAGES I & II

FIGURE 9

MACKIE MARTIN & ASSOCIATES PTY. LTD.

APPENDIX 1

Hydrographic Data for the Area



Water Level mAHD
Years
T380 WAWA HYDROGRAPH
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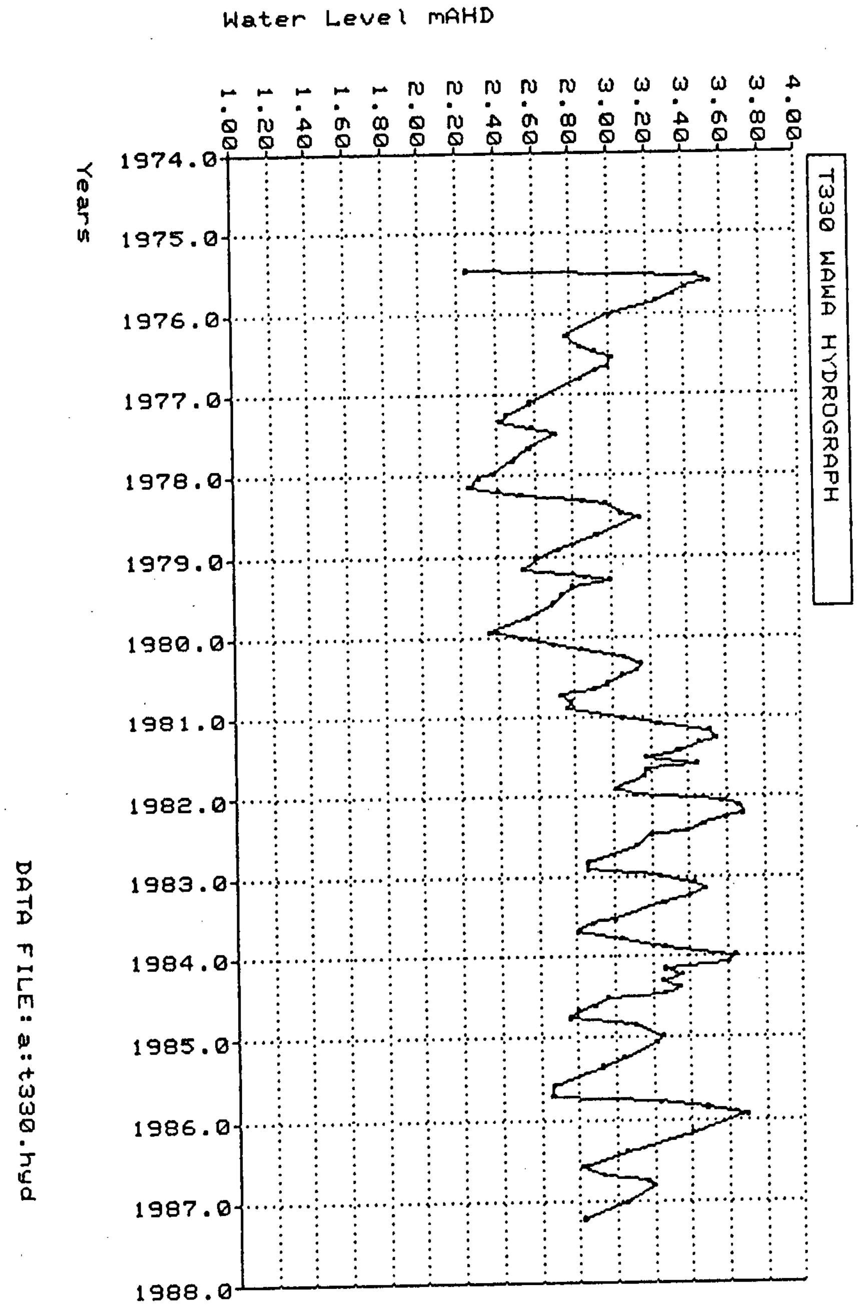

Water Level mAHD
Years
T330 WAWA HYDROGRAPH
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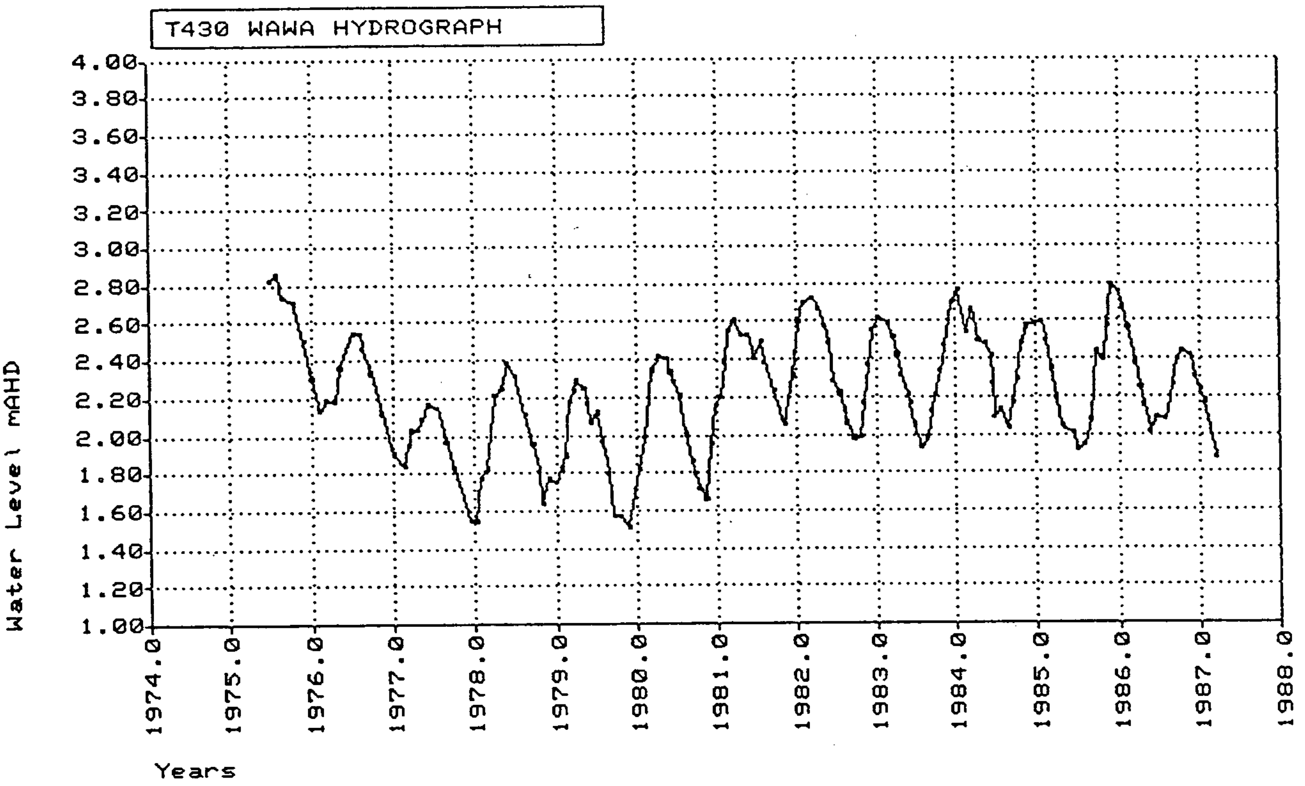

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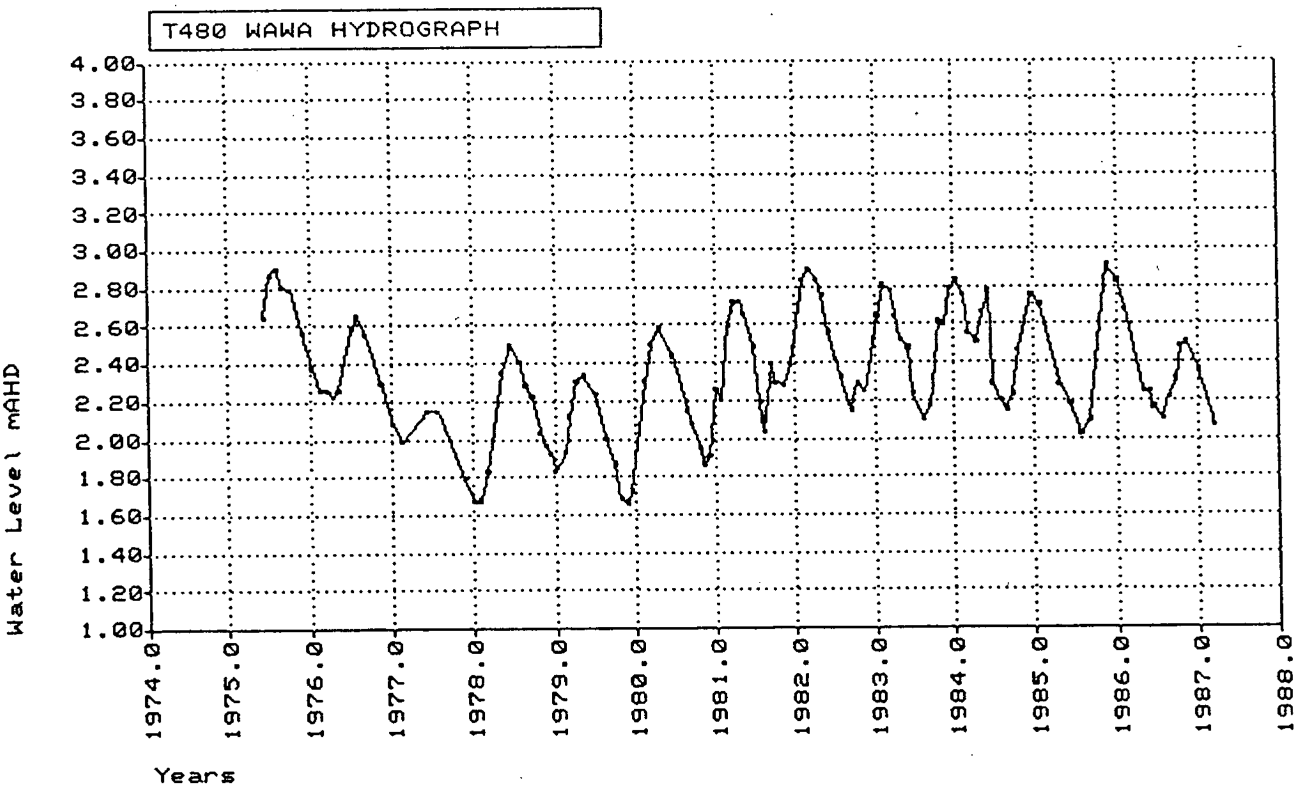

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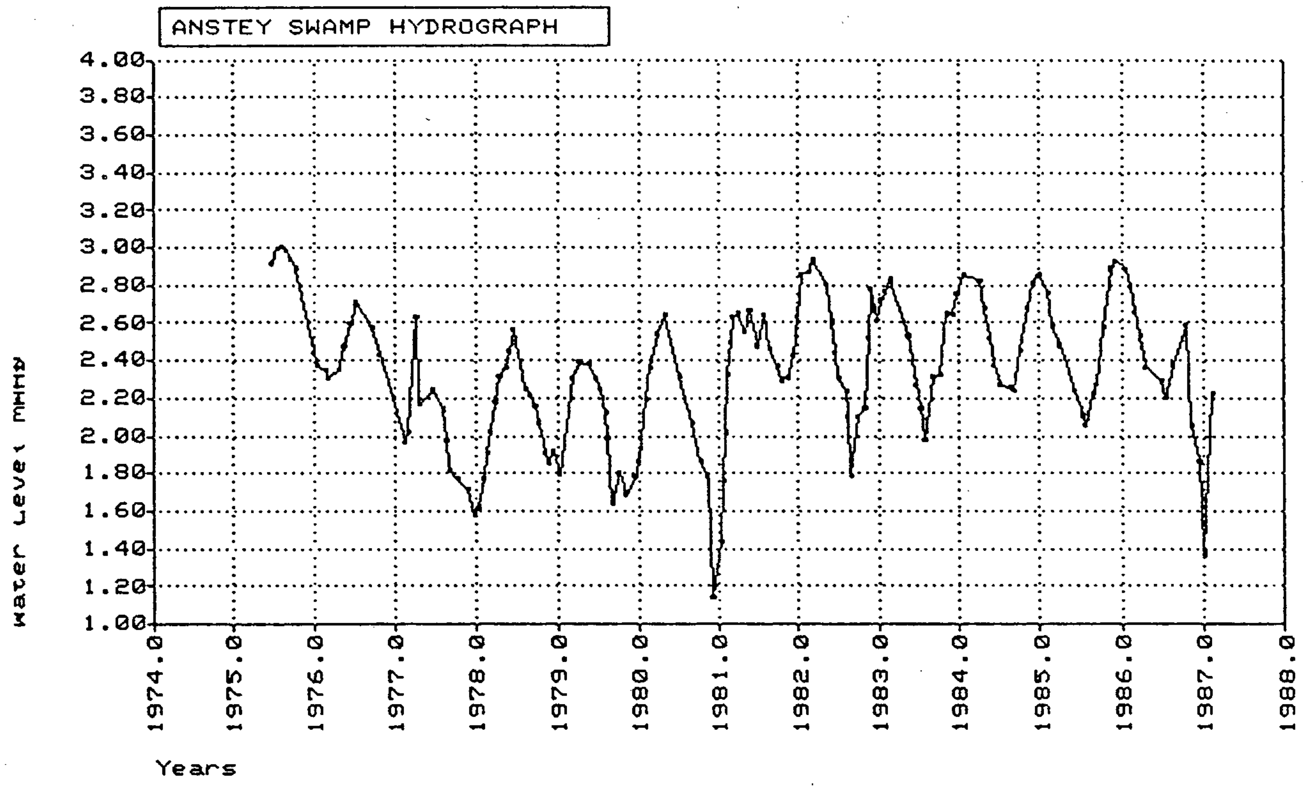

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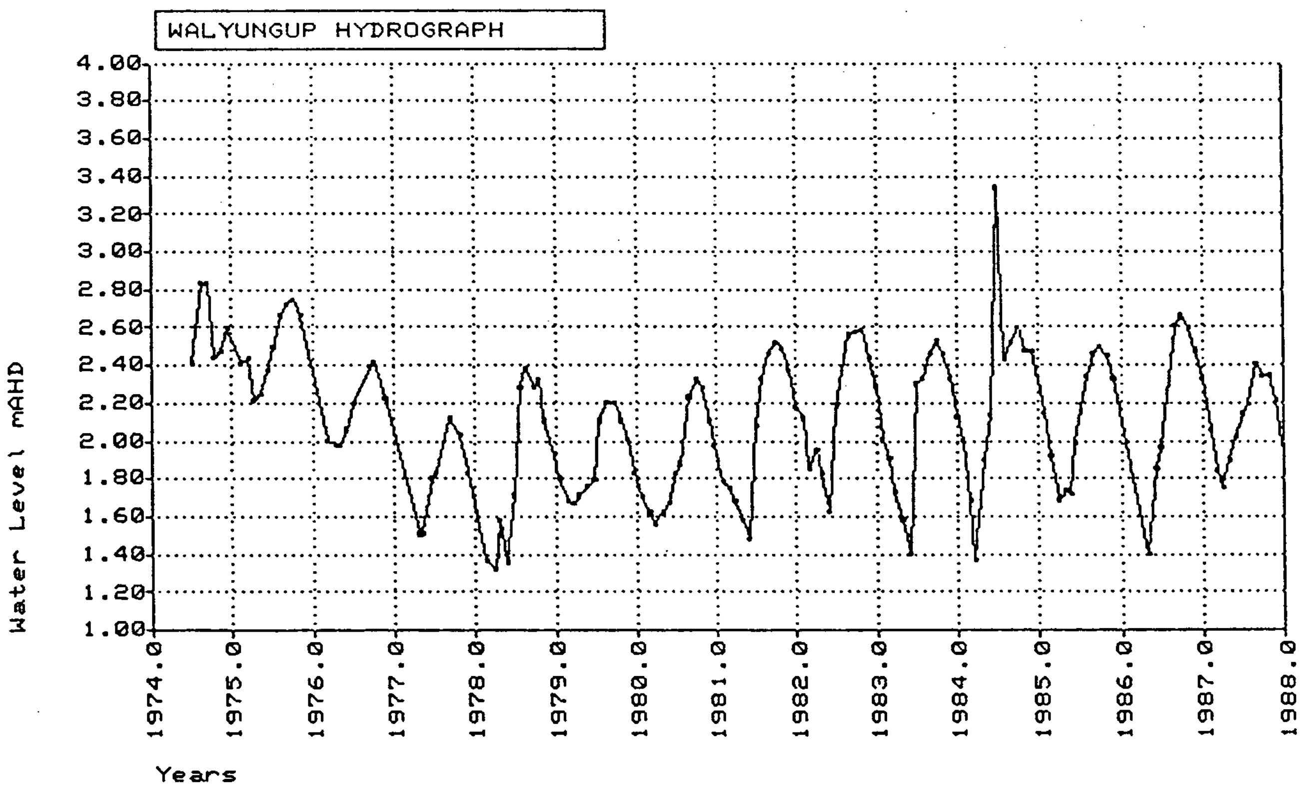

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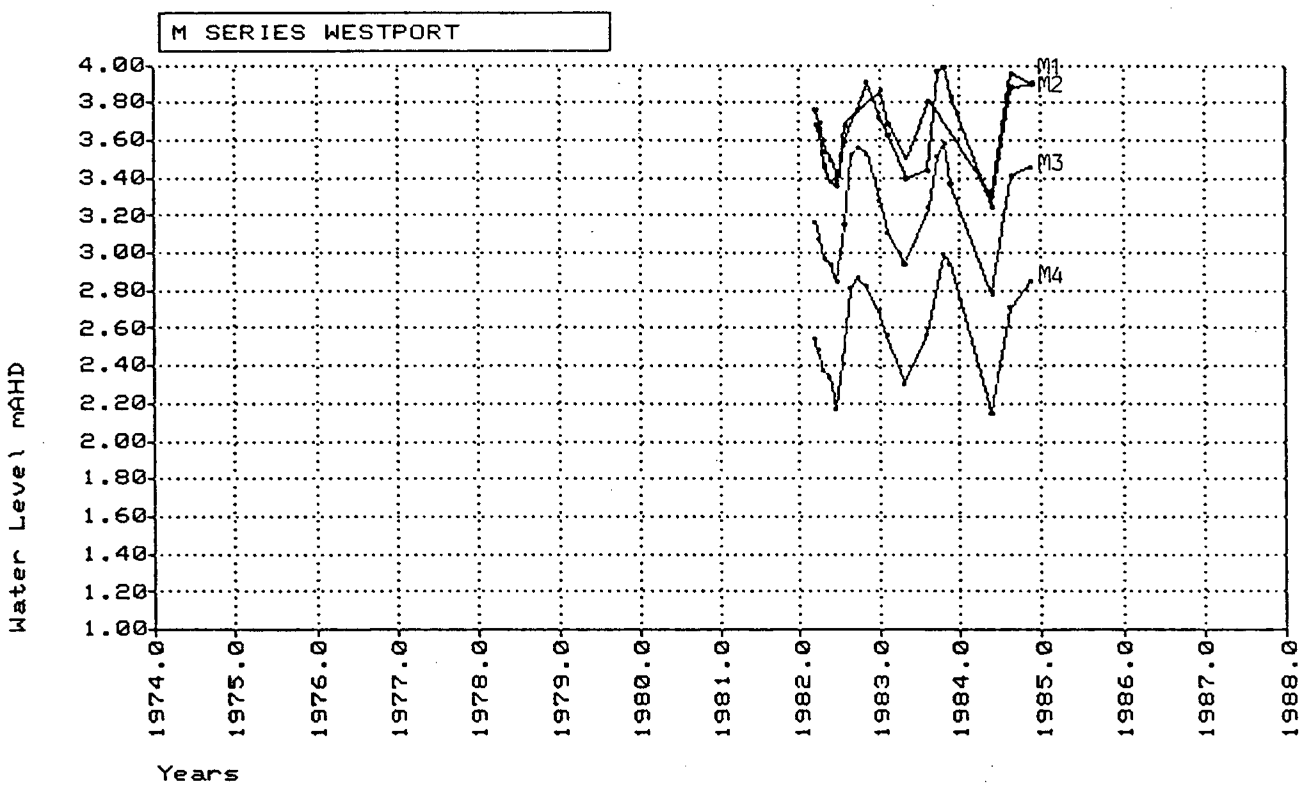

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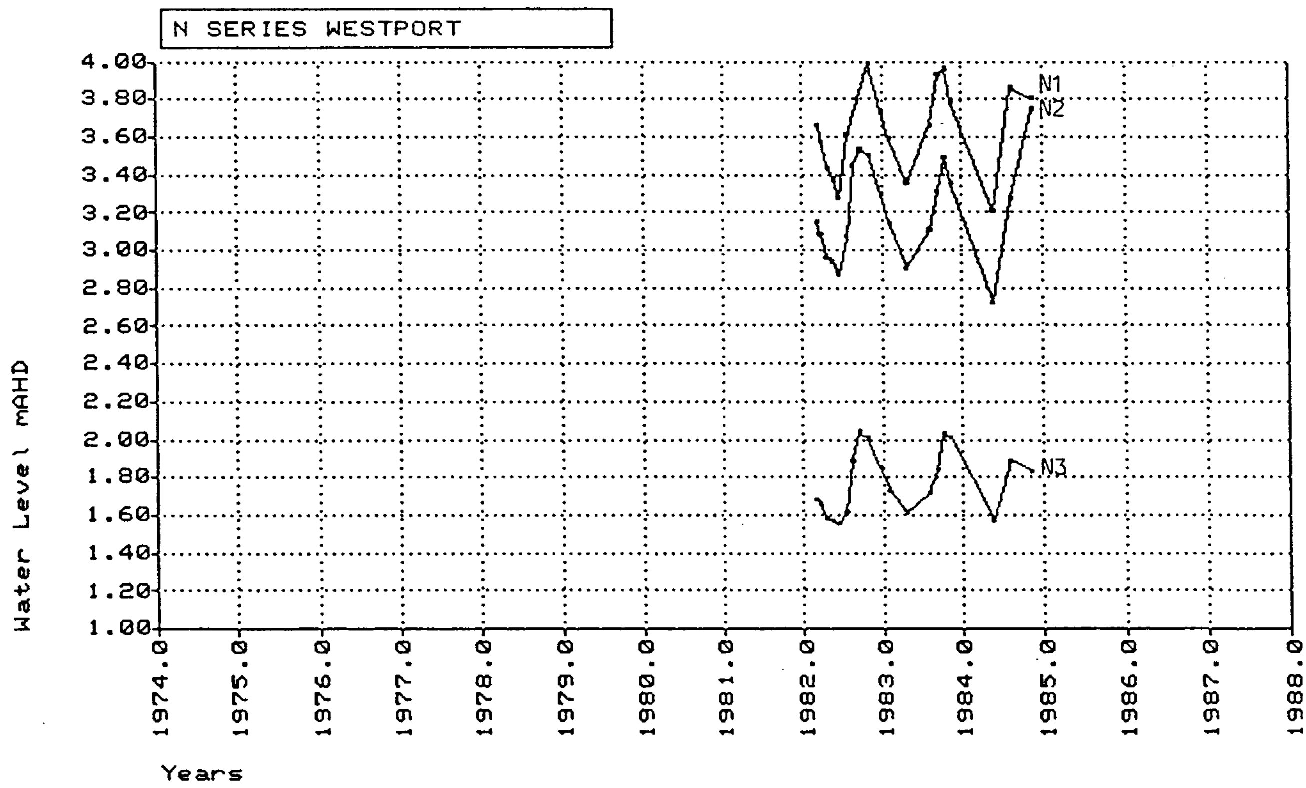

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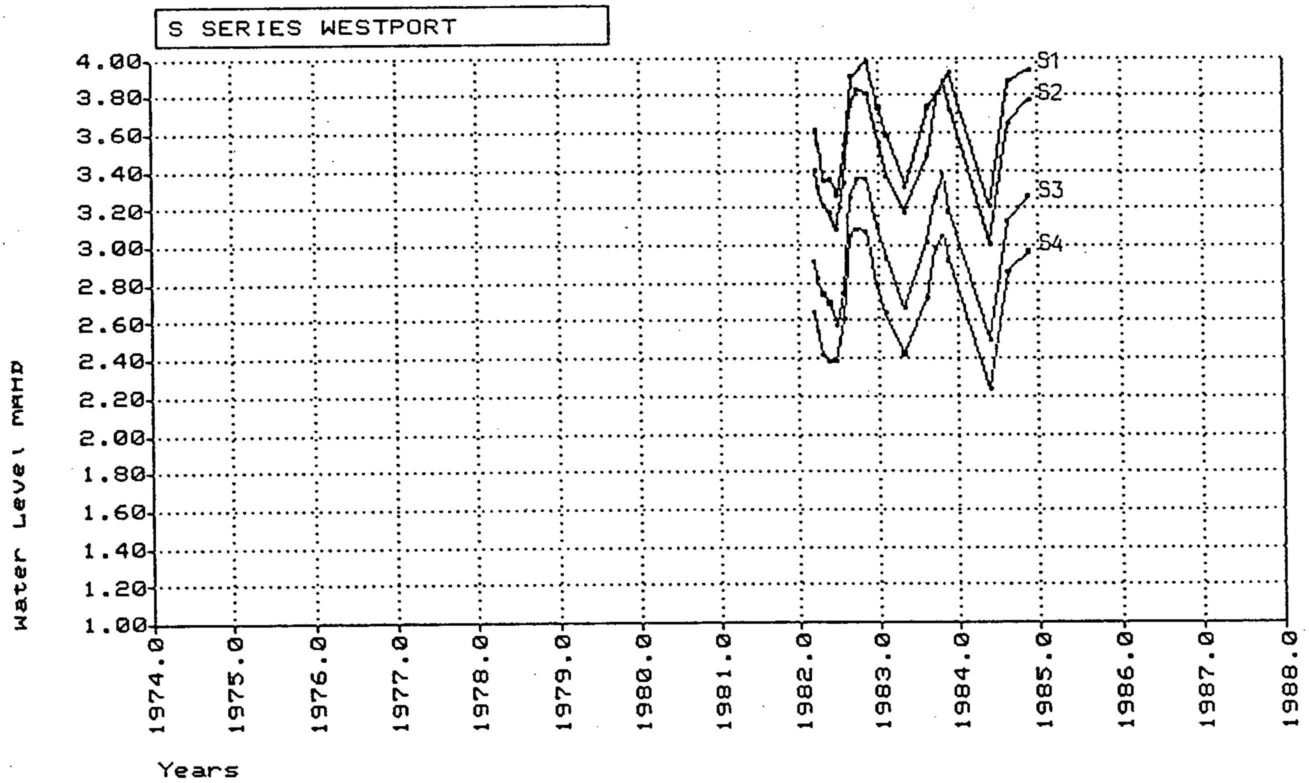

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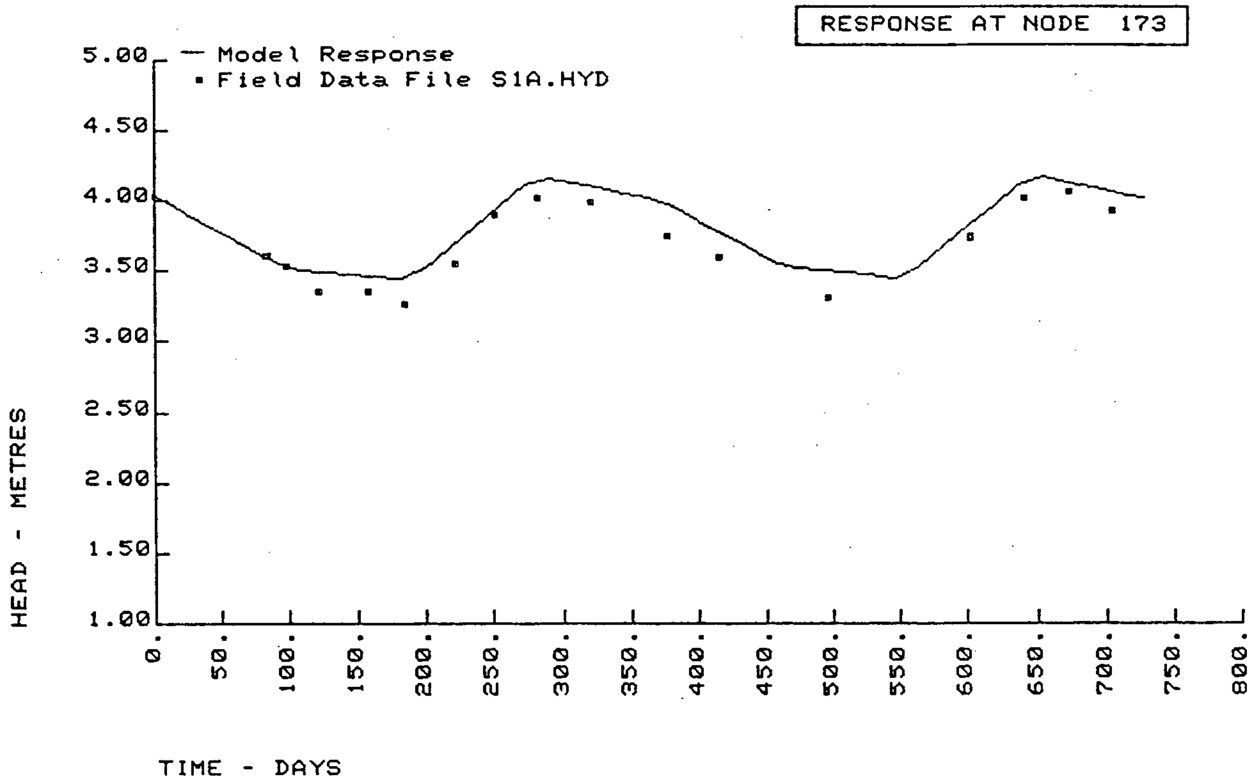
APPENDIX 2

Results of Model Calibration - Westport Hydrographs



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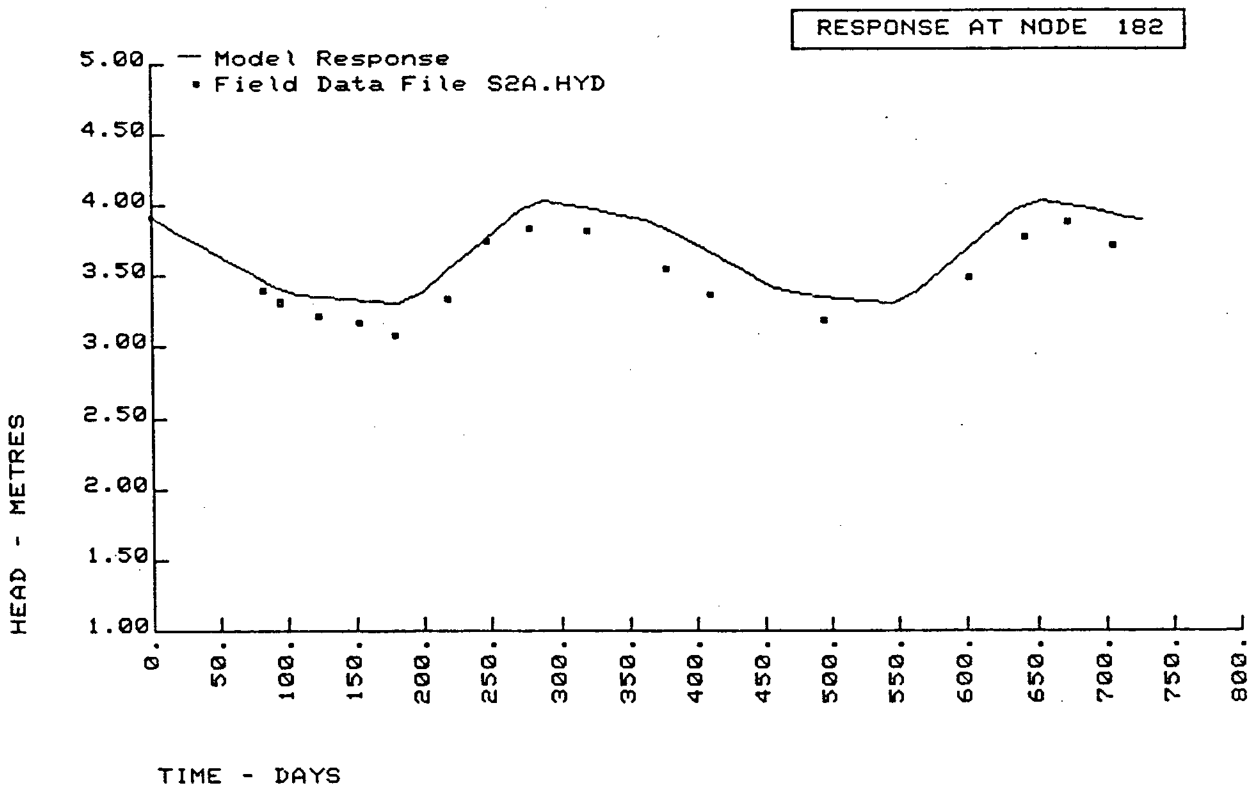

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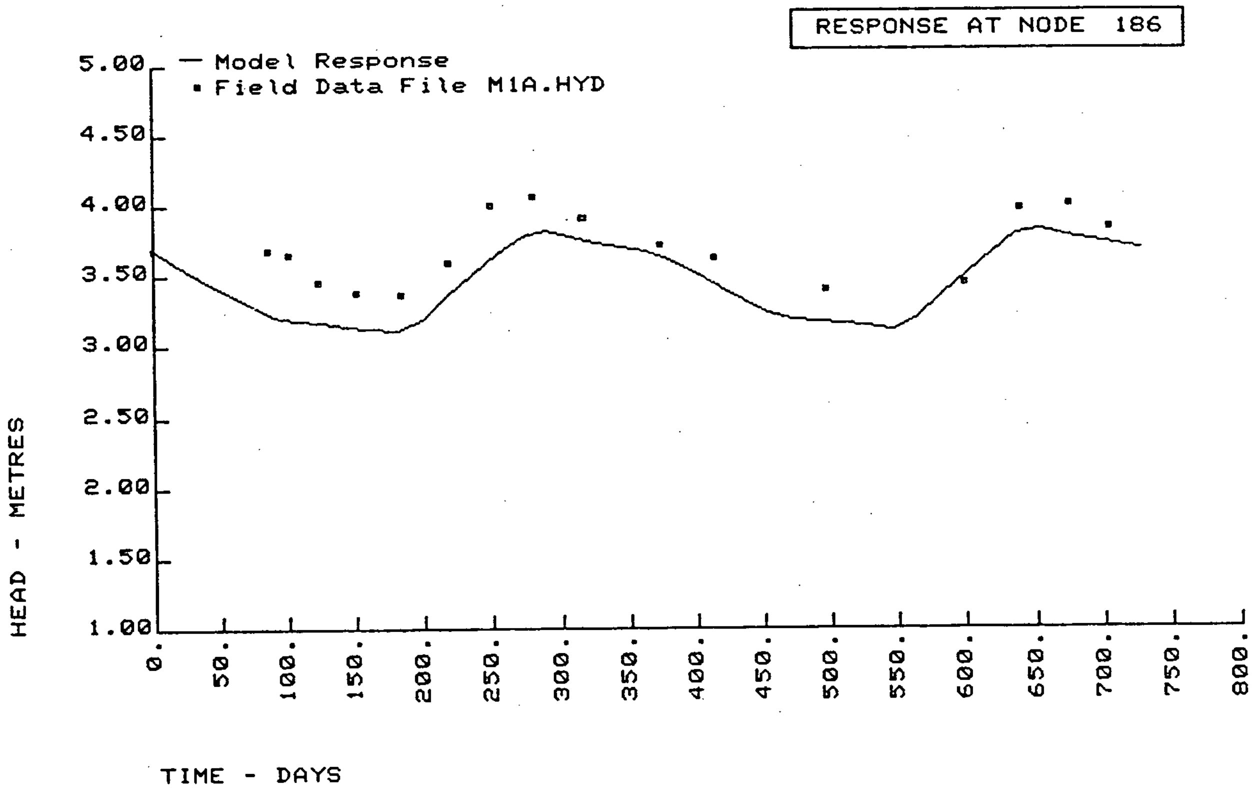
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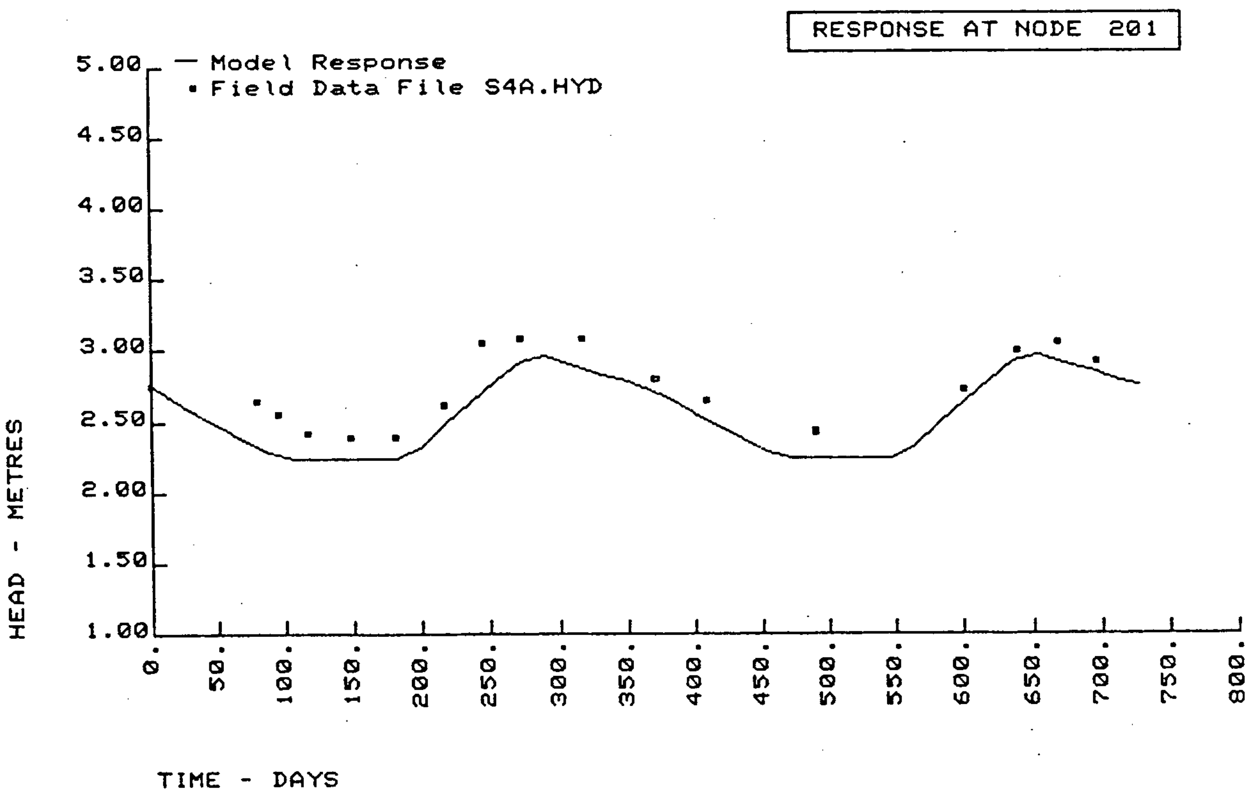
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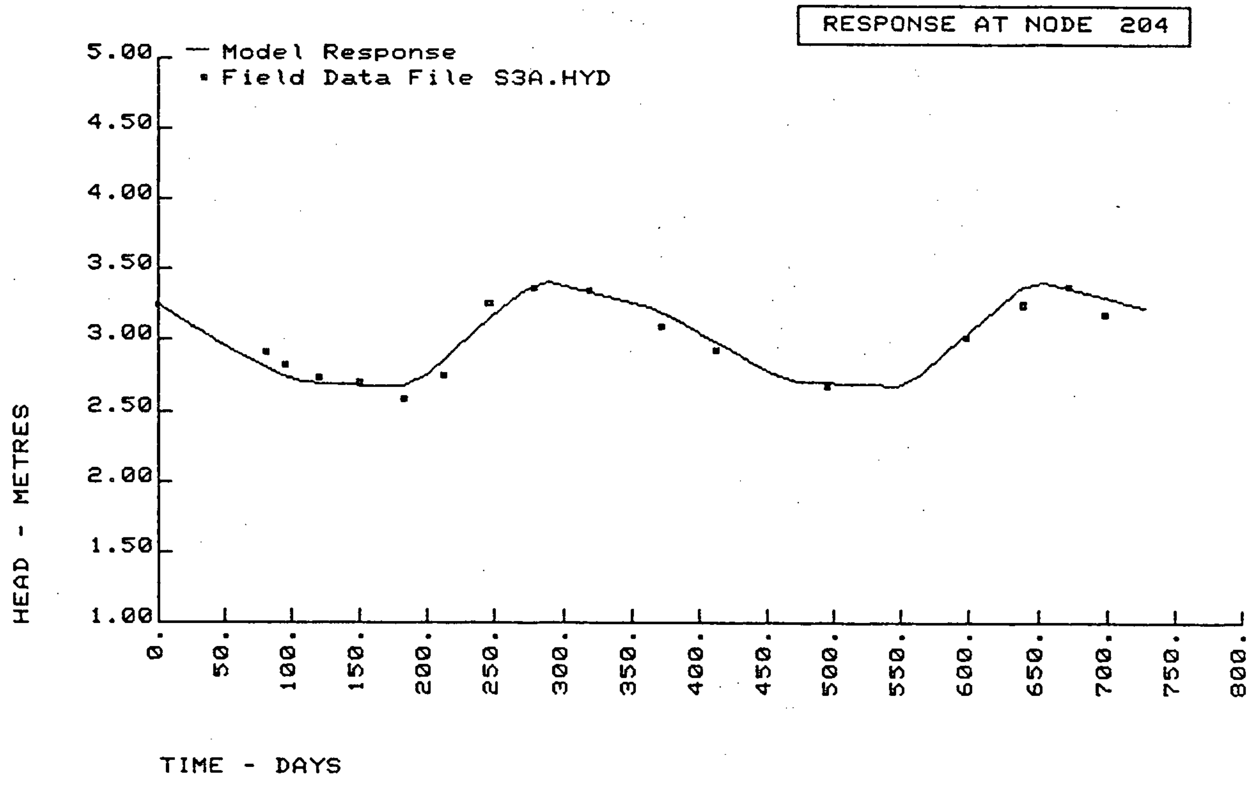

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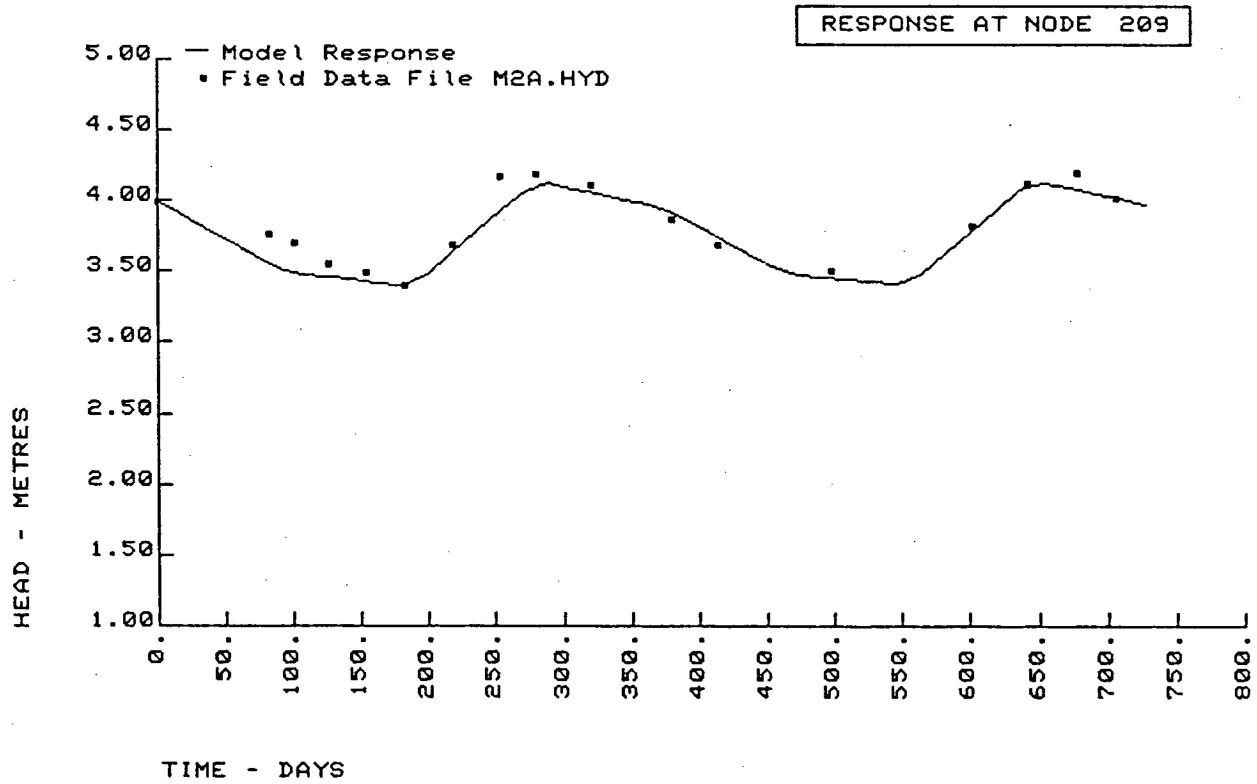

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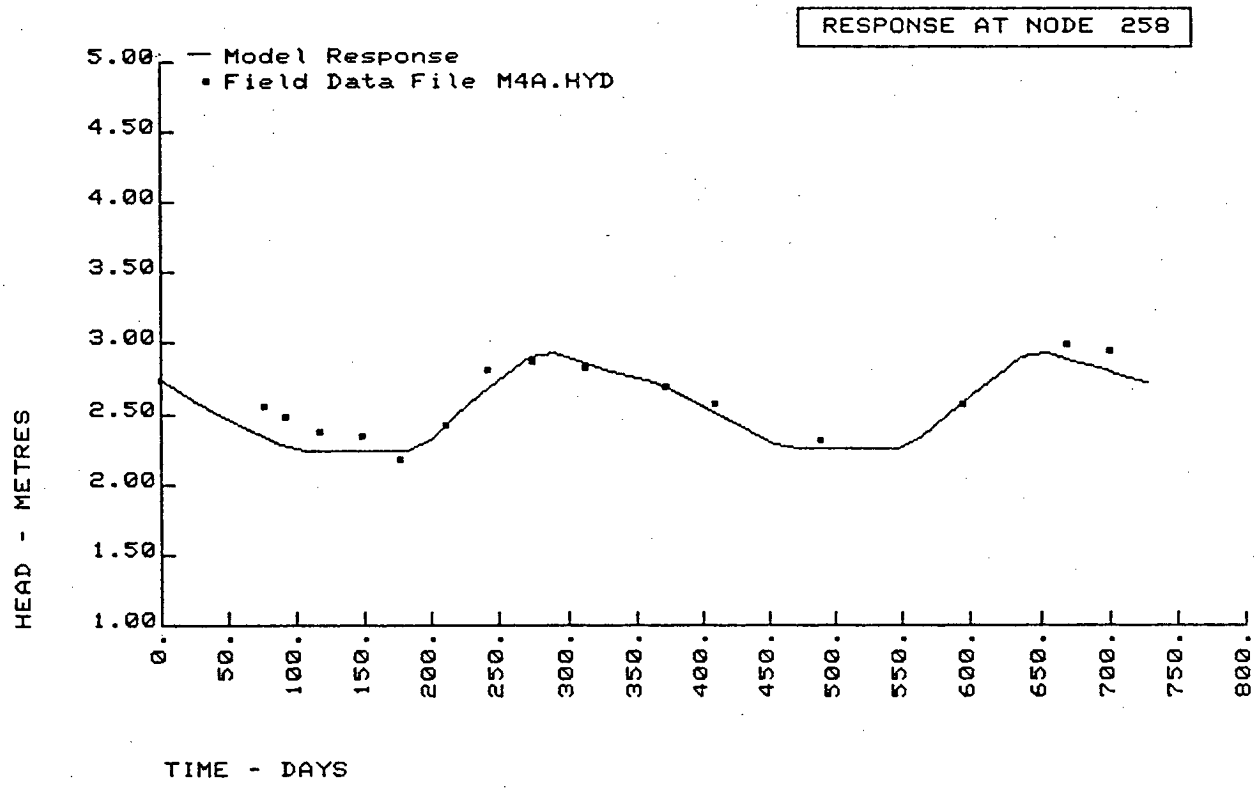
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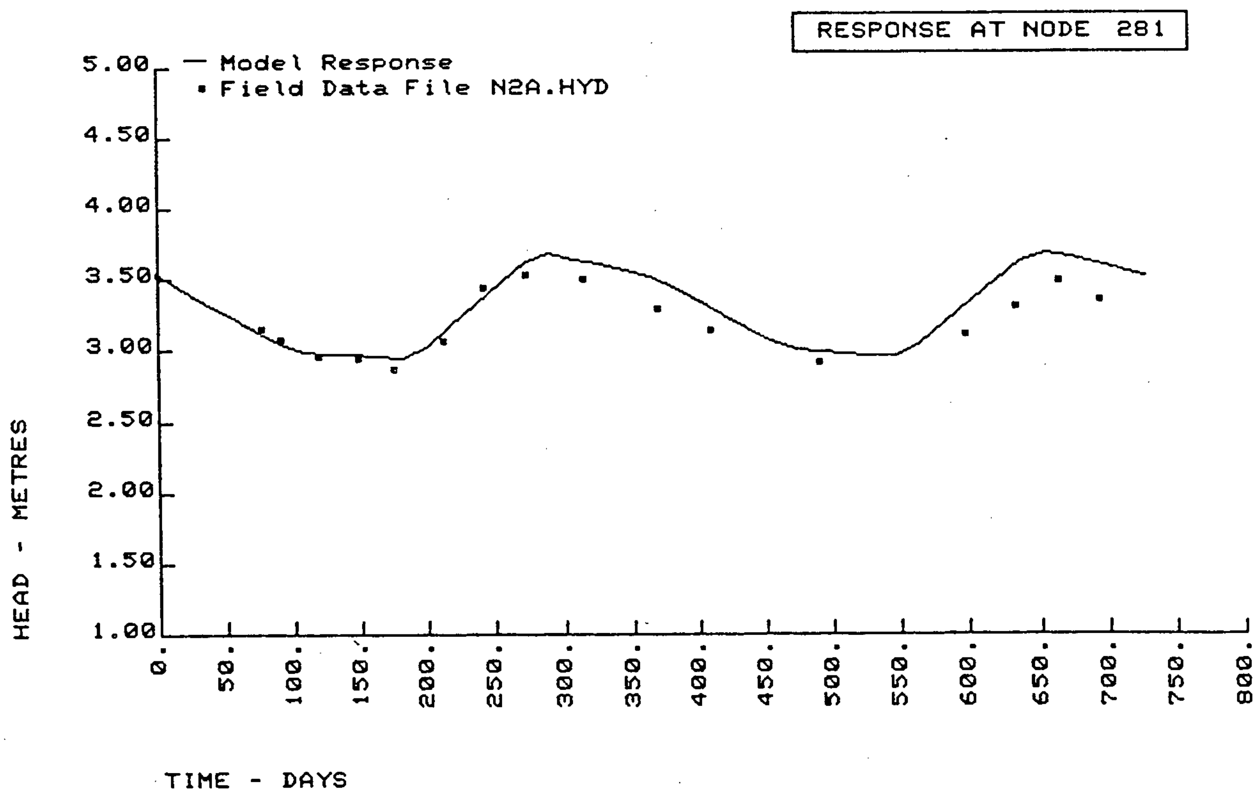
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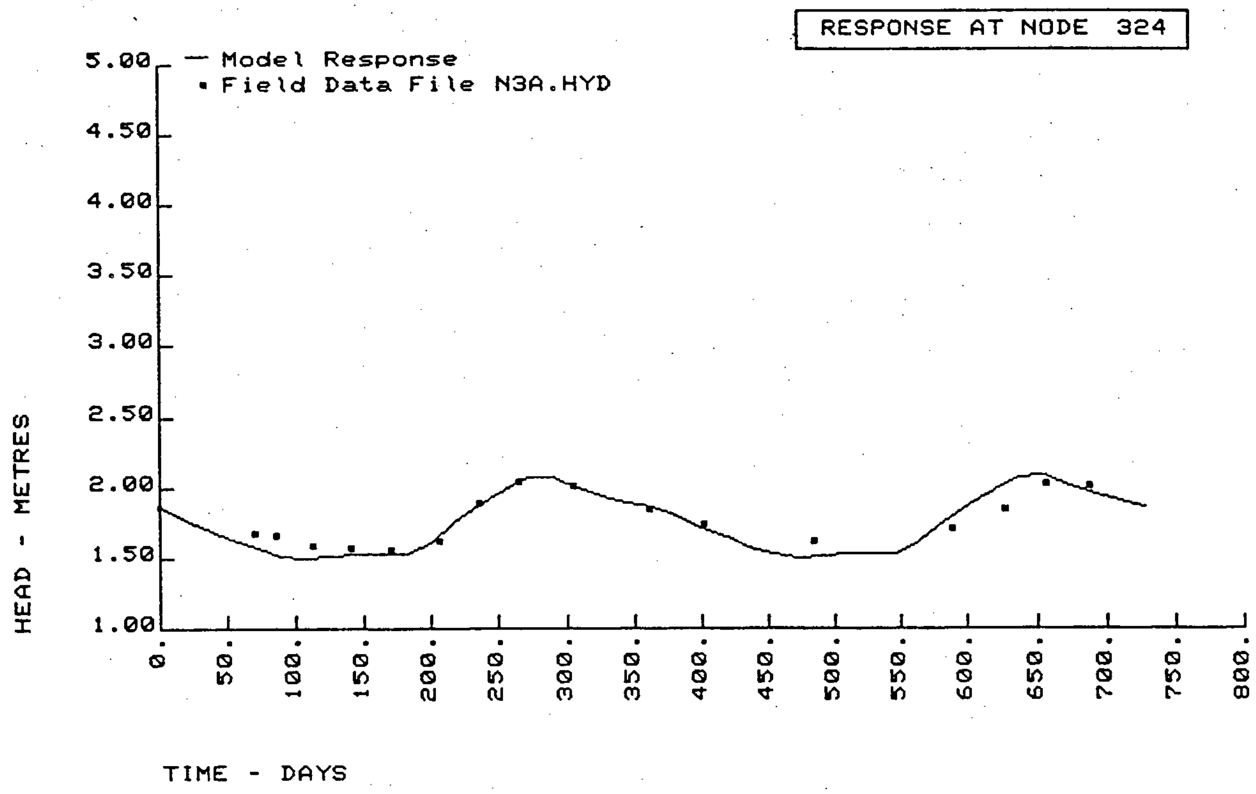

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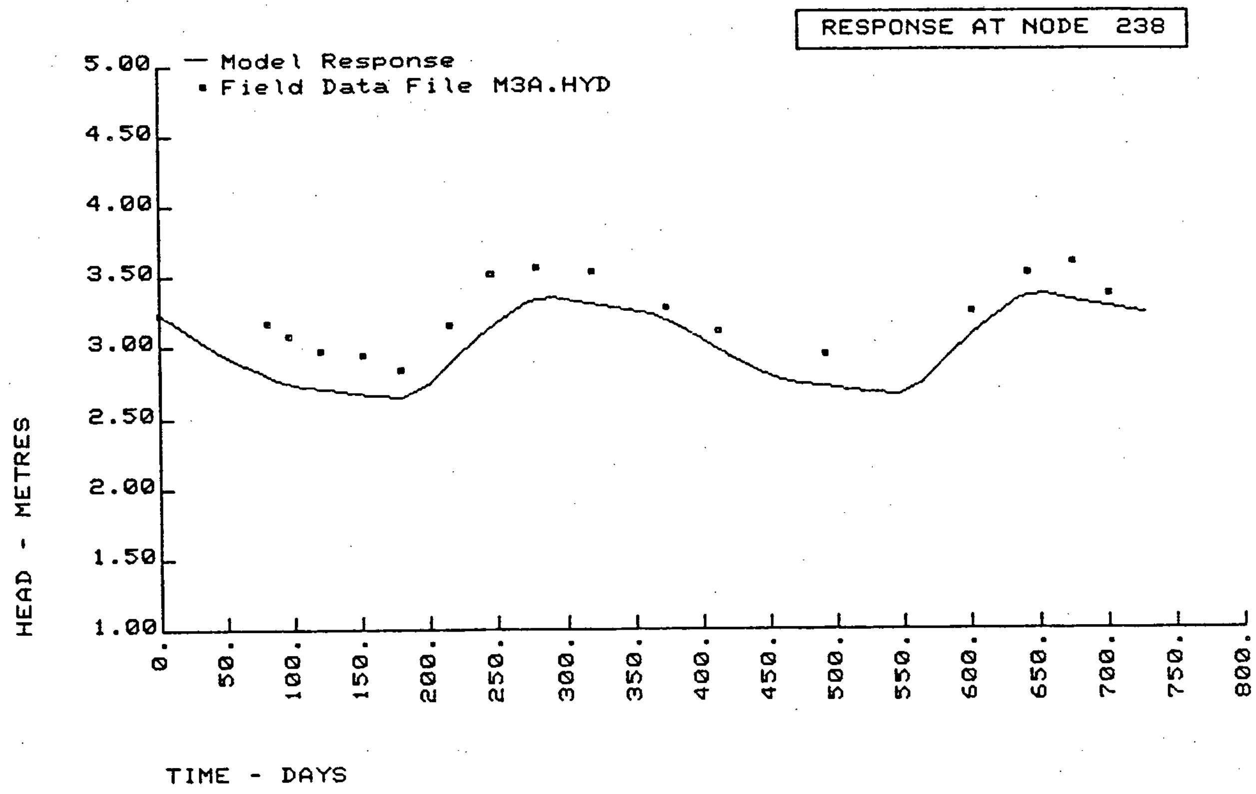
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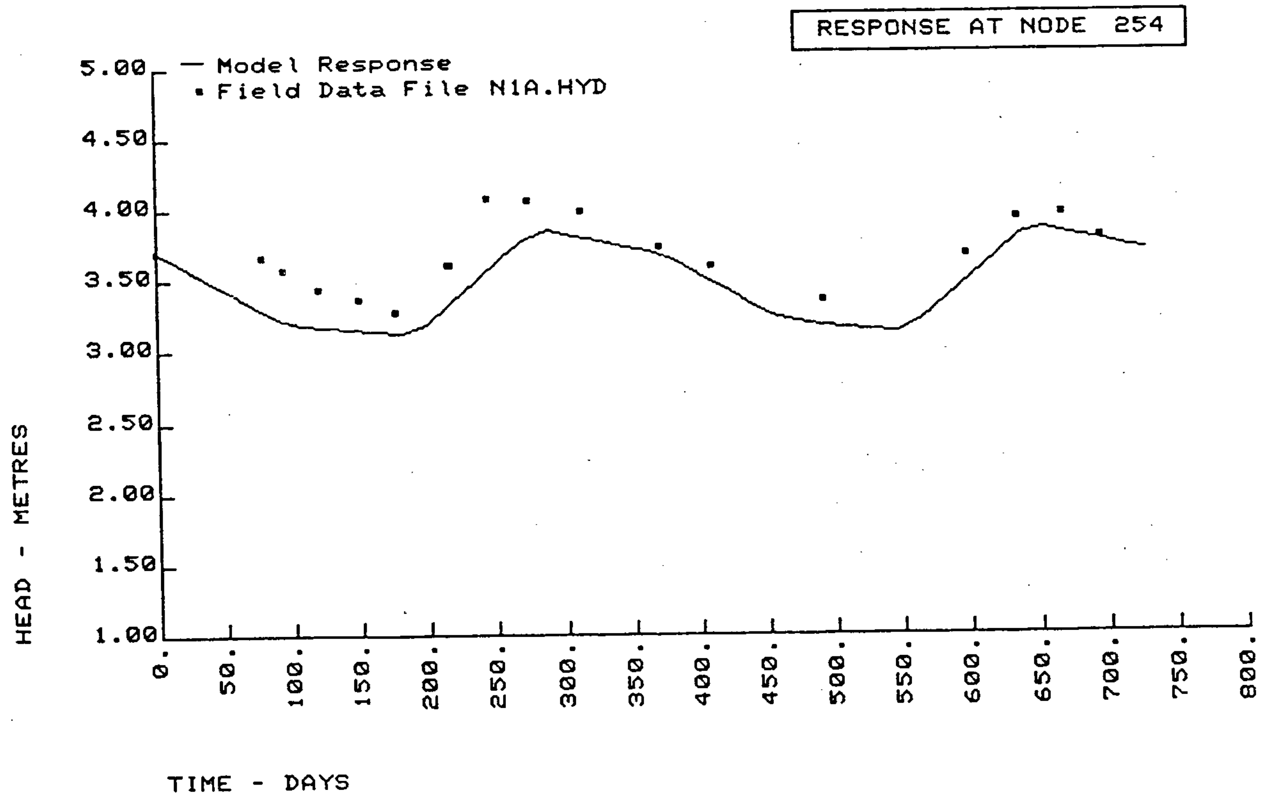
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APPENDIX C: TERRESTRIAL ENVIRONMENTAL INVESTIGATIONS

BOWMAN BISHAW & ASSOCIATES

<u>APPENDIX C</u>
TERRESTRIAL ENVIRONMENTAL INVESTIGATIONS FOR THE PORT KENNEDY REGIONAL RECREATION CENTRE STAGE 1
JULY 1988

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TABLE OF CONTENTS

		Page No.
1.0	INTRODUCTION	C4
2.0	PROJECT DESCRIPTION	C7
3.0	DESCRIPTION OF THE PORT KENNEDY AREA	C8
	3.1 Physical Environment	C8
	3.1.1 Location	C8
	3.1.2 Landform, Geomorphology and Stratigraphy	C8
	(1) Regional Context	C8
	(2) Local Context	C10
	(3) Specific Landform, Topographic and Soil Characteristics of the Project Area	C14
	3.2 Biological Environment	C21
	3.2.1 Regional Perspective	C21
	3.2.2 Vegetation and Flora	C22
	3.2.3 Fauna	C28
	3.2.4 Ecological Processes	C29
	3.3 Land Use	C36
	3.3.1 Regional Development Context	C36
	3.3.2 Present Land Use at Becher Point	C38
4.0	EVALUATION OF CONSERVATION VALUE	C40
	4.1 Effects of Previous Use	C40
	4.2 The Condition of the Vegetation	C43
	4.3 Representation of Landform Flora and Vegetation	C45
	4.4 Conservation Value	C47
5.0	EVALUATION OF ENVIRONMENTAL IMPACT	C51
	5.1 Landform Modification	C51
	5.2 Clearing of Vegetation and Flora	C53
	5.3 Ecological Processes	C54
	5.4 Conservation Value	C60
6.0	ENVIRONMENTAL MANAGEMENT REQUIREMENTS	C62
7.0	CONCLUSIONS	C63
BIBLIOGRAPHY		C67
APPENDIX C(i): A Compilation of Fauna Records for the Project Area		C70

LIST OF FIGURES

		Page No.
Figure 1	Regional Location	C5
Figure 2	Becher/Rockingham Beachridge Plain	C11
Figure 3	Cape Bouvard-Trigg Island Sector	C13
Figure 4	Port Kennedy Geomorphology	C17
Figure 5A	Crossection of the A-B Transect at Port Kennedy	C18
Figure 5B	Crossection of the C-D Transect at Port Kennedy	C18
Figure 6	Port Kennedy Soil Distribution	C19
Figure 7	Vegetation of the Port Kennedy Study Area	C23
Figure 8	Hydrological Cycle	C32
Figure 9	Phosphorus Cycle	C33
Figure 10	Nitrogen Cycle	C33
Figure 11	Existing Land Use and Current Proposals	C37
Figure 12	Port Kennedy - Areas of Physical Disturbance	C42
Figure 13	Condition of the Vegetation at Port Kennedy	C44

1.0 INTRODUCTION

Fleuris Pty Ltd and the Western Australian Development Corporation propose to establish a regional recreational centre at Pt Kennedy within a parcel of vacant Crown land that lies on the coast south of Rockingham.

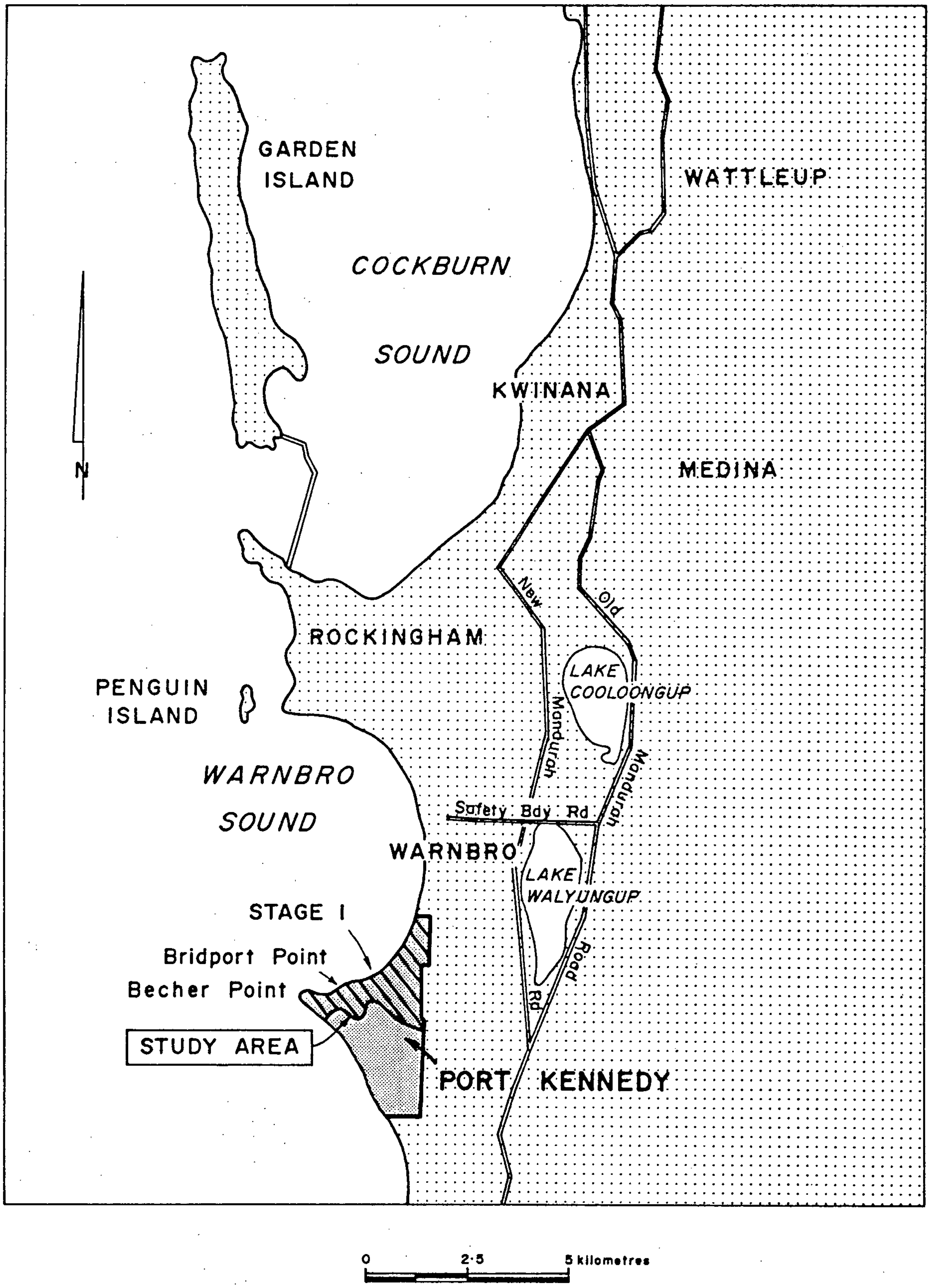
The development will be implemented in several stages. This document examines the terrestrial environmental implications of Stage 1, which will occupy the northern sector of the land and will include a 36 hole golf course, a marina, an international hotel and support facilities.

Whilst Stage 1 of the proposal will affect only a portion of the entire landholding, investigations of the existing environment have considered the whole site in equal detail. Thus, reference in the ensuing descriptive text to "the study area" includes all land within the Port Kennedy area boundary, whilst "Stage 1 areas" comprise only the northern portion as indicated on Fig 1.

The study area currently consists of naturally vegetated coastal dune terrain. Whilst the establishment of a squatters' settlement, extensive offroad vehicle use, rubbish disposal and fire have significantly modified the natural environment, the previous characteristics of the land have mostly survived, due largely to the persistence of the native vegetation.

Therefore, evaluation of the environmental implications of development has necessarily been based on information gathered by detailed review of the study area. This has included extensive site examinations, review of aerial photographic records and consideration of existing scientific literature describing the physical and biological characteristics of the study area.

Whilst the recreational potential of the study area has been accepted for some time, the conservation potential has recently also been recognized. A State Government review of conservation requirements and potential within System Six (DCE, 1983) included a specific recommendation that land at Port Kennedy



REGIONAL LOCATION – FIG 1

should be utilized for conservation within the context of a Regional Park (Recommendation M106 DCE 1983). This recommendation has therefore been a major consideration in determining the environmental acceptability of the proposal.

The findings of investigation are described following a review of the physical, biological and ecological characteristics of the site, its regional and local conservation value and the environmental effects that will result from the proposed development.

2.0 PROJECT DESCRIPTION

Assessment of environmental impact was conducted on the basis that development of the site would entail construction and operation of the facilities listed below. The layout of the proposed development is shown in the first volume of the ERMP.

(i) Two eighteen hole golf course to be located within the northern and central regions of the study area.

(ii) A marina and associated holiday accommodation and facilities at Bridport Point.

(iii) An international hotel and support facilities to be located behind the primary dune adjacent to the golf course.

(iv) A groundwater abstraction facility which would provide irrigation water from the superficial aquifer in the central inland parts of the study area.

3.0 DESCRIPTION OF THE PORT KENNEDY AREA

3.1 Physical Environment

3.1.1 Location

The project site is located at Port Kennedy, on the south-west coast of Western Australia within undeveloped land adjacent to the southern region of Warnbro Sound. (Fig. 1.)

The closest urban centres are at Rockingham, 8 km to the north, and Mandurah some 21 km to the south. The nearest urban development is located to the north and north-east at Warnbro, where suburban residential development lies within 750 m of the project area boundary. There is also a current proposal to develop vacant land to the immediate north and east of the project area to create a canal based residential area that is linked to Warnbro Sound by a channel through the coastal dunes.

Land further to the east comprises farming and agricultural land and also contains a large wetland area that has been nominated as a suitable Regional Park, (DCE 1983). Along the south coast, land is largely uncleared but contains pockets of holiday/residential housing development that are continuing to expand in area. A planned major canal based residential development at Singleton, known as the Secret Harbour Project, is understood to be "on hold" at the present time.

3.1.2 Landforms, Geomorphology and Stratigraphy

(1) Regional Context

The project site is located within coastal sand dune terrain which is recognized as the Quindalup Dune System of McArthur and Bettenay, (1960). This landform type is widespread along the seaward fringe of the Swan Coastal Plain and typically consists of parabolic dunes, beach ridges and complex mixed dune terrain formed from unconsolidated, sandy calcareous skeletal sediments that were deposited on shore during the Holocene.

The Quindalup Dunes are often confined in their occurrence to a narrow band parallel to the coast, frequently less than 1 km wide. However, there are a number of locations along the central south-western coast, of which the project area is one, where substantial localized accumulation of Holocene sediments has occurred. At these locations accretionary progradation of the coastline during the Holocene has created a broad plain of low, parallel dunes formed by the consecutive deposition of foredunes and primary dunes along previous shoreline positions. The shape and topographic form of the prograding shoreline and hinterland is quite consistent between sites along the south-west coast where major Holocene sediment accumulation has occurred. The typical coastal landform consists of a triangular subaerial promontory which culminates westwards in a cusp that is fringed by contemporary beach ridges, linear primary dunes and parabolic dune sequences. The hinterland consists of a plain of consecutive parallel or curvilinear, relict foredunes.

Searle (1984), and Searle and Semeniuk (1985) proposed a coastal development model for the Cape Bouvard to Trigg Island coastal region, of which the project site is a component, wherein the landforms and accretionary patterns evident on the coastline and adjacent hinterland, have been caused and controlled by the supply of marine sediments through a breach in the Garden Island submarine ridge. Shoreward sediment transport across the Cockburn-Warnbro depression has formed a barrier bank which has functioned as a sediment supply "conduit" to the Pleistoscene coastline, and has resulted in deposition of marine sediments on the shore. Relative consistency of sea level, climatic conditions and the interaction of the south-west ocean swell regime with the bathymetry of the drowned Pleistocene landscape over an extended period, has caused the formation and westward progradation of a broad foredune plain with consistent topographic and geomorphic form.

Five Holocene accretionary cusps have been formed by analogous processes within the Cape Bouvard to Trigg Island coastal sector. Further accretionary cusps along more northern seaward margins of the Swan coastal plain have resulted from recurrence of the marine geological, bathymetric and oceanographic conditions experienced in the Cape Bouvard-Trigg Island coastal sector. Becher Point is the southernmost accretionary cusp within the south-west coast of the State.

(2) Local Context

Substantial accumulation of Holocene sediments has occurred along the coast between Kwinana and Mandurah as a result of the depositional processes described above. The resultant landform, commonly referred to as the Rockingham-Mandurah Plain, consists of low broad coastal plain of relict beach ridges often with a shoreline fringe of contemporary or recent dunes of parabolic, beach-ridge or mixed complex topographic form. The plain terminates to the east against the older Pleistocene sediments of the Spearwood Dune System. At Becher Point the beach ridge plain has a width of approximately 6 km. To the north, the plain broadens slightly at Cape Peron before becoming progressively narrower towards its northern extent at Kwinana. Towards Mandurah the plain becomes progressively narrower and terminates a short distance north of the Mandurah Channel.

Woods and Searle (1983) combined geomorphic and stratigraphic analysis with radiocarbon dating procedures to elucidate the Holocene history of beach ridges between Becher Point and Rockingham (Becher-Rockingham Beachridge Plain). The time plan diagram produced by them illustrates the seaward advance of the coastline through the recurring formation of beach ridges at successive coastline positions. (Fig. 2).

Deposition of sediments that form the eastern margins of the Rockingham-Becher Plain began some 6,500 years before present. Deposition of the sediments that would eventually form part of the Becher Point accretionary cusp began some 3,000 - 3,600 years before present and has continued until the present time.

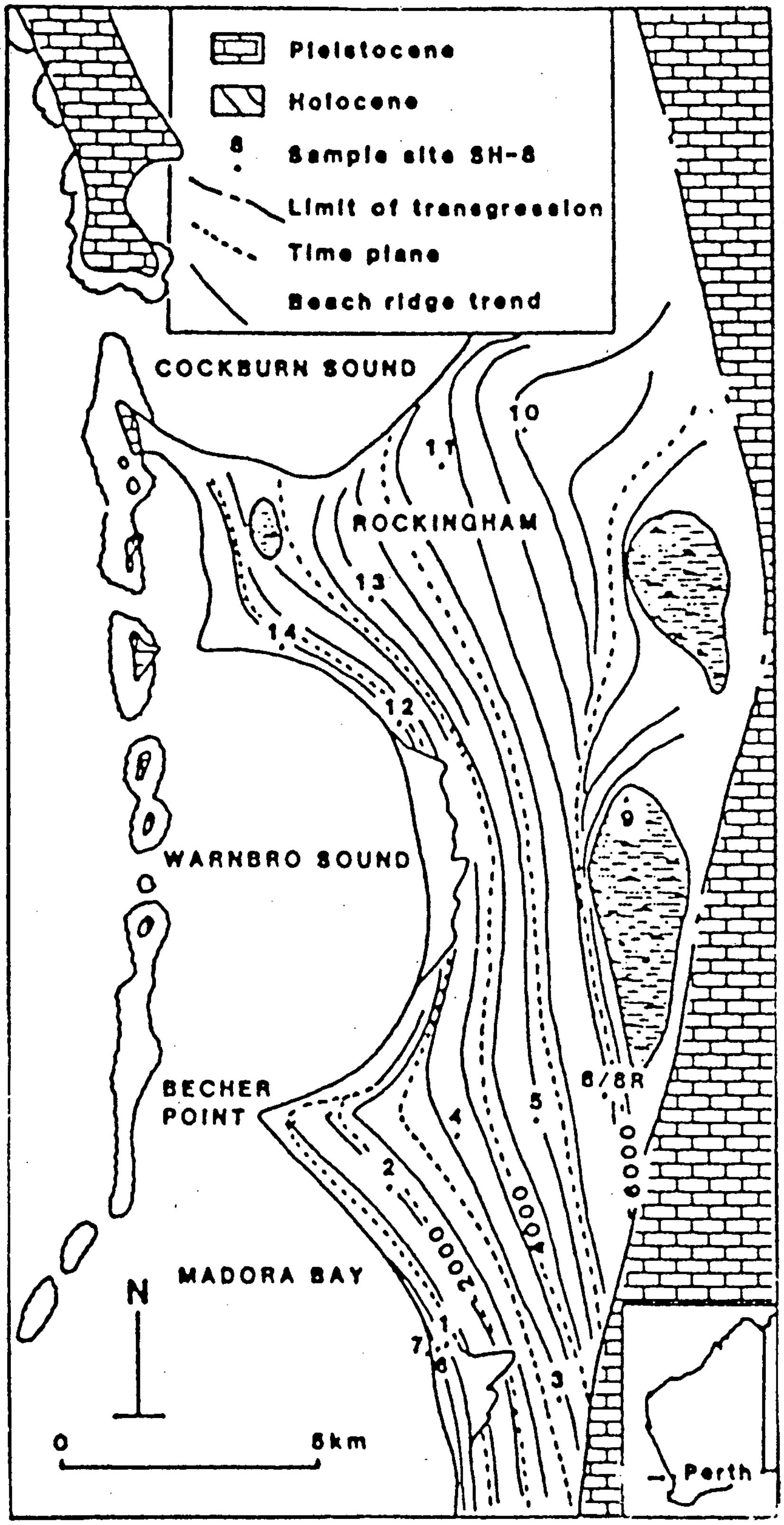


FIG. 2 The Becher/Rockingham beachridge plain showing beachridge trends, location of radiocarbon sample sites and 1000 year time planes.

(After Woods and Searle, 1983)

Within Warnbro Sound, the shores are presently stable or slowly prograding (Woods & Searle, 1983). Some distance south of Becher Point there has been significant recent erosion of the coastline whereby some 200 m of shore width have been removed by shoreline erosion. Aerial photographic records indicate that the axis of Becher Point has been stable for a long period.

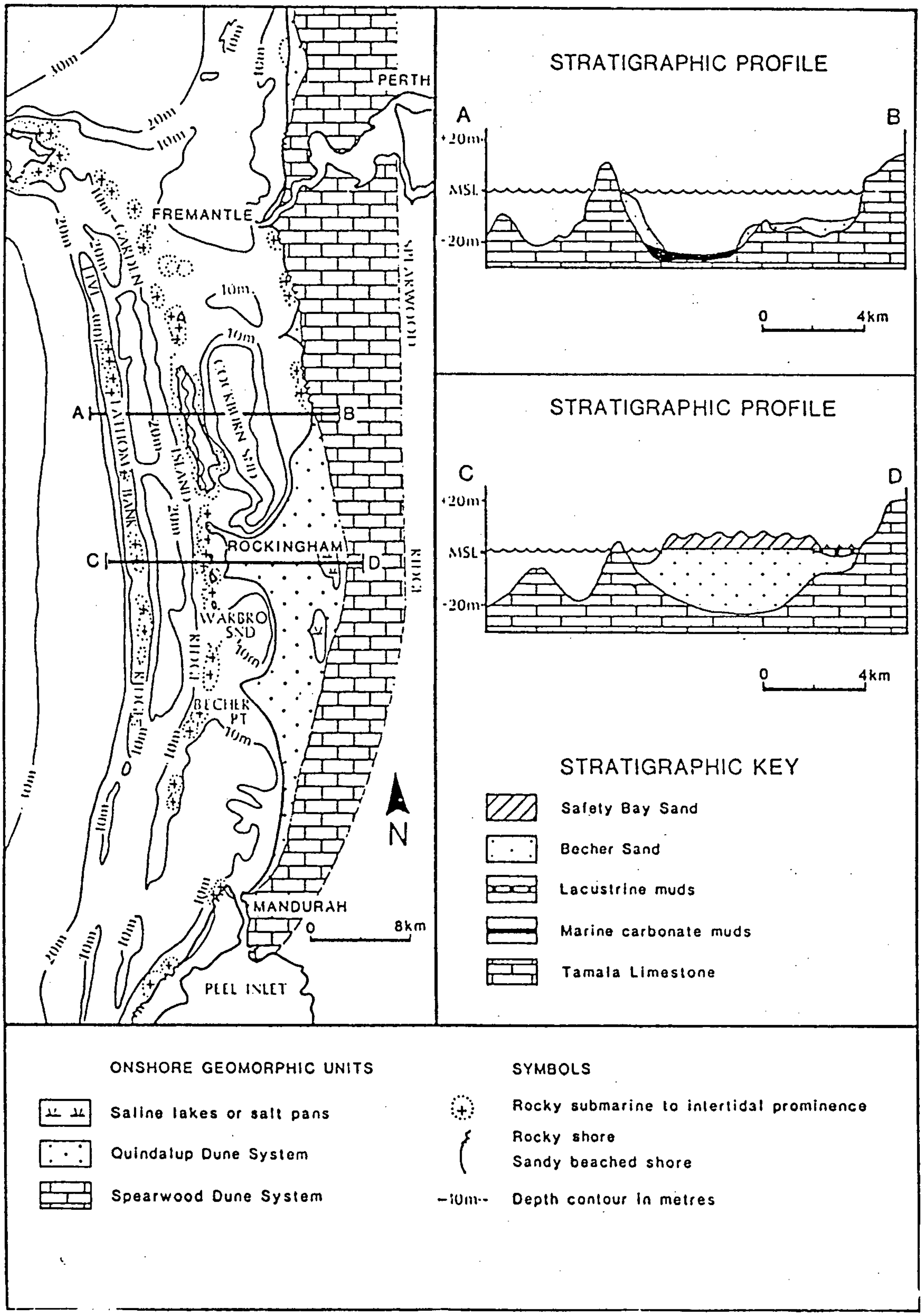
Individually the relict beach ridges within the dune plain area are 2 - 5 m high and occur in largely parallel lines or curves with 20 m - 50 m separation between crests. More recently formed parabolic dunes occur both to the north and south of Becher Point and have migrated a short distance inland transgressing the older relict beach ridge formations. These are generally slightly higher in relief than the adjacent foredune plain.

The shallow stratigraphy of the Rockingham- Becher Plain area has been described by Semeniuk and Searle (1985b) who compiled and refined previous work by several investigators in combination with additional detailed analysis of lithofacies retrieved from shallow investigation boreholes. The shallow stratigraphic relationships defined by them are consistent with the coastal development model proposed in Searle and Semeniuk (1985) and Woods and Searle (1983). Thus, Becher Point is recognized as a system where Safety Bay Sand is prograding over Becher Sand (Semeniuk and Searle, 1985b) to produce the shallow stratigraphic sequence illustrated in Fig. 3.

The primary elements of the shallow stratigraphic sequence are -

(i) The Safety Bay Sand, (Passmore (1970)), described as "fine to coarse grained calcareous sand consisting in most places of more than 50% skeletal fragments of marine organisms and lesser amounts of quartz grain". This material forms the Quindalup Dunes of MacArthur & Bettenay (1960).

(ii) The Becher Sand, which was first formally described by Semeniuk and Searle (1985b) and consists of "grey structureless to bioturbated fine and medium quartzo-skeletal sand with lesser muddy sand, layered mud and



<u>FIG 3.</u> Cape Bouvard-Trigg Island sector showing extensive Holocene cuspate and tombolo accretionary plains, general coastal form, geomorphic units, complex nearshore bathymetry of ridges and depressions and selected stratigraphic profiles.

(After Searle and Semeniuk, 1985)

seagrass peat that underlies modern (contemporary) seagrass beds and prograded coastal plain sequences".

(iii) Tamala Limestone. Described as quartzo-calareous sand variably cemented into limestone, friable limestone and calcrete capstone.

(3) Specific Landform, Topographic and Soil Characteristics of the Project Area

The occurrence and distribution of geomorphic elements within the project site was determined by analysis of available maps and descriptive work. Broad information gathered from the scientific literature was further refined through the evaluation of colour and black and white aerial photography at scales of 1:5000 and 1:25000. The resultant detailed site information was ground truthed by transects and site inspections throughout the area during which soil profiles, topographic and landform trends, vegetation patterns, drainage and shoreline dynamics were examined. Site surveys were conducted in April and May 1988.

Investigation and field survey have shown that the site consists of five geomorphic units.

(i) Contemporary relict foredune plain
(ii) Active or recently active foredune
(iii) Relict beachridge plain
(iv) Prominant relict foredune
(v) Linear depression/seasonal wetland.

The distribution of these geomorphic elements within the site is shown on Fig. 4, whilst topographic relationships are illustrated in the cross sections given as Fig. 5. (The distribution of seasonal wetlands is shown more accurately on Fig. 7, based on detailed site survey.)

Although all of the soil types that occur at the site could be broadly considered as Safety Bay Sand, differential development between the geomorphic elements has created subtlety characteristic soil types that are definable at the scale of mapping employed in this investigation and are shown in Fig. 6. As the distribution of soil types is closely related to the geomorphic elements, soil type descriptions are provided within descriptions of the geomorphic elements. Mapping symbols used for each geomorphic element are given in parentheses.

(i) Contemporary Relict Foredune Plain (Qf4)

A narrow band of contemporary or recently deposited foredunes of very low relief (< 2 m AHD) lies behind the present active beach zone, within a section of shore to the east of Becher Point. This low beach ridge plain extends for a distance of some 2 km along the Warnbro Sound shoreline. Soils within this unit consist of white to grey, fine grained calcareous skeletal sands that have been partially to well stabilized by pioneer vegetation. The foredune plain is not present on the southern shores of the Becher Point cusp where coastal erosion has been recently active.

These small circular wetlands have developed on low lying ground within this landform near Becher Point. The wetlands are saline, very shallow and are based on saline groundwater which lies very close to the surface. Soils within the wetland are similar to foredune soils described above but have accumulated salt from seaspray and organic matter from the plants that have established within them.

(ii) Active or Recently Active Foredune (Qf1)

This unit is the primary dune formation behind the present shore and is believed to correspond to the Quindalup Dune Q4 geomorphic sub unit of McArthur and Bartle 1980. Within the Stage 1 area, this unit lies at 2 - 5 m AHD near Bridport Point and rises to approximately 5 - 10 m AHD with some isolated higher ridges in the northern sector.

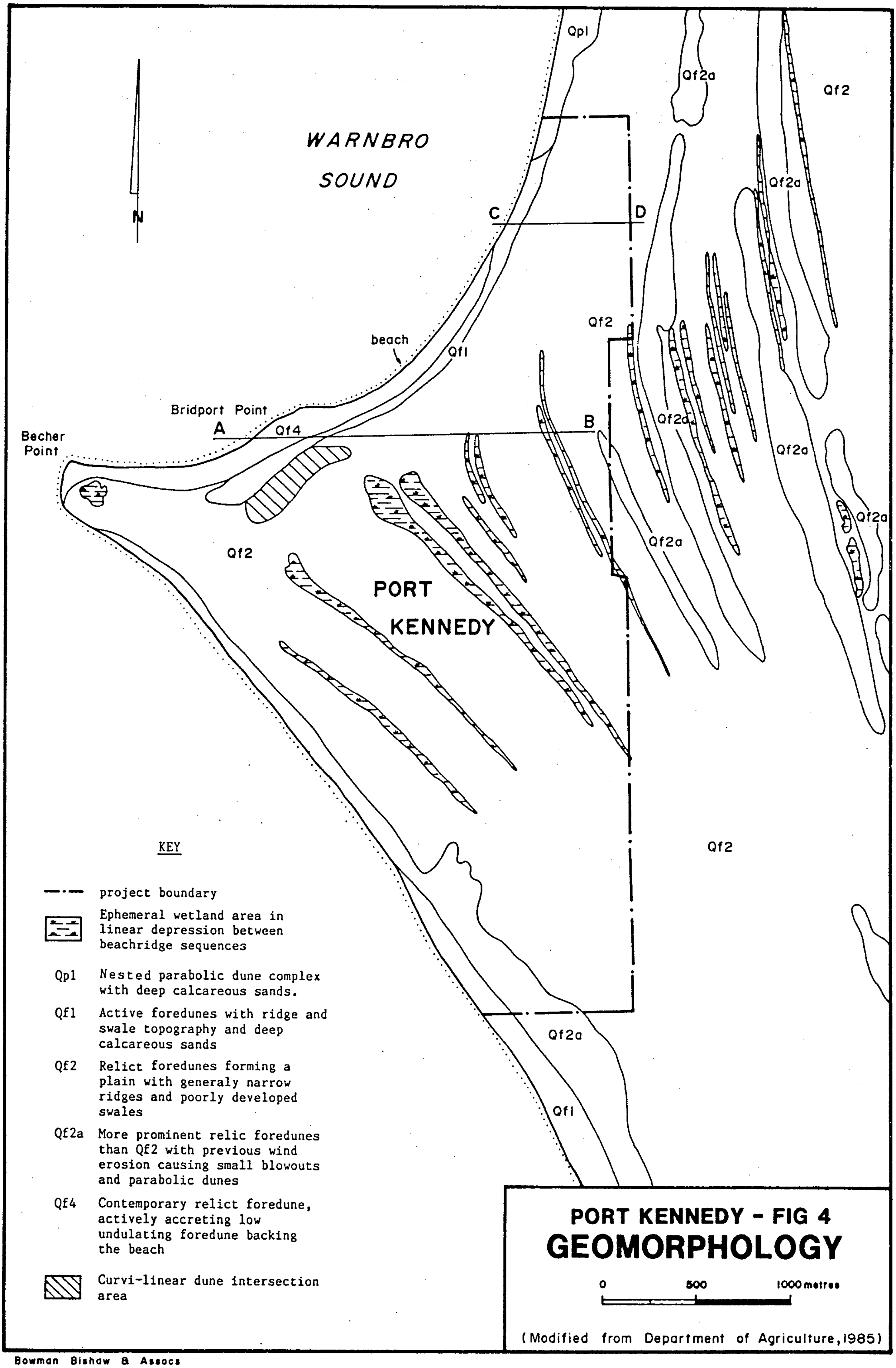
North of Becher Point, the unit has parallel dune and swale topography consistent with a relict beach ridge landform. However at the very northern end of the Stage 1 project area the topography becomes more complex and displays some parabolic character, which is even more pronounced further north in Warnbro Sound. Surface soils consist of grey-white, fine grained, calcareous skeletal sands that closely resemble those of QF4 but have very minor organic accumulation near the surface. This unit is stabilized by vegetation, which has also provided the organic detrital material in the form of minor leaf litter at the surface and root material in the shallow subsurface.

(iii) Relict Foredune Plain (Qf2)

This geomorphic unit forms much of the hinterland of Becher Point and the Rockingham-Becher Plain. It is characterized by a regular gently undulating surface with continuous linear or curvilinear ridges in parallel sequences that mark successive shoreline positions through time (Woods and Searle, 1983.) Topographically, the beach ridge plain generally lies between 4 - 8 m AHD, however higher ridges up to 12 - 14 m AHD and deeper swales (which are also separately described in (viii)) which may lie as low as 2 - 4 m AHD also occur.

The surface soils are grey-brown, fine grained, calcareous skeletal sands that feature minor organic accumulation in the upper 25 - 40 m and overlie cream-buff coloured sands. These are analagous to the upper soil layer but lack significant accumulation of organic material.

To the immediate south and south west of Bridport Point there is an area of some 2 - 3 ha (Fig. 4) where the development of relict foredunes during very recent geological time has encroached upon much older relict foredunes to produce an area of sharply curvilinear or crescentic shaped dunes. Whilst the northern "arm" of the "dune crescent" consists of sediments of 500 to 1000 years age, the south-westerly "arm" has an age of 2000 - 3000 years. It appears that a period of foredune development on the Warnbro Sound coastline has been followed by a period of erosion, then by a further period of deposition which has continued until the present time. Apart from a small area near Bridport Point this peculiar



KEY

- project boundary
- Ephemeral wetland area in linear depression between beachridge sequences

Qpl Nested parabolic dune complex with deep calcareous sands.

Qf1 Active foredunes with ridge and swale topography and deep calcareous sands

Qf2 Relict foredunes forming a plain with generaly narrow ridges and poorly developed swales

Qf2a More prominent relic foredunes than Qf2 with previous wind erosion causing small blowouts and parabolic dunes

Qf4 Contemporary relict foredune, actively accreting low undulating foredune backing the beach

- Curvi-linear dune intersection area

PORT KENNEDY - FIG 4

GEOMORPHOLOGY

0 500 1000 metres

(Modified from Department of Agriculture, 1985)

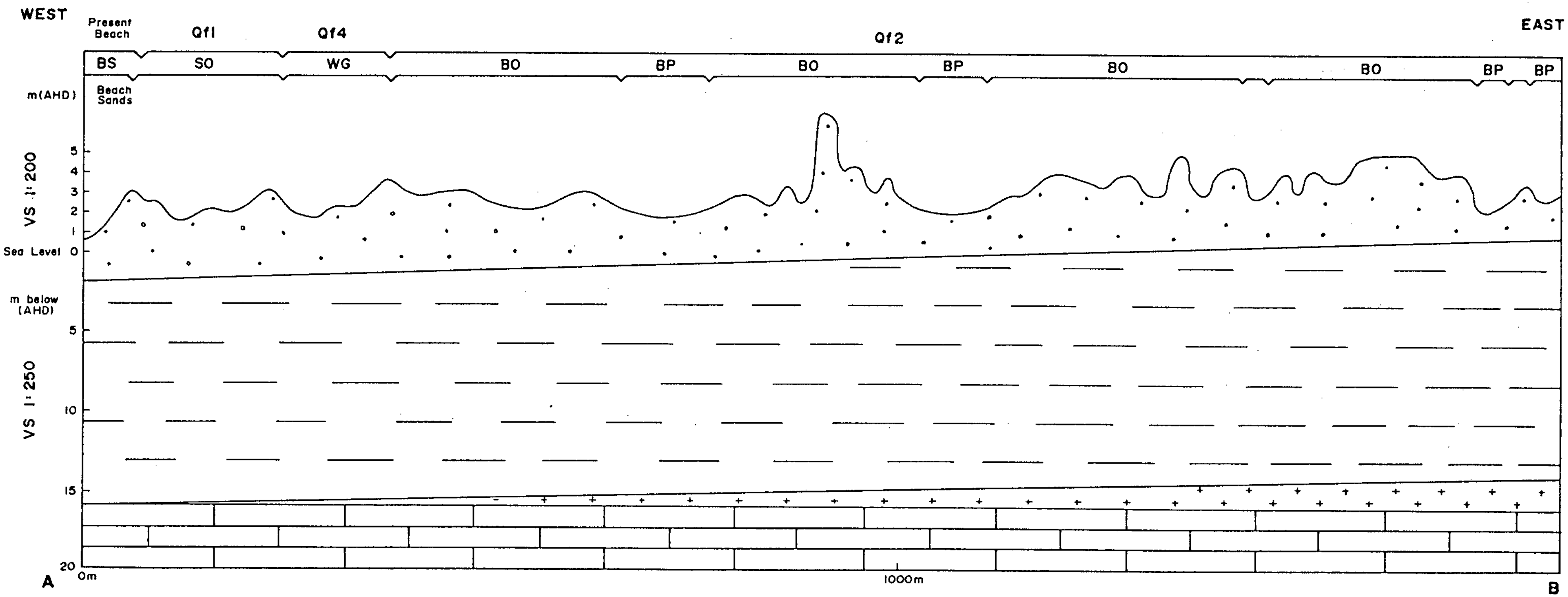


FIG 5A - CROSSECTION OF THE A-B TRANSECT AT PORT KENNEDY (Refer Fig 4)

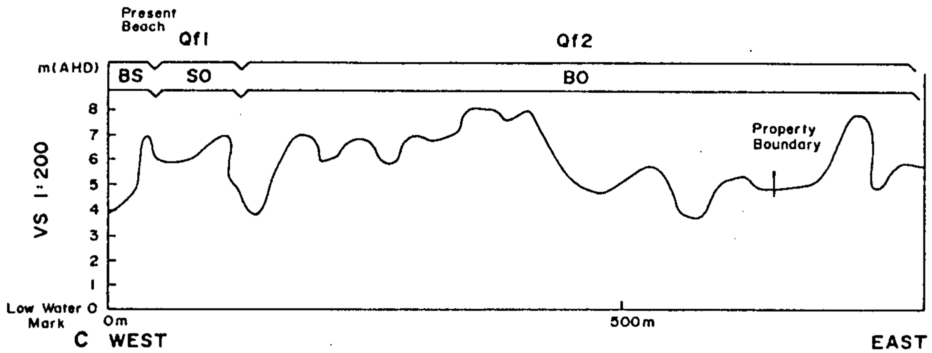


FIG 5B - CROSSECTION OF THE C-D TRANSECT AT PORT KENNEDY (Refer Fig 4)

KEY

Geomorphic Units

Qf1	Active foredunes with ridge and swale topography and deep calcareous sands
Qf2	Relict foredunes forming a plain with generally narrow ridges and poorly developed swales
Qf2a	More prominent relict foredunes than Qf2 with previous wind erosion causing small blowouts and parabolic dunes
Qf4	Contemporary relict foredune actively accreting low undulating foredune backing the beach

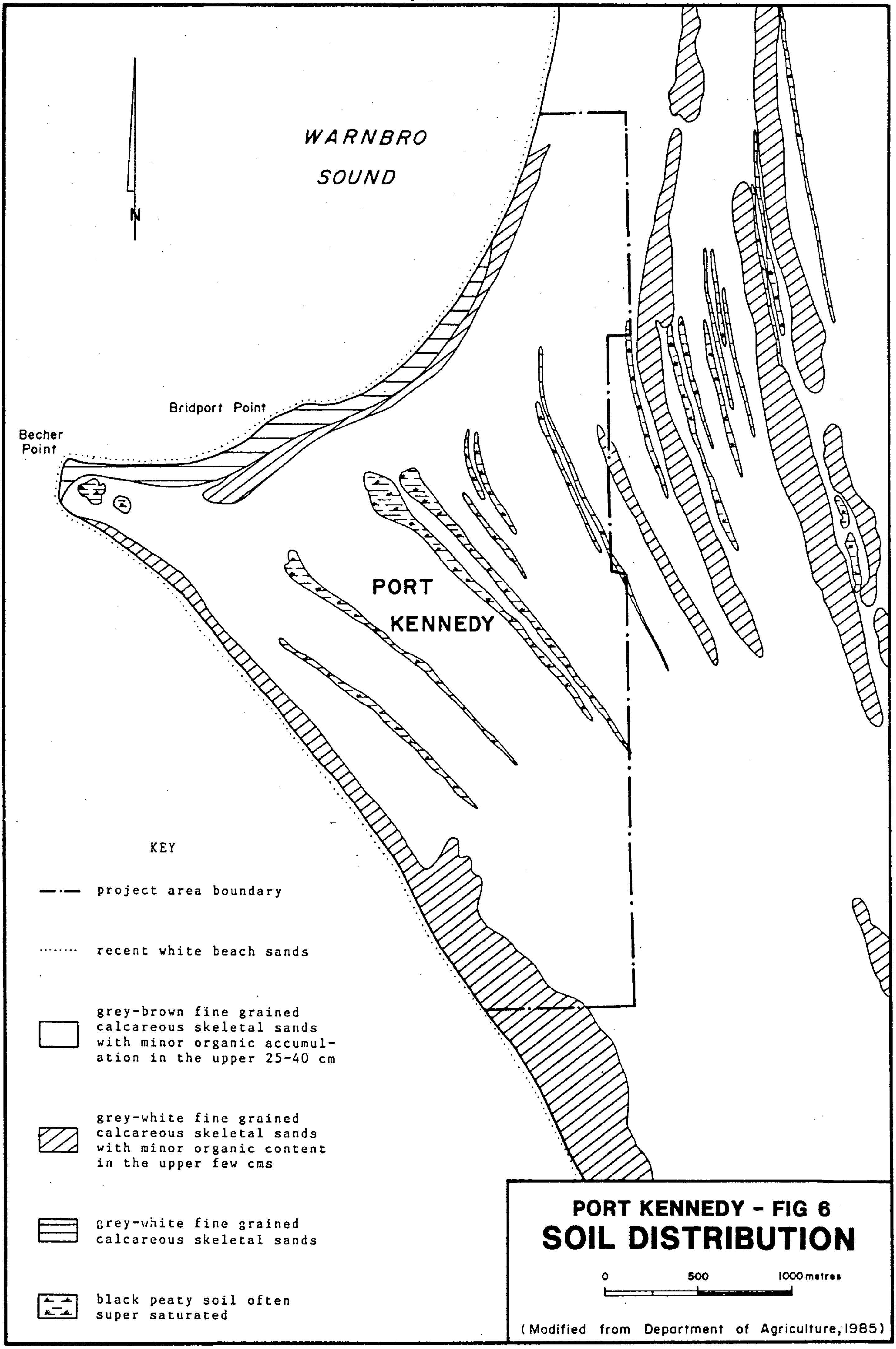
Surface Soils

BS	Recent white beach sands
BP	Grey-white fine grained calcareous skeletal sands with minor organic content
WG	Grey-brown fine grained calcareous skeletal sands with minor organic accumulation in the upper 25-40 cm
SO	Grey-white fine grained calcareous skeletal sands
BO	Black peaty soil often with high moisture content

Stratigraphic Units

- Safety Bay Sands
- Becher Sands
- Stratigraphically undefined quartz sand
- Tamala Limestone

SOURCE: Modified from Le Provost, Semeniuk and Chalmer, (1986) and Department of Agriculture (1985)



Bowman Bishaw & Assocs

landform is not readily evident on the ground, but is clearly visible on aerial photographs at Scale 1:25,000 and larger.

(iv) Prominent Relict Foredune (Qf2a)

No land of this geomorphic form occurs within the Stage 1 area. A soil map compiled by the Department of Agriculture (1985) shows expression of this geomorphic form to the east of the Stage 1 area and along the coastline south of Becher Point. Both areas have topographic range of 5 - 10 m AHD.

The unit is described as "more prominent relic foredunes occurring within unit Qf2 with linear swamps often developed within swales". Examination of aerial photographs during the present investigation indicated that south of Point Becher the land mapped as Qf2 does not closely comply with the type-description and is more characteristic of Qf1, (MacArthur and Bartle's Q4) having long dune walls and some parabolic character.

Soils of the Qf2a geomorphic unit within the study area (outside Stage 1) consist of fine-medium grained, grey-white, calcareous skeletal sands with little organic development other than within the uppermost few centimetres of the profile.

(v) Linear Depression/Seasonal Wetland

Whilst strictly speaking this geomorphic unit is a component of the relic foredune plain geomorphic unit (QF2), for the purposes of detailed review of the area, separate discussion is included here.

Five of the major linear depressions and several minor linear depressions within the study area lie low in the landscape (< 3 m AHD) and are sufficiently close to the unconfined water table to experience inundation during periods of seasonally high levels. These areas have commonly been mapped as permanent wetlands by previous investigators. However, site inspections of vegetation and soils within the depressions located only one small area of approximately 50 m^2 of apparent permanent surface water and suggested that inundation of the linear depressions would be confined to the wet months of the year. Inspections also indicated that plant species characteristic of persistent or permanent surface water were absent from all but one depression.

The soils within the major linear depressions consist of heavy, black, peaty soils that have been formed by the accumulation of decaying plant materials. These have a depth of approximately one metre. The apparent low permeability of the black peaty soils undoubtedly provides for surface ponding of rainfall, retention of soil moisture and therefore enhancement of ephemeral wetland character. The high organic content of this soil type compared to the surrounding dune soils is consistent with perennially moist soil conditions, and accumulation of organic detritus in a seasonally inundated soil horizon.

3.2 Biological Environment

3.2.1 Regional Perspective

Characterization of the biological environment of the study area on a regional basis utilizes the perspective provided by the vegetation systems that have been identified as these have been quite intensively investigated and mapped by biological researchers.

The project area lies within the South-West Botanical District, the Drummond Sub-District and the Rockingham System of Speck (1978) and Smith (1974) (Beard 1979). The Rockingham System is the most specific classification of those listed above and is considered to include Rottnest, Carnac and Garden Islands and the coastal vegetation from Fremantle, south to Cape Naturaliste (Beard 1981).

Thus, vegetation and plant communities that are broadly typical of the project site extend along the coastal fringe of Quindalup Dunes between Fremantle and Cape Naturaliste. North of Fremantle, coastal dune vegetation is often largely similar but has been classified as the Guilderton System (Beard (1981)).

3.2.2 Vegetation and Flora

A detailed specialist botanical survey of the study area for this investigation was conducted during May 1988. The objectives of the survey were as follows:-

(i) prepare a vegetation map of the site

(ii) describe the flora and determine whether any gazetted rare or endangered species were present

(iii) determine the condition of the vegetation

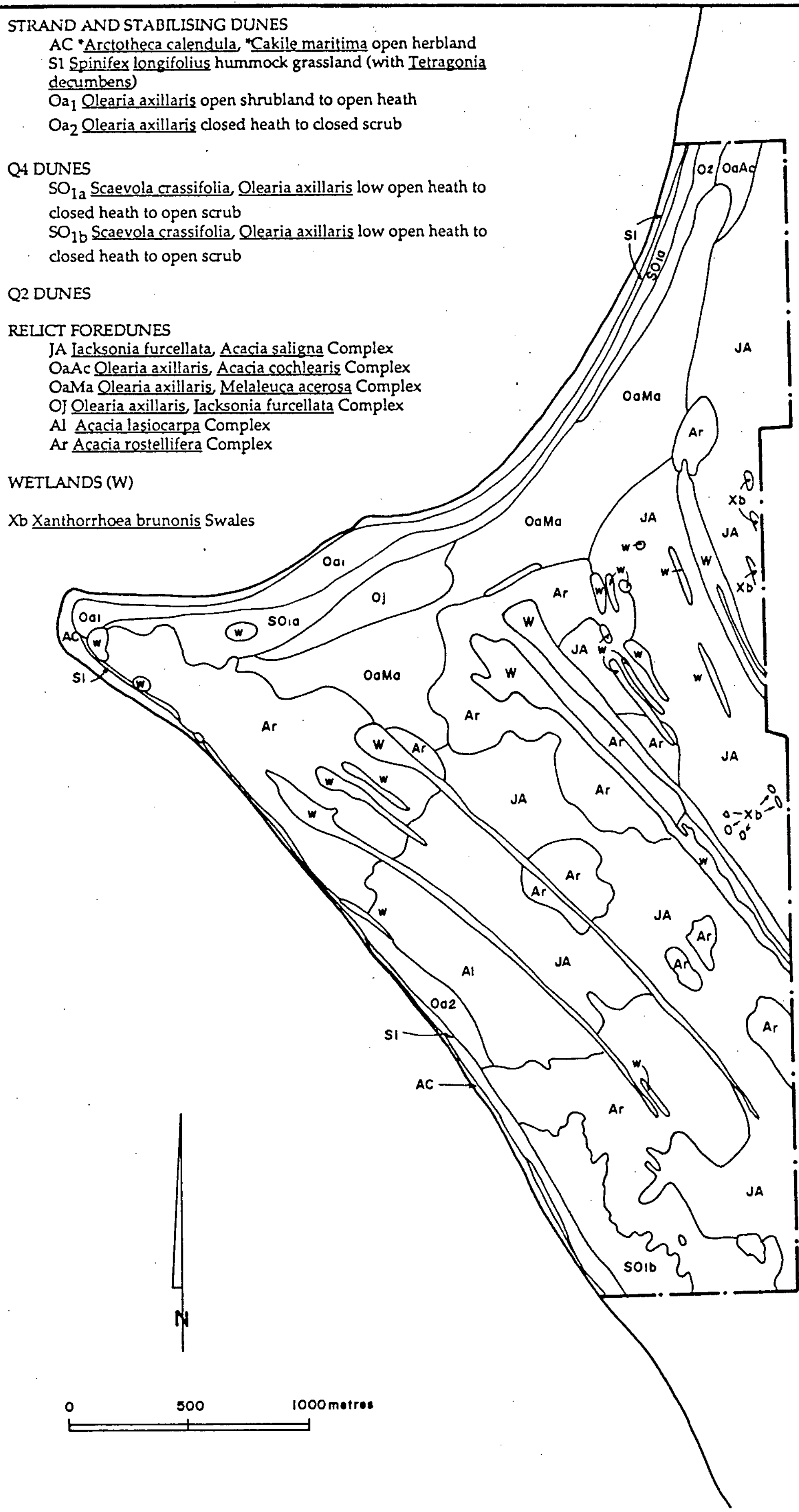
(iv) assess the regional conservation values of the site's vegetation.

A series of vehicle and foot traverses was conducted and species lists at forty two selected sites were prepared. Species whose identity was not recognized in the field were collected for identification at the W.A. Herbarium.

A vegetation map was prepared using recent colour photography at a scale of 1:25,000 and is reproduced here as Fig. 7. The condition of the vegetation was determined by both qualitative and quantitive assessment and was recorded on a scale of three categories as follows:-

Category A - Significant changes resulting from human influences, may have significant numbers of weeds including some of the more aggressive ones. Original vegetation largely removed.

Category B - Has definite signs of impacts by man (such as grazing) which have caused identifiable but not substantial changes. Weeds may be present but not aggressive. Basic structure of vegetation still present.



VEGETATION OF THE PORT KENNEDY STUDY AREA FIG 7

Category C - Shows no evidence of impact by man or shows signs of reversible impacts such as increased fire frequency, few tracks and little rubbish.

The use of this scale needs some explanation. Areas that have been recently burnt are recorded depending on their perceived ability to regain their normal structure and density. So areas that have been frequently burnt and are not likely to regenerate well in a reasonable time would be scored lower on the scale than areas that had been burnt recently but which have not been burnt frequently.

The results of the survey are summarized in the following section and are given in full in Appendix D.

The botanical survey was limited by season in that annual plants had only just commenced germination and cryptophytes had not emerged.

a) Flora

Seventy three species of flowering plants (angiosperms) were recorded while mapping the vegetation. This probably represented almost all of the perennial species (excepting cryptophytes) that would be recorded in the study area by a systematic search for flora. However very few of the annual species that would be expected in the area were available for collection due to the season the survey was carried out.

The species recorded are generally common or widespread in the vegetation types found in the study area, however they are not evenly dispersed throughout the study area. In particular those species associated with the swamps are not found in the other units.

No gazetted rare or endangered, or geographically restricted species were identified within the site by the survey.

b) Vegetation

The vegetation was described in relation to the soil types and geomorphic units that occur at the site (with reference to the geomorphic classification of coastal dunes developed by McArthur and Bartle). i.e. Strand Zone, Q4 dunes (mapped as QF2 in section 3.1.2) the Q2 dunes, relict beach ridges and ephemeral wetlands. The vegetation units that were identified are as follows: The key notation used in mapping is included in parentheses.

(i) Strand and Contemporary Foredune

- Arctotheca calendula, Cakile maritima Open Herbland (AC)
- Spinifex longifolius Hummock Grassland (with Tetragonia decumbens) (S1)
- Olearia axillaris Open Shrubland to Open Heath (Oa_1)
- Olearia axillaris Closed Heath to Closed Scrub (Oa_2)

(ii) Q4 Dunes

- Scaevola crassifolia, Olearia axillaris Low Open Heath, Closed Heath, Open Scrub (SO_{1a})
- Scaevola crassifolia, Olearia axillaris Low Open Heath, Closed Heath, Open Scrub (SO_{1b})

(iii) Q2 Dunes

- Lomandra maritama Closed Herbland, Mixed Low Open Shrubland, Low

Closed Heath (Lm)

- Acacia rostellifera Low Open Heath, Open Heath over Melaleuca acerosa (Ar2)

(iv) Relict Foredunes

- Jacksonia furcellata, Acacia saligna Complex (JA)

  - Jacksonia furcellata, Acacia saligna Open Shrubland (JA)

  - Jacksonia furcellata, Acacia saligna Open Shrubland over Acacia lasiocarpa Low Open Shrubland to Low Shrubland (JAAl)

  - Jacksonia furcellata, Acacia saligna Open Shrubland over Hemiandra pungens (JAH)

- Olearia axillaris Complex (Oa Ac)

  - Olearia axillaris, Acacia cochlearis Shrubland over Acacia lasiocarpa (Low Shrubland (Oa Acl)

- Olearia axillaris, Melaleuca acerosa Complex (Oa Ma)

  - Olearia axillaris, Acacia saligna Open Shrubland over Melaleuca acerosa Low Shrubland (Oa As Ma_1)

  - Olearia axillaris, Acacia saligna Open Shrubland over Melaleuca acerosa Low Open Shrubland to Shrubland (Oa As Ma_2)

  - Olearia axillaris, Jacksonia furcellata Open Heath (OJ_1)

- Olearia axillaris, Jacksonia furcellata Open Heath (OJ_2)

. Acacia lasiocarpa Complex (Al)

- Jacksonia furcellata Open Shrubland over Acacia lasiocarpa Low Closed Heath (Al_1)

- Jacksonia furcellata, Acacia saligna Open Shrubland over Acacia lasiocarpa Low Heath (Al_2),

. Acacia rostellifera Complex (Ar)

(v) Inland Stands

. Acacia rostellifera Open Scrub over Melaleuca acerosa Low Shrubland (ArMa)

. Stipa, Lepidosperma tenue Open Grassland/Sedgeland (SL)

(vi) Stands near the Coast

. Diplolaena dampieri, Acacia rostellifera Low Shrubland (Dd Ar)

. Acacia rostellifera Low Open Heath to Closed Heath to Open or Closed Scrub to Low Forest (Ar)

. Acacia rostellifera Low Open Shrubland over Stipa Open Grassland (ArS).

(vii) Wetlands

. Juncus sp Closed Sedgeland (J_1)

- Juncus sp Open Sedgeland over Sarcocornia Closed Herbland (J_1)

- Linear Wetlands (w)

- Xanthorrhoea Swales

3.2.3 Fauna

Evaluation of the fauna of the study area has been conducted as a desk top review, supplemented by opportunistic sightings during site inspection. The lower level of detail that has been assigned to this part of the Study is appropriate due to several factors:-

(i) much of the area has been severely burnt and now provides little value as habitat;

(ii) the low abundance of conspicuous fauna indicates very extensive field survey would be necessary to enable all species present to be identified.

As a result, assessment of fauna species was believed to be most appropriately conducted by evaluation of previous records from the area and an assessment of the types of fauna that could utilize various habitats that are available. Appendix II provides lists of the vertebrate fauna likely that could inhabit the study area. The lists were compiled on the basis of the habitats available and were checked against Museum records, and opportunistic sightings in late April and May 1988. It must be emphasised that the lists are only an indication of potential fauna populations and there can be no certainty that any or all of these species would be present at any one time.

The mammals that are likely to inhabit the study area are mainly introduced species including foxes, rabbits, black rats, house mice, feral cats. Their presence virtually precludes the existence of some of the smaller native marsupials that could be expected in the available habitats. The Western Grey Kangaroo is likely to inhabit the area, while a short-nosed bandicoot has been recorded by the Museum, south of Warnbro Beach. This specimen was collected in 1972 and it is unlikely that significant large populations of the bandicoot still exist in the study area, particularly the northern sector as a result of frequent fires and consequent "alienation of habitat".

A number of snakes such as the Tiger Snake, the Dugite, and Gould's snake could be expected to be present. A variety of frogs, including Heleoporus eyrei, Ranidella insignifera and Limnodynastes dorsalis would inhabit the interdunal depressions, particularly the ephemeral wetlands. Conversely, skinks such as Ctenotus fallens, Hemiergis quadrilineata and Lerista elegans would inhabit the ridges and drier more exposed areas of Port Kennedy although they may have been significantly reduced in abundence by introduced mammals.

The birds that could inhabit the study area are of greater diversity than the mammals and reptiles and the list given in Appendix II is probably far from complete. Bird species that may be common include sea and strand birds (terns, gulls, cormorants, pipits) as well as low scrub and heath dwelling birds (wrens, fantails, honeyeaters, tree martins).

Overall the native fauna of the study area is likely to be relatively impoverished within a regional context. The abundance and diversity of species that are potential inhabitants are very low compared to that of the Rockingham Lakes Regional Open Space. This is probably due to the frequent fires in the northern section of the site, human disturbance of the vegetation and the invasion of introduced feral animals.

3.2.4 Ecological Processes

Qualitative descriptions of the ecological processes that are operative at the site are provided as a basis for evaluation of environmental impact. Application of quantitative data to these descriptions has not been possible as due to inherent difficulties in measurement of ecological processes, no appropriate or relevant data is available. Whilst this restricts evaluation to a simple treatment, the comparative ecological simplicity of the coastal environment suggests this approach is acceptable. A review of the principal physical ecological processes in the environment is followed by a review of nutrient cycles.

(1) Physical Processes

(a) Dune Building

The geomorphology of the site indicates that wind driven dune building processes have been the crucial controlling factors in respect of the physical environment. Dune building processes have controlled the formation and morphological characteristics of the site and also are believed to have been a critical factor in the development of the unusual vegetation complexes that have been recognized.

Vegetation has now largely stabilized the form of the land surface within geologically older inland areas of the site. However along the coastal fringe that is directly exposed to wind, sediment deposition, relocation and removal is ongoing and is in dynamic equilibrium.

The Warnbro Sound shoreline is stable or slowly prograding, and primary dune formations are largely stable. However, along the Madora Bay coast south of Becher Point the presence of transgressive dunes and shoreline erosion indicates that sediment relocation and removal processes are currently operative.

(b) Water

The site's hydrological characteristics are also straightforward and simply described. Rainfall is the only source of water to the terrestrial ecosystem. There are no active drainages on site, which indicates that surface water is neither imported nor exported along the land surface.

The very high porosity of surface soil enables all rainfall that does not re-evaporate or is not assimilated by vegetation, to drain to the superficial aquifer. Groundwater is the principal water storage within the ecosystem. Loss of water from the system occurs due to gravity drainage to the ocean, direct evaporation and evapotranspiration by plants. The site's hydrological cycle is depicted in Fig 8.

(c) Fire

Fire is generally considered to be an essential component of terrestrial ecosystems in Western Australia, particularly in relation to the reproductive cycle of particular plant species. However, too frequent fire has a number of detrimental effects including:-

(i) loss or reduction of stature and density

(ii) loss of habitat value

(iii) facilitation of weed invasion

(iv) loss of nutrients from the ecosystem

(v) loss of species particularly obligate seed regenerators. (Trudgen 1988, In press).

Overly frequent fires have been a significant factor within the study area. All of the effects noted above, with the possible exception of (v) are evident within the Stage 1 area.

The frequency of burning that could be sustained by the vegetation without suffering detrimental effects is unknown and could only be guessed. However the sustainable or ecologically necessary fire regime is unlikely to resemble that of the recent decades wherein the vegetation may have been burnt as often as annually or more.

FIGURE 8. HYDROLOGICAL CYCLE

Rainfall

Evaporation

Transpiration

Water Table

Evaporation

Discharge

Safety Bay Sand

Ocean

Becher Sand

Aquifer

Coastal Limestone Aquifer

Impermeable Strata

(2) Nutrient Cycles

(a) Phosphorus Cycle

The principal elements and salient features of the phosphorus cycle in the study area environment are described as follows and depicted as Fig 9.

FIGURE 9 - PHOSPHORUS CYCLE

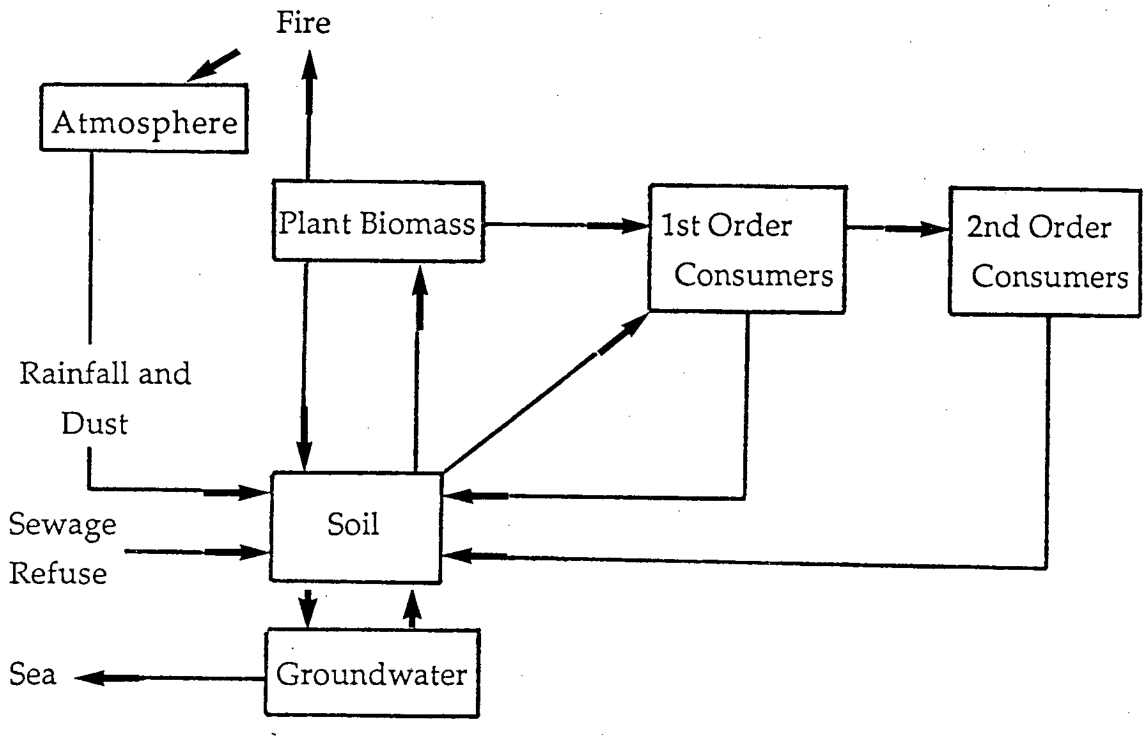
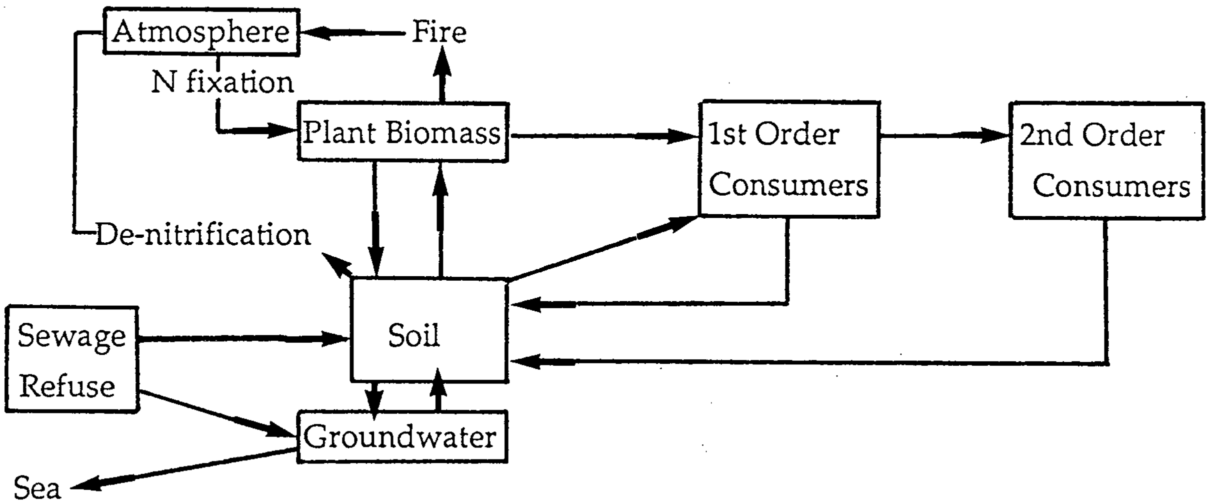


FIGURE 10 - NITROGEN CYCLE



(i) The major source of biologically available phosphorus is rainfall and atmospheric dust fallout. Seagrass deposited on shore by tidal and wave action may also provide some phosphorus to very new shoreline deposits. However loss by winnowing and leaching would probably quickly reduce the available phosphorus levels.

(ii) The site's natural surface soils are naturally very low in phosphorus and have little retention capability. Phosphorus that is deposited on surface soils but not assimilated by plants would be quickly leached to groundwater.

(iii) The primary biotic pool of phosphorus is within the living plant biomass.

(iv) Very small proportions of the phosphorus inventory reside within first and second order consumers. This inventory recycles to the soil and may exit the ecosystem following leaching to the groundwater.

(v) Groundwater is the primary abiotic phosphorus pool.

(vi) Losses of phosphorus from the ecosystem occur as a result of groundwater discharge and fire. Mineralization of biologically available phosphorus is likely to be negligible.

(vii) Disposal of sewage and refuse from human activities contributes additional phosphorus to the system.

(viii) The low availability of biologically assimilable phosphorus is evident in the apparent low diversity and abundance of first and second order consumers and the sparse and slow growing low density nature of the vegetation.

(b) Nitrogen Cycle

The coastal ecosystem has a similarly low inventory of biologically available nitrogen.

The principal features of the coastal nitrogen cycle (Fig. 10) are as follows:-

(i) Fixation of atmospheric nitrogen by soil bacteria and legumes is the primary source. Small quantities are provided by rainfall, however the sandy surface soils have extremely low nitrogen retention capability and negligible inherent nitrogen content. Small quantities of nitrogen may be available to shoreline areas from seagrass debris washed onshore. However winnowing and leaching should quickly remove this source of nitrogen.

(ii) First order consumers obtain nitrogen directly from the plant biomass, which is the primary biotic pool. Second order consumers derive nitrogen from first order consumers. Both orders of consumers recontribute nitrogen to the soil through faeces and ultimately senescence and decomposition.

(iii) Storage in groundwater is the major abiotic nitrogen pool within the ecosystem (apart from the atmosphere).

(iv) Losses of nitrogen from the system occur as a result of groundwater discharge, de-nitrification by soil bacteria and fire.

(v) Sewage and refuse from human usage also contribute nitrogen to the ecosystem where both direct assimilation and leaching to the groundwater occur.

3.3 Land Use

3.3.1 Regional Development Context

The project site lies near the southern boundary of the south-west corridor of the metropolitan region. The State Planning Commission's recent review of the Metropolitan Region Scheme (SPC, 1988) confirmed the desirability in a planning context of extending urban development south along the coast to the southern boundary of the metropolitan region. Intensification of urban development at Baldivis, some 10 km east of the project site was also recognized to be desirable.

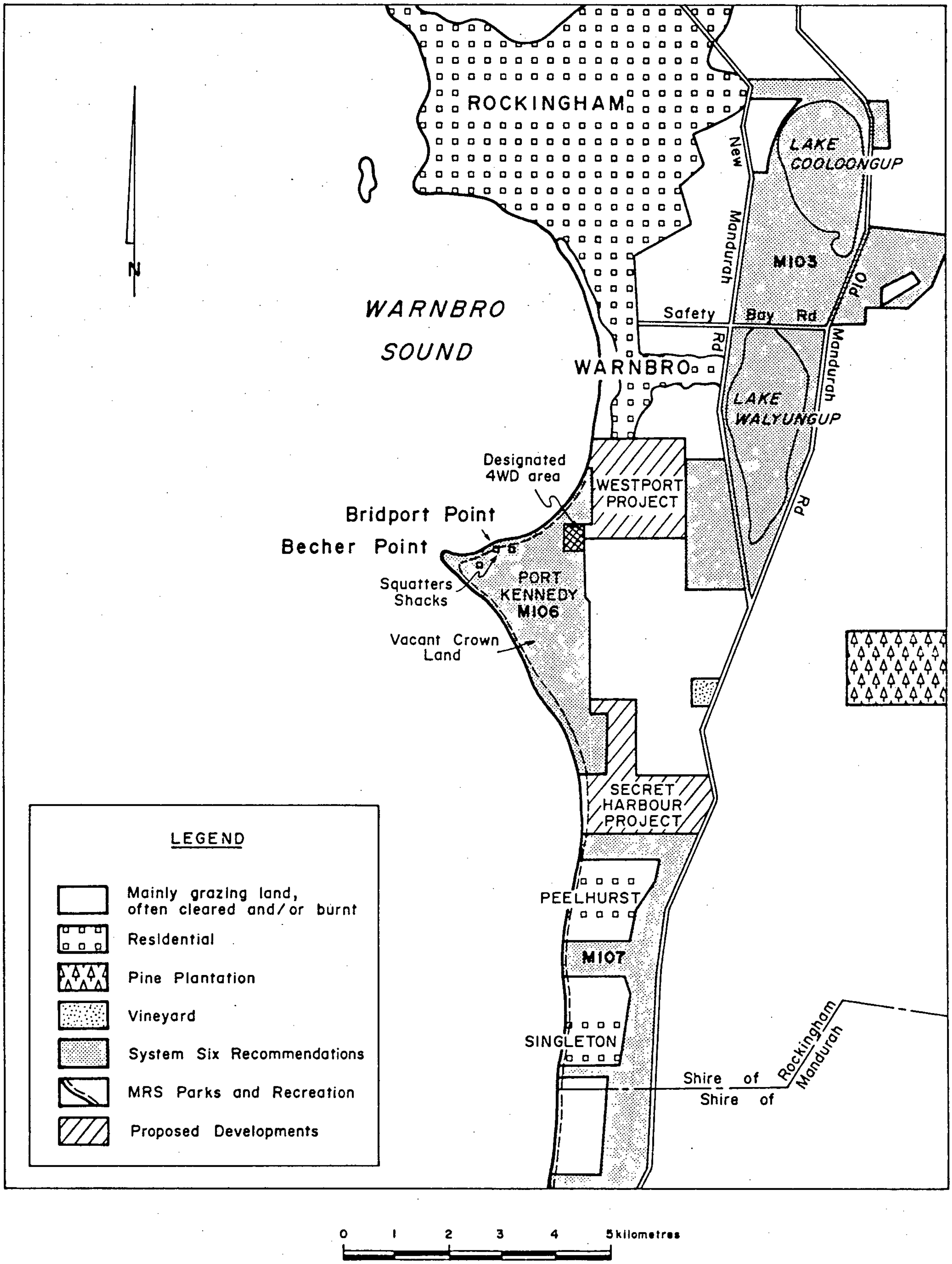
The land surrounding the project area is presently utilized for the following purposes, as shown on Fig 11.

(i) To the north of the site residential and associated light industrial developments have established at Rockingham and Warnbro.

(ii) Land to the immediate north and east of the project site is currently undeveloped, but is the subject of a development proposal known as Westport. The development comprises a canal based residential development, linked to Warnbro Sound by a channel that will be cut through the coastal dunes.

(iii) The Rockingham Lakes regional open space lies to the immediate east of the Westport project site and extends a further 10 km to the north. This area comprises wetlands, fringing vegetation and relict beach ridge plain. The Rockingham Lakes regional open space is the subject of System Six Recommendation M103 (DCE, 1983).

(iv) South of Westport and the Rockingham Lakes regional open space, and immediately east of the project area, land is undeveloped, and is used principally for agistment of stock. A small vineyard has been established.



EXISTING LAND USE AND CURRENT PROPOSALS

FIG 11

(v) To the immediate south and south-east of the project area private land that is presently undeveloped is subject to a development proposal known as Secret Harbour. This project will be largely similar to the Westport project, consisting of a canal based residential development linked to the sea by a channel through the coastal dunes. It is understood that this project has been "placed on hold" until land market conditions are more favourable.

(vi) South of the Secret Harbour project area the coastal plain comprises a combination of seaside holiday residential developments and uncleared land. Parts of the coastal plain in this area are the subject of System Six Study Recommendation M107 (DCE 1983).

(vii) Land to the east of Mandurah Road has been largely developed for agriculture, notably market gardening and livestock agistment.

3.3.2 Present Land Use at Becher Point

Current land uses within the project area are as follows:-

(i) Squatters

Since the early 1950's fishermen and regular weekend holidaymakers have been constructing shacks at Port Kennedy and approximately 90 - 100 are currently inhabited. The shacks are mainly located on the contemporary foredune and primary dune near Bridport Point. There have been various attempts to evict the squatters since 1961 but none have been successful.

The squatters and other itinerant visitors have been poor managers of the land. Rubbish disposal has occurred on an ad-hoc basis in the dune country immediately east of Bridport Point. In addition to household refuse, discarded domestic appliances and food waste, car bodies have also been deposited throughout the site, particularly within the northern sector.

The proliferation of access tracks created by squatters and day visitors has also scarred the site and has initiated many wind erosion problem areas.

(ii) Passive and Active Coastal Recreation

Beach areas both north and south of Becher Point have been popular venues for fishermen, surfers, swimmers and sunbathers for many years. The section of beach along the northern sector of the project area has also been a popular nude sunbathing location for a number of years. Recognition of the recreational potential of the coastal parts of this area led the Metropolitan Regional Planning Authority to reserve the coastal fringe of the project area for Parks and Recreation.

The Department of Community Services operates a "beach camp" holiday facility within a reserve at the southern margins of the study area. Beach activities as well as horse riding are the most common pursuits of patrons.

(iii) Off Road Vehicles (ORV)

The relatively remote location of the study area, the gently undulating terrain and the generally sparse and accessible vegetation cover has attracted off road vehicle users over a number of years. Whilst there is an area within the south eastern sector of Stage 1 that the Rockingham Shire Council has gazetted for ORV users, ORV activity appears to extend over the whole site, although in parts it is mainly restricted to existing tracks.

4.0 EVALUATION OF CONSERVATION VALUE:

The conservation potential of the project site is considered here in respect of the following factors:-

(a) the broad scale changes that have resulted from human usage;

(b) the condition of the residual vegetation;

(c) representation of the landform, flora and vegetation complexes that occur within the site, in nearby conservation reserves and other areas;

(d) conservation value.

4.1 Effects of Previous Use

Human usage of the project site and surrounding land has resulted in significant and readily evident modification of the natural physical and biological environment. The most significant causative factors that have been recognized are:-

(i) clearing of vegetation for squatter shacks and access trails
(ii) unnaturally frequent burning of vegetation
(iii) introduction of exotic plant and animal species
(iv) illegal dumping of rubbish.

The results of these activities are very evident within the Stage 1 area, however many parts of the remainder of the site are much less affected. This is undoubtedly related to the presence of the squatter shacks and the concentration of human activity within this part of the study area.

(i) Land has been cleared to establish squatters' shacks, parking areas and access tracks. The results of this activity are particularly evident within the Stage 1 area where a major squatters' settlement of some 90 - 100 shacks has been established. Three principal access tracks extend from Chelmsford Avenue at Warnbro into the site. There is also a myriad of interconnecting tracks joining the main access tracks and crossing the primary dune to the beach. An area set aside by Rockingham Shire Council for offroad vehicles has been heavily dissected by tracks, and contains large open expanses of bare sand and peaty soils. Widespread destabilization of the sandy surface soils has resulted from removal of native vegetation within and adjacent to access tracks. Fig 12 gives an indication of the location of areas that have been significantly degraded.

(ii) The unnaturally high frequency of fire, particularly within the relict foredunes in the northern and central parts of the study area and around Bridport Point has caused significant change to the physical structure of the vegetation. However, the floristic composition of the communities has largely persisted.

Vegetation of the relict foredune plain appears to have been locally more affected than primary dune and foredune. Changes to the physical structure are visually apparent. There are many areas that may well have been quite densely vegetated prior to settlement but now have smaller structural forms and very much reduced cover.

The floristic framework of these areas has apparently undergone less change than physical structure. This suggests that there would be some potential for regeneration within a carefully managed fire and access regime.

(iii) Fire has probably also assisted weed invasion by creating open ground where weeds are strong competitors. The creation of tracks and clearings has also contributed by creating open ground. Weed invasion is identifiable along access tracks and within fire affected areas of relict foredunes, but is generally not widespread outside these areas. The extremely low fertility of the soil may well be a contributing factor in the natural control of weed invasion.

The fauna of the study area is not well documented therefore it is difficult to be precise in evaluating the extent to which invasion of foreign species has occurred or the effects that have resulted. However, it is probably fair to presume that major displacement of fauna, particularly ground dwellers, has occurred.

Rabbits are known to be widespread in the area and whilst specific supportive data is not available, it should be anticipated that domestic and feral cats, foxes, house mice and domestic rats have established and displaced native ground dwelling fauna to a significant extent.

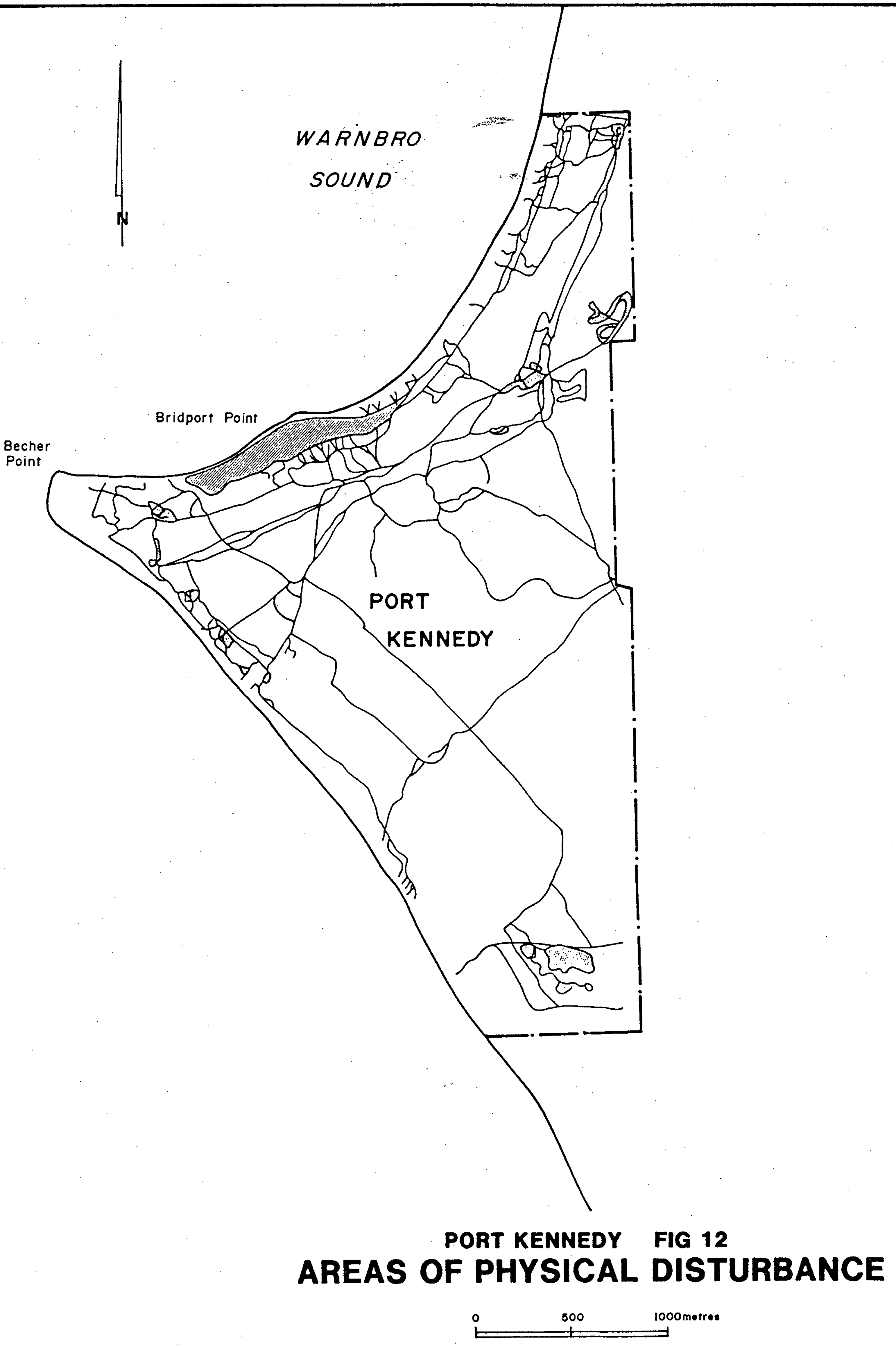
Loss of habitat is also a factor. Heavily burnt vegetation within the northern sector of the study area is a degraded habitat.

(iv) Dumping of household refuse has been extensive throughout the study area and has been particularly rampant at a number of locations within Stage 1. The physical presence of rubbish dumps has alienated flora, fauna and habitat as well as producing a highly undesirable aesthetic character. The practice of firing rubbish has sterilized much of the ground in the vicinity of the dumps and appears to have spread into adjacent vegetation, which now has reduced stature and cover.

4.2 The Condition of the Vegetation

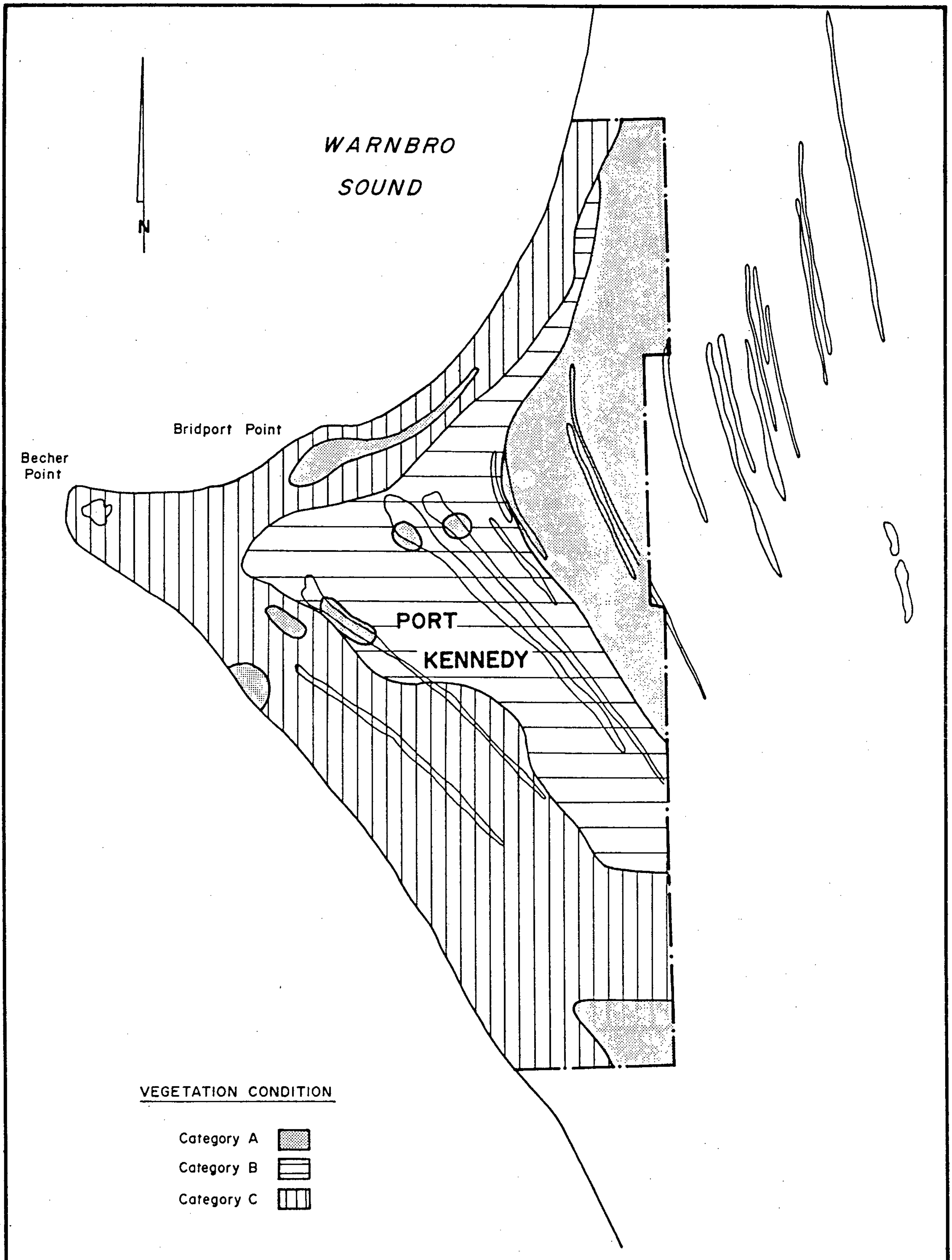
The results of detailed botanical survey indicate that the site can be divided into three broad classes in respect of the "condition" of the vegetation. These classes are somewhat subjective, but are based on a rigorous consideraton of structural form, floristic composition, fire history and the biology of the characteristic plant species and associations.

Fig. 13, which is reproduced from Appendix D shows the distribution of



PORT KENNEDY FIG 12

AREAS OF PHYSICAL DISTURBANCE



PORT KENNEDY FIG 13

CONDITION OF VEGETATION

"vegetation condition classes". The information is at broad scale and does not necessarily show the numerous but often small cleared areas and rubbish dumps.

The salient features of the condition of the vegetation can be generally summarized as follows:-

(i) Substantial tracts of the area, notably much of the relict foredune plain are in poor structural but reasonable floristic condition as a result of fire. The area behind Bridport Point, currently heavily utilized by squatters, is also visibly degraded due to clearing and burning, and vehicle movements.

(ii) The vegetation of the primary dune area (mapped as Qf2 landform) to the north of the squatters settlement is in Category C condition despite frequent dissection by sandy tracks leading to the beach.

(iii) Vegetation at Becher Point, and in a band that lies back from the coast and extends to the south-east, is in Category C condition and has suffered little change due to human usage.

(iv) Commencing from approximately 1 km south-east of Becher Point there is an area of vegetation along the coast that is in Category C condition and has undergone very minor changes due to human influence and usage.

Reference is made to Section 3.2.2 for qualification of the mapping units used above.

4.3 Representation of Landform, Flora and Vegetation

4.3.1 Landform

Becher Point is the most extensively and uniformly developed of the accretionary cusps that occur along the south-west coast. It is the only example of this landform in the near metropolitan area that has not been significantly altered by urban or industrial development.

Becher Point is also significant in that it contains two landform features that are not known to occur at other accretionary cusps. These are:-

(i) The sharply curvilinear or crescentic dunes that occur within the relict beachridge plain landform area that lies behind Bridport Point.

(ii) The NW-SE trending series of narrow linear depressions with seasonal wetland character that occur within the project area.

Whilst these landform elements are not necessarily remarkable in themselves they are not known to occur at any other locations within the south-west of the State.

On the basis of representation of the range of landforms that constitute the south-western Australian coast the Becher Point accretionary cusp has significant conservation potential. It is the largest and best developed accretionary cusp, and the only example of this landform in the near metropolitan area that has not been significantly modified by development. It retains much of its natural vegetation and also contains two geomorphic elements that are believed to be unique.

4.3.2 Flora

No gazetted rare, endangered or geographically restricted species of indigenous flora were identified within the project area. All species identified are known or believed to occur at alternate locations along the south-western coastal plain. Representation within conservation reserves identified in the System Six Study Recommendations (DCE, 1983) has not been evaluated on a species by species basis. However it can be reasonably suggested that most of the characteristic species of the site would be represented in other coastal locations in this region.

4.3.3 Vegetation Complexes

Many of the plant species that have been identified within the study area are widely represented along the south-west coastal areas. However the vegetation complexes that have been formed at Port Kennedy by the co-existence of particular species are not widely distributed along the coast and are under increasing pressures due to development of coastal land for urban purposes.

Much of the vegetation is not well represented in other conservation reserves in the region. Vegetation complexes found within the active or recently active relict foredune (primary dune) and those within the relict foredune plain are significant in this regard. Three units that occur within relict foredune areas are not known to occur outside the study area. These units are the Acacia lasiocarpa complex, the Olearia axillaris - Melaleuca acerosa complex and the Olearia axillaris-Jacksonia furcellata open heath. Examination of aerial photographs and topographic maps indicate they probably only occur within the study area.

In combination, the existence of good stands of vegetation complexes that are characteristic of south-west coastal areas and are not well represented in conservation reserves, together with the occurrence of three complexes that are thought not to occur outside the study area, indicate that parts of the study area, particularly at Becher Point and along the southern coast have high conservation potential on both a regional and local scale.

4.4 Conservation Value

Assessment of the study area's conservation potential, on the basis of the information presented previously in this section, leads to a number of conclusions. The definition and objectives of conservation that were defined by the "System Six Study" are implicit to these.

Conservation is "the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations". (DCE, 1983).

It has been subsequently reiterated by the EPA that the "primary aim of this (System Six) study was to identify opportunities for setting aside areas of land in the most intensively used part of Western Australia for the purpose of conservation of natural areas and retention in a natural setting". (EPA, 1988).

(i) Investigation has shown that the study area can be considered to consist of three broad classes of land:-

(a) land that has been physically and biologically degraded to a significant extent and could only be regenerated by intense effort, capital expenditure and stringent management of fire, access and weed invasion (for example, areas with vegetation of Category A condition);

(b) land that has been modified by previous usage but retains the essential framework of its ecological character (for example, areas with vegetation of Category B condition);

(c) land that has been minimally affected by previous usage and has effectively fully retained its ecological character (for example, areas with vegetation of Category C conditon).

In general, degraded land is located in the north of the study area, at Bridport Point and adjacent landward areas, and within the interior of the site where farmland that has been burnt and grazed, lies within close proximity. Land that is in good or better condition occurs within the narrow belt of primary dunes to the north of the squatter settlement, at Becher Point and in a belt that extends along the south coastal regions of the site. There are pockets of land within these areas where major degradation has occurred but is localized.

(ii) Whilst relict foredune landforms are widespread in the locality and are present at other locations on the south-west coast they are not well represented in conservation reserves. In particular, there is no local representation of the transition from coastal dune to foredune plain and the associated vegetation, within a conservation reserve.

The area of crescentic dunes formed by the intersection of adjacent accreting foredune systems is a geomorphic curiosity that is not known to occur elsewhere within a conservation reserve, or System Six recommendation area.

There are broadly similar landforms at Jurien Bay where periods of erosion followed by accretion have truncated an accreting foredune system then deposited fresh sediments against much older formations. However the intersection areas appear to be dissimilar to those at Becher Point and do not exhibit the unusual crescent shape. Significantly, the Jurien Bay relict foredune plains have been cleared for agriculture.

The linear depressions that support ephemeral wetlands are not known at any other locations in the south-west of the State, within conservation reserves, or within System Six recommendation areas. Although linear depressions that have wetland character occur outside the study area, to the east, these are believed to be significantly degraded, as are those within the northern parts of the study area.

(iii) Whilst none of the flora is unique to the site or area, three of the vegetation complexes that occur at the site are not known to occur outside of the project area, within conservation reserves, or System Six recommendation areas. It appears that the geomorphic processes that have created the Becher Point landform, and the biological environment of adjacent land over the period of deposition, have influenced the development of vegetation and have created some unusual combinations of flora.

(iv) The study area is one of the largest remaining tracts of coastal vegetation between Perth and Mandurah characteristic of this sector of the coast and contains areas that have not been significantly degraded by previous use.

(v) In combination these factors indicate that parts of the site have significant conservation value. These are:-

(a) active or recently active foredune and primary dune areas north of the squatter settlement at Bridport Point;

(b) land at Becher Point and in a band along the south-west coastal parts of the site, that is in good condition and contains some vegetation complexes that are peculiar to the study area;

(c) linear depressions/seasonal wetlands, particularly those adjacent to the south-west coastline that have not been degraded by previous use, and are lower in the landscape than more inland depressions and have strong wetland characteristics;

(d) the area of sharply curvilinear or crescent shaped dunes formed by the intersection of adjacent foredune systems, in particular the western portion of this area where the dunes have not been modified by access tracks and still clearly show the unusual crescent shape.

5.0 EVALUATION OF ENVIRONMENTAL IMPACT

Whilst investigation and subsequent reporting of physical, biological and ecological characteristics has treated the whole of the Port Kennedy area in equal detail, this evaluation of environmental impact deals specifically and only with Stage 1 of the proposal. No detailed plans for further stages are currently in place, therefore there is no basis upon which to evaluate development within the remainder of the study area. If and when proposals for development of additional stages are formulated they will be separately referred for technical assessment.

As the primary conclusion in respect of the environmental acceptability of development within the study area is clear, it should be stated here to provide a background to evaluation of Stage 1.

Primary Conclusion

A proportion of the study area has been degraded by previous use and could be acceptably developed provided appropriate management is also implemented. However, other parts of the study area have significant conservation value and are unsuitable for significant development, particularly that which involves substantial clearing of vegetation that is floristically unusual or structurally well preserved. In general, the northern sector of the study area including Bridport Point, in which Stage 1 of the project is proposed, is most heavily degraded, whilst conservation values are highest in the south of the study area and at Becher Point.

The discussion of the environmental impacts that will be specific to Stage 1 of the development proposal should be reviewed in this context.

5.1 Landform Modification

The existing landform will be significantly modified at two locations:-

(i) Strand, berm, recent beachridge and primary dune landforms will be removed to allow construction of the marina and hotel. Spoil will be relocated a short distance inland and recontoured to a sympathetic shape and alignment. The hotel will be located in this area.

(ii) The golf courses will be established on relict beachridge landform in the northern sector of the site. Some recontouring of the land surface will be necessary for fairway construction within the relict beachridge plain, however earthworks will not extend into the adjacent primary dune areas.

The area of land that will be affected by the marina and hotel represents a very small proportion of the total area within the site that has analogous landform. Significantly, this area has been badly affected by squatters. Recognizing that there are similar dune landforms to the north of the marina and on the south coast of the study area, that are in better physical (and biological) condition and will not be disturbed, the recontouring that will be necessary to enable the marina and hotel to be constructed is considered to be environmentally acceptable.

In contrast the area of crescent shaped dunes south and south-west of Bridport Point, particularly the western sector of this area where the landform is well preserved, has demonstrable conservation value. In recognition of the objectives of the System Six Study and of the specific recommendations for this site, retention of the bulk of this landform, for the recognized purpose of scientific reference and education, has been incorporated in the development plan. Limited partial development at the periphery of the area of occurrence should be considered to be acceptable.

The relict beachridge plain that forms the site of the proposed golf course is extensive throughout the study area, and in adjacent land to the east and south of Port Kennedy. It is noted also that examples of relict foredunes are located within the Rockingham Lakes area. (M103).

The layout of the proposed golf courses will reflect the existing topography, which is well suited to this purpose. Although some recontouring of the relict beach ridges and swales will be conducted, the final topography will strongly resemble the present form. Recontouring associated with golf course construction should not be considered a constraint to development.

Modification of the northern portions of the linear depression/seasonal wetland areas in the interior of the study area, as required for establishment of the golf courses, should not be considered a constraint as they are generally in a degraded state. Earthworks and other landscape treatments that will be conducted will be mostly restricted to those areas within Stage 1 that are in need of reinstatement and will upgrade the aesthetic appeal of these areas. As previously noted, the seasonal wetlands within the south of the study area, that have retained their natural character, will be retained, therefore development of portions of the degraded seasonal wetlands should not be considered a contentious issue.

5.2 Clearing of Vegetation and Flora

The areas that will require vegetation to be removed prior to development are largely the same as those discussed above. Limited further areas adjacent to proposed facilities will need to be cleared for roads, parking and support facilities associated with the marina, hotel and golf course.

The site of the proposed marina and town centre has been partially cleared and greatly dissected by current and previous users. Although the remaining vegetation was found to be in reasonable condition, the complexes are known to occur in other parts of the site where their present condition is better. Removal of vegetation to enable construction of the marina and town centre should therefore not be considered a constraint to development.

The area of land behind Bridport Point contains two vegetation complexes. Olearia axillaris - Jacksonia furcellata complex and Olearia axillaris - Melaleuca acerosa complex that are believed to be limited in occurrence to this site. Whilst these plant species are widely represented at other coastal locations, the conservation value that arises from their occurrence here in unusual association, has been recognized in the development proposal. Approximately 50% of the Olearia axillaris - Jacksonia furcellata complex and 35% of the Olearia axillaris - Melaleuca acerosa complex will be retained in managed reserve areas that are incorporated in the proposed layout. The remaining areas will be cleared for incorporation into the development. This balance between conservation and development is considered to be appropriate in the overall context of the project.

The site of the proposed golf courses contains Jacksonia furcellata - Acacia saligna complex, Olearia axillaris - Melaleuca acerosa complex, Xanthorrhoea swales and seasonal wetlands. Much of the vegetation, particularly the Jacksonia furcellata - Acacia saligna complex and the seasonal wetlands, have been significantly modified by previous use. The presence elsewhere within the study area, of representative stands of these complexes that are in better condition and will not be affected by the Stage 1 devlopment is noted, as is the proposal to preserve Olearia axillaris - Melaleuca acerosa complex within a Stage 1 conservation area. The indigenous vegetation will also be retained and appropriately restored in green belts between fairways. Preservation within a Stage 1 conservation zone of a 15 ha tract of indigenous vegetation is also noted.

Recognising the allowances for retention of vegetation that are contained in the development proposal, the clearing of vegetation that will be necessary to allow development should not be considered a constraint to the acceptability of the project.

None of the proposals to clear vegetation that are discussed above will result in the removal of any plant species that are rare, endangered or geographically restricted.

5.3 Ecological Processes

The major elements of the development proposal that have potential to impact upon the primary ecological processes that sustain the site are:-

(i) Clearing of vegetation and earthworks

(ii) Introduction of nutrients

(iii) Introduction of weeds

(iv) Provision of enhanced access and increased usage of the area

(v) Abstraction of groundwater and resultant water table drawdown.

These are discussed in respect of the way in which the primary ecological processes identified in Section 3.2.4 will be affected.

(i) <u>Dune Building and Land Stability</u>

The role of vegetation in stabilizing the unconsolidated surface sediments is clear, as is the potential of clearing, earthworks and increased access through the site to destabilize surface stability.

Detailed planning of the development and subsequent construction activities will take careful account of the need to restrict clearing to those areas that will be subsequently restabilized against wind erosion. It is noted that apart from the proposed marina, all development will be located outside the primary dune areas. Due to their relatively steep slopes and unconsolidated soils these are the most susceptible parts of the site to erosional damage resulting from loss of vegetation. Provision of access to beaches through the primary dunes would be successfully achieved by careful route planning. However there is a strong need to prevent significant foot or vehicle access outside specific pathways.

Provided construction activities and subsequent access corridors involve limited clearing, restabilization procedures are implemented, and access through foredunes is strictly controlled, soil and landform stability should be sustainable following implementation of the proposal.

(ii) Fire

There is clearly no intention of purposely encouraging or increasing the frequency of fire in vegetated areas that will remain adjacent to the completed developed areas. However, the increased fire risk that accompanies provision of greater access and consequent increased utilization of the site for recreation is readily apparent.

The vegetation within the study area has already undergone detrimental change due to overly frequent burning. The need to institute control measures is apparent in the present condition of vegetation in the northern sector of the project area.

The development will therefore incorporate fire management devices and procedures in detailed planning. Whilst failure of management procedures, resulting in frequent burning of the vegetation would have obvious detrimental effects, mangement that is successful in preventing or reducing fire to below the present frequency should be considered to be a substantial benefit of the proposed development.

(ii) Hydrological Cycle

The abstraction of groundwater to provide supplies for irrigation purposes will result in a drawdown of the water table within the superficial aquifer. Drawdown will be greatest in the central inland sectors of the site where lowering of the winter water table by up to approximately 2.0 m over an area of approximately 20 ha is anticipated. Drawdown within areas closer to the coast will generally be in the order of 0.5 m or less.

Most of the interior of the site comprises relatively high ground. Vegetation of the dune crests and most of the swales does not rely on the availability of groundwater for survival. Vegetation on high ground that is retained within the development area, and within adjacent undeveloped areas is therefore not expected to exhibit any signs of stress or change as a result of groundwater abstraction.

In contrast, the seasonal wetlands have developed a vegetation that relies at least in part, on the availability of shallow groundwater. The role of the seasonal surface ponding of rainwater in sustaining the wetland vegetation is not clear. Therefore, whilst it can be reasonably expected that lowering of the water table will have some effects on the natural vegetation within these seasonal wetlands, the extent of change is difficult to predict as surface ponding of rainfall will continue to occur. Reduction of available water in the soil profile, should preferentially affect plant species that require very high moisture, or are very shallow rooted. Deep rooted vegetation within these areas should not be as significantly affected. A shift in species composition away from those species that must have very high soil moisture and are very shallow rooted may well result from groundwater abstraction.

The development proposal has included a wetland and groundwater monitoring programme that will examine the future condition of the seasonal wetlands under the influence of groundwater abstraction. This is an appropriate response to the environmental management requirements that arise from the proposal to abstract groundwater.

Three factors are relevant in determining the acceptability of vegetation effects within these areas:-

(i) Seasonal wetlands that will experience the greatest water table drawdown, lie in the central parts of the site, within the zone of greatest land degradation from previous use. Clearing, trampling, burning and rubbish disposal have caused substantial modification to the ecological characteristics of these particular areas. Partial reinstatement of these wetlands to enhance the visual qualities of the golf courses will be conducted.

(ii) The best examples of the linear seasonal wetlands lie within the southern coastal sector of the site which will be minimally affected by water table drawdown and will not be physically affected by other Stage 1 developments. Water table drawdown is not anticipated in the area of the small circular wetlands near Becher Point.

(iii) Monitoring of groundwater levels and wetland vegetation as proposed in the southern coastal areas will enable the effects of water table drawdown (if any) to be determined and will provide a basis for corrective modification of groundwater abstraction.

Recognising these factors, the possibility that groundwater abstraction may result in changes to the species composition of seasonal wetlands within the interior of the site should not be considered a constraint to development.

As the proposed development does not include other changes to the land surface that would significantly affect recharge of the superficial aquifer, or flow within the aquifer, no other significant effects on the hydrology of the site are anticipated.

<u>Nutrient Cycles</u>

In view of the primary role played by vegetation in the nutrient cycles within the study area, retention of substantial areas of native vegetation is the only way in which the nutrient cycles can be preserved. Whilst clearing of certain parts of the site will reduce the quantity of nutrients within the biotic nutrient inventory, as long as significant areas of vegetation are also retained, the framework of the nutrient cycles will be preserved.

Clearing will reduce the biotic component of the nutrient inventory, however, the application of artificial fertilisers will introduce additional nutrients to the total nutrient pool. It is therefore important to examine how these additonal nutrients will behave in the study area following the establishing of Stage 1.

Vegetation within coastal areas of the south-west of the state has adapted to development and survival in a nutrient depauperate environment. Consequently it is apparent that artificial nourishment of vegetation adjacent to developed areas, through the application of fertilisers, may well cause undesirable structural and floristic changes. Increasing the nutrient status of natural vegetation areas would probably also assist the invasion of weeds.

Nutrients will be imported to the site to sustain park and garden areas within the marina and hotel complex and for the maintenance of grassed areas within the golf course. Examination of the way in which these will behave in the study area identifies two primary factors:-

(i) the demonstrated inability of sandy coastal soils to retain nutrients against leaching by rainfall;

(ii) the high infiltration capacity of surface soils and the resultant absence of surface water drainage lines that lead into or out of the site.

In combination, these factors indicate that effectively all fertiliser that is imported to the site for landscape maintenance will be rapidly leached by rainfall and irrigation and will be directly incorporated in the superficial groundwater. This is the natural nutrient sink in the ecosystem. As the site's vegetation does not exclusively utilize groundwater for survival, this additional nutrient will generally not be available to the natural vegetation.

In summary it can be concluded that retention of areas of vegetation will preserve the nutrient cycles, although the biotic inventory will be reduced by clearing. Artificial fertiliser should not affect the natural nutrient cycles provided application is confined to developed areas and fertilisation of natural vegetation does not occur.

5.4 Conservation Value

The conservation values that have been identified at the study area and the way in which they are constituted by specific components of the natural environment have been discussed in previous sections. It is therefore adequate here, to simply reiterate the primary conclusion of the study.

The study area contains landform and vegetation types that have been degraded by previous use and are better represented elsewhere, together with land that has good physical and biological condition and is restricted in occurrence to either the project area or adjacent land. Development work within Stage 1 of the proposal mostly affects land that consists of the former of these categories and thus can be implemented without significant loss of conservation values.

The area of unusual crescent-shaped dunes which also supports the plant associations Olearia axillaris - Jacksonia furcellata and Olearia axillaris - Melaleuca acerosa, is an exception. In recognition of the high conservation value of this area careful consideration has been given to the retention of representative examples of these elements of the site, within a conservation area that is a component of the Stage 1 proposal and will be managed as such. This is considered to be an appropriate response to the conservation values that have been identified.

The validity of these conclusions relies entirely on the successful implementation of management procedures that will preserve the conservation values within the remainder of the site, that are identified and discussed in previous sections of this report.

It is noted that implementation of the proposal, and successful complementary management of conservation values in adjacent undeveloped parts of the study area, will provide increased opportunity for passive recreation within a natural setting. This is a prime objective of the System Six Study Recommendations (DCE, 1983, EPA 1988).

The location of the study area in relation to local and regional population areas indicates that sensitive planning, careful development and stringent management following implementation will result in a recreational facility that significantly increases the publicly available resources for active or passive recreation in a natural setting.

6.0 ENVIRONMENTAL MANAGEMENT REQUIREMENTS

On the basis of the development proposal described in Volume II of the ERMP, and the technical evaluation of the study area environment reported previously in this document, environmental management of both the construction phase and the operational phase of the project will need to embrace the following general areas:-

(i) Control of access to vegetated areas

(ii) Maintenance of soil stability

(iii) Prevention of fire

(iv) Revegetation of all areas disturbed by construction

(v) Control of weeds

(vi) Management of fertiliser and waste water

(vii) Monitoring of groundwater levels and seasonal wetland vegetation in the southern coastal region of the study area.

It is relevant to also recognize, that implementation of management programmes that address the areas listed above, will inherently result in the maintenance of a high quality environment that will also support and contribute to the desirability of the location as a site for recreation, and therefore to the success of the project.

7.0 CONCLUSIONS

Investigation of the environmental implications of the proposal to establish the Port Kennedy Regional Recreation Centre Stage 1, in the context of information presented describing the physical, biological and ecological characteristics of the site, has the following conclusions.

1. The study area comprises land that has been significantly degraded by previous use, together with land that has undergone much less change and retains its essential ecological character, largely through the persistence of natural vegetation.

2. In general terms, the northern sector of the study area and the Bridport Point area have been the most heavily used and therefore have suffered the most degradation. Land that has good conditon is located on the coastal fringe, at Becher Point and in the general southern regions of the study area.

3. Parts of the study area have high conservation potential. This is a result of the presence of natural vegetation that is in good condition and vegetation complexes that are either not believed to occur outside the study area, or are poorly representated in conservation reserves, or other areas subject to System Six Study recommendations. The study area also contains some unusual landforms that are not known to occur at other locations, and therefore are perceived to have conservation value.

4. The development proposal evaluated by the investigation is considered to be environmentally acceptable. Further stages of development will need to be separately referred to the Environmental Protection Authority for evaluation and approval.

5. In general, the development will be substantially confined to the northern sector of the site where previous use has resulted in degradation of the

natural environment.

6. Development of the golf courses will require relatively minor modification of the existing landform and will remove vegetation that has been previously modified by fire, clearing, rubbish disposal and general access. This part of the study area has reduced intrinsic value and habitat potential.

7. The on-land component of the marina facility will utilize a location where landform and vegetation have been significantly modified by previous use. The presence of better examples of this site's landform and vegetation types at other locations within the study area, indicate marina construction should be considered environmentally acceptable.

   Clearing of Olearia-axillaris - Jacksonia furcellata complex at the periphery of the marina area, and Olearia-axillaris - Melaleuca acerosa complex at the proposed hotel site is considered to be acceptable subject to the retention of representative stands in conservation zones, as described previously.

   The area of curvilinear dunes near Bridport Point is not suited to total development. The development proposal recognizes the conservation value of this landform and has appropriately included the bulk of the area within a conservation zone.

8. Drawdown of the superficial aquifer will occur within areas that will be largely cleared for the golf courses. Whilst dune vegetation that is retained both within and beyond the proposed golf courses is not expected to be affected by drawdown, seasonal wetlands within these areas will likely undergo some changes in floristic composition and structure. The precise nature of these changes is not clear due to the unknown relative importance of ponded rainfall. Importantly, the seasonal wetlands within the proposed golf course locations are presently in poor condition.

The seasonal wetlands in the southern sector of the study area are likely to experience minor water table drawdown as a result of groundwater abstraction. However, the continued occurrence of winter surface ponding may well cause the effects of drawdown to be very minor. Monitoring of the water table height in the vicinity of these wetlands, and of the condition of the wetland vegetation is considered to be an appropriate level of environmental management.

The small circular wetlands at Becher Point will not experience water table drawdown.

9. The utilization of artificial fertilisers within the golf course and landscaped areas of the hotel and marina complex should not result in detrimental terrestrial ecological effects. Nutrient that is not quickly assimilated by vegetation should be rapidly leached to the superficial aquifer, which is the natural nutrient sink of the ecosystem.

10. The conservation potential of land outside Stage 1 will be retained provided that environmental management correctly addresses the following issues:

    (a) control of access to areas of native vegetation

    (b) maintenance of soil stability

    (c) prevention of fire

    (d) revegetation of all areas disturbed by construction

    (e) control of weeds

    (f) management of fertiliser and wastewater

(g) monitoring of groundwater levels and seasonal wetland vegetation in the southern coastal region of the study area.

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APPENDIX C(i)

A COMPILATION OF FAUNA RECORDS FOR THE PROJECT AREA

The following lists have been compiled from three sources -

(i) records from the W.A. Museum

(ii) other literature cited in the bibliography

(iii) opportunistic sightings during field survey.

It is important to recognize that rigorous field survey to support this data has not been conducted. Therefore the list may be incomplete or may contain species that are not always present. Species marked + are from Museum records, whilst those marked * were identified during survey in April and May 1988.

MAMMALS

Introduced:

Fox	Vulpes vulpes
Rabbit	Ocycrolagus cuniculus *
Black rat	Rattus rattus
House mouse	Mus musculus+
Feral cat	Felis catus

Native:

Western Grey Kangaroo	Macropus fuliginosus
Short-nose bandicoot	Isoodon obesulus+

REPTILES

Tiger Snake	Notrechis scutatus occidentalis*
Skink	Ctenolus fallens
Burton's legless lizard	Lialis burtonis+
Skink	Herniergis quadrilineata
Skink	Lerista elegons
Gould's snake	Rhinoplocephalus gouldii+
Dugite	Pseudonaja affinis

AMPHIBIA

Moaning frog	Heleioporus eyrei+
Frog	Ranidella insignifera
Banjo Frog	Limnodynastes dorsalis

AVIFAUNA

Grey Butcher-bird	Cracticus torquatus*
Singing Honeyeater	Lichenostomus virescens*
Silver Gull	Larus novaehollandiae*
Crested Tern	Sterna bergii
Willy Wagtail	Rhipidura leucophrys*
Silvereye	Zosterops lateralis
Richard's Pipit	Anthus novae seelandiae*
Roseate Tern	Sterna dougalli
Pied Cormorant	Phalacrocorax varius
Nankeen Kestrel	Falco cenchroides
Tree Martin	Petrochelidon nigricane
Splendid Blue Wren	Malurus splendens
Grey Fantail	Rhipidura fuliginosa

Avifauna cont'd

Common Bronzewing	Phaps chalcoptera
Twenty-eight Parrot	Barnadius zonarius
Spotted Harrier	Circus assimilis *
Swamp Harrier	Circus approximans *
Australian Pelican	Pelecanus conspicillatus *
Curlew Sandpiper	Calidris ferruginea *
Australian Magpie	Gymnorhina tibicen *
Australian Raven	Corvus coronoides *
Brown Quail	Coturnix australis

APPENDIX D: VEGETATION SURVEY

FOR BOWMAN BISHAW BY MALCOLM TRUDGEN

APPENDIX D

VEGETATION SURVEY OF THE POINT BECHER AREA

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1.0 INTRODUCTION

The study area is a roughly triangular sandy point on the Western Australian coast about fifty km south of Perth and lies south of Rockingham and north of Mandurah. Its north-west side (Port Kennedy) is the gently curved southern section of Warnbro Sound (a large bay protected by a string of rocky islets), the western tip is Point Becher, the south-western side an almost straight beach with the third side running north-south (following property lines) and located so as to just include Becher Point and its immediate hinterland.

The whole study area is the subject of recommendations (numbers M106.1 & M106.2) in the System Six Report (DCE 1983, p300) which advocates that the area be subject to its general recommendations on planning and management of regional parks and that the Metropolitan Region Planning Authority (which has been superseded by the State Planning Commission) "consider "reserving" those portions not already "reserved" for Parks and Recreation under the Metropolitan Region Scheme" (a strip from a half to one km wide along the coast is already reserved). While not specifically recommending it, the System Six Report also suggests that the recreation potential of the area "could be even greater if a link is provided between Port Kennedy and the White Lakes Region Open Space (M103)......" (DCE 1983, p300).

The System Six Report also makes the following observations about the study area: "The area's conservation value is high, because there is little similar land available between Fremantle and Mandurah." and "The area has obvious potential for recreation, and is already used for fishing, camping and off-road vehicles." (DCE 1983, p300).

2.0 AIMS, METHODS AND LIMITATIONS

Aims

The aims of this report are to map and describe the vegetation of the study area in sufficient detail to allow an analysis of its regional conservation values and to record the flora to enable comment on its value.

Methods

The study area was visited (May 1988) and vehicle and foot transects were made as was necessary to draw a vegetation map, describe the vegetation and note the condition of the vegetation. The cover and height of the species present at selected sites were noted to allow description of the vegetation present in the study area (there were 42 recording sites in all).

The major species in the vegetation are well known to the author and specimens were only collected where the species was not known or a confirmation was needed. The condition of the vegetation was recorded on a three point scale (see map one).

The vegetation units are described using the Classification of Specht as modified by Aplin (1979).

Limitations

The major limitation of the study is that the flora list provided is incomplete as the field survey was carried out at the beginning of winter and annual plants were only just beginning to germinate and cryptophytes had not emerged.

3.0 PHYSICAL SETTING

As noted above the study area is a roughly triangular sandy point on the coast south of Perth. Its genesis is very important for this report as the vegetation developed in the study area has been closely controlled by the interaction of the species available for colonising the area with the various niches formed.

Most of the study area consists of series of relict foredunes or "beach-ridges" (and the swales between them) that have been successively cut off from the coast as it has moved westwards. Many of the swales are damp even at the beginning of winter and a number probably have free water in winter. The relict foredunes roughly parallel the present coastline and are usually separated from the beach by a younger and taller dune that is equivalent to the Q4 (or youngest) age dunes of the Quindalup Dune sequence described for the Mandurah to Bunbury region by McArthur and Bartle (1980). However in the northern part of the study area between the Q4 age dune and the relict foredunes there is a thin band of irregular dunes that have similar topography (although lower) and vegetation to areas south of Mandurah mapped as Q2 age dunes by McArthur and Bartle. This band is treated as Q2 dunes in this report although they have not been assigned to this group previously. In the southern part of the study area there are stabilised blowouts that have encroached (from the Q4 dunes) on to the relict foredunes, these are treated as Q4 in age. In front of these stabilised blowouts there are younger recently stabilised dunes.

Whereas the Q2 dunes are very extensive in area between Mandurah and Bunbury and the Q4 dunes are reasonably extensive south of Mandurah the relict foredunes are not found in the Mandurah to Bunbury strip.

4.0 FLORA

Seventy two species of native flowering plants (angiosperms) were recorded while mapping the vegetation. This probably represents almost all of the perennial species (excepting cryptophytes) that would be recorded in the study area by a systematic search for flora. However very few of the annual species (and none of the cryptophytes, especially orchids) that would be expected in the area were available for collection due to the season the survey was carried out. One individual of the Rottnest Island Pine (Callitris preissii) was also recorded (by M. Bowman).

The species recorded are generally common or widespread in the vegetation types found in the study area and in other coastal vegetation, however they are not evenly dispersed throught the study area. In particular those species associated with the swamps are not found in the other units.

In addition to the native flora recorded eighteen species of introduced plants were recorded. With Poaceae (grasses) and Asteraceae (daisies) being the most abundant families. However species from several other families were also present including *Trachyandra divaricata (onion weed) and *Euphorbia terracina both of which are agressive weeds although the *Euphorbia seems to be restricted more to disturbed areas than the *Trachyandra.

5.0 VEGETATION

The vegetation of the study area will be described in relation to the soils units that they occur on, that is the relict beach ridges, the Q2 Dunes, the Q4 Dunes and the strand. Vegetation stabilising currently developing or recently developed dunes is described with the strand and the stabilised blowouts with the Q4 dunes. The swales that are damp enough to develop distinctive vegetation are treated separately as wetlands.

STRAND AND STABILISING DUNES

AC *Arctotheca calendula, *Cakile maritima open herbland

This unit occurs at the back of the beach berm between the shore and the dunes. It occurs as open patches of the Arctotheca and the Cakile (both of which are introduced) with small amounts of Salsola kali. At the time of the survey there was very little of the Arctotheca present, but this may have been due to the time of the year. In some places it has significant amounts of Tetragonia decumbens (this is probably an intergrade to unit Sl).

This unit is subject to disturbance from storms and disturbance by man but the species in it are adapted to this as part of their adaptation to a hostile environment. It occurs commonly on beaches in the south-west of Western Australia. On the south west facing side of the point this unit was producing irregular relief on the strand due to the accumulation of sand around the plants and was being invaded by Spinifex longifolius and S. hirsutus (both with < 1% cover).

Sl Spinifex longifolius hummock grassland (with Tetragonia decumbens)

This unit occurs between the unit described above (AC) and the Q4 age Quindalup Dunes. It has very variable composition, for example at site 2 (on the beach opposite the extension of Chelmsford Ave.) the Spinifex had 40% cover and the Tetragonia 10% while at site 30 on the tip of the Point the Spinifex had 15-20% cover and the Tetragonia 50-60% cover (but at places in the same stand had down to 35% cover) and at site 36 the Spinifex had 25% cover the Tetragonia 35% cover and there was 5% cover of Olearia axillaris. At site 2 the stand occurred on an encroaching lens of sand at the base of a Q4 age Quindalup Dune, while at site 30 it occurred on a separate dune encroaching on a small wetland. Other species found in this unit include *Cakile maritima, *Arctotheca nivea, Spinifex hirsutus and Olearia axillaris (when this is present the unit is trending towards unit Oa_1).

Like unit AC this unit also occurs commonly on beaches in the south-west of Western Australia, although it does not usually have significant amounts of the Tetragonia.

Oa_1 Olearia axillaris open shrubland to open heath

In the study area this unit occurs on low, relatively young dunes that occur on the seaward side of Q4 age dunes (sites 15, 16, near squatters shacks) at port Kennedy. Sites 15 and 16 are on two low dune crests, the cover of the Olearia in this stand varies from 1% to 30%, beneath it there is 25-30% of Spinifex hirsutus and small amounts of Pelargonium, Acanthocarpos preissii, Tetragonia decumbens and Carpobrotus. Occassional larger shrubs of Alyxia buxifolia, Spyridium globulosum and Acacia cyclops occur also. In the area of sites 15 and 16 there is moderate weed invasion of annual grasses, this is due to the close proximity of the squatters shacks. *Trachyandra divaricata (onion weed) is also present, although it is not yet a significant problem.

Although Olearia axillaris is very common along the coast of the south-west of Western Australia it rarely forms vegetation units where it is the sole dominant in the shrub layer. For example on the coast of the shire of Mandurah it forms heath units with Acacia rostellifera and Scaevola crassifolia but does not form units like this one or the following one (Trudgen, 1987).

Oa_2 Olearia axillaris closed heath to closed scrub

This unit occurs on an apparently relatively young dune on the south west facing side of the point (site 37). This dune is much larger than those the preceding unit occurs on and the more developed (denser) vegetation probably indicates that it is slightly older. The Olearia is 1-2 m tall and had 80% cover, Acacia saligna was also present in the upper shrub layer but with very little cover (1%). Other species present included Acanthocarpos preissii (15-20%), Lomandra maritima (1-15%, variable), Lepidosperma gladiatum (in patches) and some Hardenbergia comptoniana, Tetragonia decumbens and Pelargonium capitatum. On the windward side this unit grades fairly abruptly to a stand of unit Sl. On the leeward side it grades much more gradually to the stand of unit Ag, with gradually increasing amounts of Acacia saligna, Acacia lasiocarpa, Lomandra maritima and in the swales Lepidosperma tenue. No weeds were observed at site 37.

Note: It is possible that this stand is a Q4 age Quindalup dune (or older given the presence of the Lomandra maritima which usually occurs on Q3 and older dunes) that has been very degraded due to the short distance from the beach and then regenerated to the current vegetation (Oa_2).

Q4 DUNES

Trudgen (1987) noted that there are two age variants in unit SO on the coast of the Shire of Mandurah, in that survey area the younger phase often occurs as a smaller dune formed on the lower slope of the windward side of the older phase. In the current survey area only the older phase occurs, but on two distinct dune forms with differing amounts of the species (SO_{1a} & SO_{1b}) found in this unit. However both variants are well within the range of variation of the unit which, though never large in area, is well represented along the coastline south of the present study area.

SO_{1a} Scaevola crassifolia, Olearia axillaris low open heath to closed heath to open scrub

This variant of unit SO is found on a dune that runs parallel to the beach from the north west corner of the study area to Point Becher. It starts out with (locally) fairly high relief but becomes gradually lower as it approaches Point Becher. In the area of the sqatters huts it is quite low and narrow but as it approaches Point Becher it becomes broader and regains a little height.

At site one on the crest and upper slopes of the dune (in the NW corner of the study area) the unit is about 1 m tall, moderately dense and relatively rich in species. The larger shrubs present were Scaevola crassifolia (5-10%), Olearia axillaris (10-15%), Spyridium globulosum (< 5%), Alyxia buxifolia (5%), Myoporum insulare (5-10%) and smaller amounts of Acacia cyclops, A. rostellifera and Hibbertia cuneiformis. Other species present were Spinifex longifolius, Lepidosperma gladiatum, Tetragonia decumbens, Acanthocarpos preissii and Hardenbergia comptoniana. On the leeward slopes of this unit where it is protected from wind and salt spray it is much taller (to 2 m) and denser (> 70%), Rhagodia baccata also occurs here and there are dense patches of Lepidosperma gladiatum (Coastal Sword Sedge).

As noted above the dune becomes lower south from site 1, at site 17 (amongst the squatters huts) the unit has changed, becoming simpler (probably partly due to disturbance) with Spyridium globulosum becoming dominant and fewer species. Close to the Point the unit is broader and rather than a single dune is undulating. In this area there is much more Acacia cyclops (to 20% cover). Along this dune *Trachyandra divaricata (Onion Weed) is present and in the area of the squatters huts there are also introduced annual grasses.

On the windward side this unit abuts units Sl (north of the squatters huts) and unit Oa_1 (from the squatters huts south). On the leeward side it abuts the Q2 dunes (north of the squatters huts) and unit Ma, except at Point Becher where it also abuts one of the stands of Acacia rostellifera.

Note: There is a small stand near the two huts on the south-west side of the point that has also been referred to this variant of SO. It is very degraded (by a combination of wind and man) and is reduced to wind pruned Spyridium globulosum bushes with Tetragonia decumbens and some Olearia axillaris between them. [The reduction to dominance by Spyridium may alternatively be a reflection of the reduced relief of this dune; note the composition of the low dune near the squatters huts on Port Kennedy.]

SO_{1b} Scaevola crassifolia, Olearia axillaris low open heath to closed heath to open scrub

This variant of unit SO is found in the south east part of the study area on an area of stabilised blowouts of fairly high relief. In species composition it is similar to the other variant, but has much more Scaevola crassifolia (from 35% to 85% rather than 5-10%) as well as more Hibbertia cuneiformis (10%) which is not usually a common species in this unit. The area of this unit was in excellent condition with no obvious signs of fire and no weeds. The high percentage of Scaevola crassifolia indicates a trend towards the younger variant of SO.

Q2 DUNES

One thin strip has been mapped as vegetation found on this dune system because of the strong similarity to the vegetation of Q2 dunes found south of Mandurah (Trudgen 1979). In contrast to the relict foredunes these dunes are much more irregular, however the occurrence of them in the study area is so narrow that they have been overlooked previously. The size of the individual areas of the vegetation types on these dunes in the study area is so small that they could not be individually mapped and Q2 on the vegetation map is a mosaic of the following vegetation types:

Lm Lomandra maritima closed herbland to mixed low open shrubland to low closed heath with Lomandra maritima

This unit occurs on the crest of the Q2 dunes, it is very low vegetation with 75 % cover of the Lomandra which although it is a lily is a "grassy" looking plant with leaves about 30 cm tall, 15-20% cover of Acanthocarpos preissii, and small amounts of other small plants including Conostylis, Lepidosperma tenue, Isolepis nodosa, Phyllanthus calycinus and Poa poiformis. There are a occassional taller shrubs of Alyxia buxifolia and Leucopogon parviflorus. Near the squatters huts there is up to 5% cover of Acacia lasiocarpa present also.

The stands of this unit seem were in good to very good condition (its low open appearance should not be mis-interpreted as being the result of degradation) although there were many tracks around them.

This unit is very common south of White Hills Road and is reasonably well represented in Yalgorup National Park.

Ar_2 Acacia rostellifera low open heath to open heath over Melaleuca acerosa

This unit occurs on the slopes of the Q2 dunes and has a moderate cover of Acacia rostellifera (20-35%, 1.8-2.2 m) and at site 4 Alyxia buxifolia (1.9 m, 20%) and Spyridium globulosum (1.8 m, 20%) over smaller amounts of lower shrubs of Melaleuca acerosa, Leucopogon parviflorus, Rhagodia baccata, Acanthocarpos preisii and Phyllanthus calycinus. Beneath the lower shrubs there is an open to moderate cover of Lomandra maritima (10-35%) with small amounts of Conostylis, Stipa flavescens and Poa poiformis. The creeper Hardenbergia comptoniana is also often present.

Sites 4 and 5 were both in very good condition, although there was some onion weed at site 5 and the area they occur in has several tracks through it.

Note: The same name has been used for this unit as in Trudgen 1987, however there is less Melaleuca acerosa present in this unit in the study area than in better developed stands. The presence of Alyxia buxifolia and Spyridium globulosum in this locality is due to the sites being close to the Q4 dunes.

RELICT FOREDUNES

These areas can have rapid changes of vegetation as the crest are often quite close together. As a consequence it has been necessary to map the vegetation found on them as a series of complexes, but giving separate descriptions of the vegetation found on the crests and in the swales. Some of these complexes are quite distinctive, others less so. However they all have many species in common, especially in the swales and after fire can look very similar. The swales of some complexes are very similar and all tend to have the same emergents. This is not surprising given the relatively low relief of these dunes. In one complex the dune crest type is not developed over large areas due to the low relief.

Interpretation of the vegetation has been made difficult by the frequent burning and the very extensive slashing of shrubs. This has been exacerbated by the sensitivity to fire of Olearia axillaris. Unlike many of the other species in the vegetation it does not regenerate from rootstocks and does not build up a store of seeds in the soil, rather it depends on seed from adjoining areas being blown in by the wind. This means that areas with dense cover of Olearia do not recover rapidly after fire but take many years to return to this species, in the interim the other species present take up the available space.

JA Jacksonia furcellata, Acacia saligna Complex

This complex is the most widespread in the study area, occupying a significant proportion of the site. It also extends inland from the study area. However its extent is still relatively limited as it only appears to occur in and near to the study area and certainly does not occur south of Mandurah (Trudgen, 1987; Keating and Trudgen, 1986).

When unburnt and not slashed (most of its stands in the study area have been burnt and slashed) it develops a moderate cover of Jacksonia furcellata and Acacia saligna. In areas that are closer to the coast Olearia axillaris is also present in the upper layer. Scattered through this complex there are areas where Acacia rostellifera occurs, where this species has significant cover it is treated as a separate unit. In the southern part of the study area the taller dune crests have a moderate cover of Acacia lasiocarpa (sites 34, 39 = JAAl).

When this complex has been recently burnt and started to regenerate the relative abundance of perennial herbs, grasses and sedges give it a "weedy" appearance that is unusual in the south-west of Western Australia, this appearance should not be mis-interpreted as being severe degradation. Although there are areas in this complex that are weedy (particularly along and near the tracks and near the eastern boundary of the study area) these are less widespread than first appearances would indicate.

Crests: **JA Jacksonia furcellata, Acacia saligna open shrubland**

This unit does not have a dense intermediate shrub layer like some of the other relict foredune complexes (for example Al). It has a low to moderate (5-15%) cover of the Jacksonia and Acacia saligna with small amounts of Leucopogon parviflorus and Exocarpos sparteus over a moderately dense (40-50%) lower shrub and herb/grass/sedge layer. At some sites there were small amounts of Olearia axillaris. In the absence of fire this species would probably be more important in the structure of this unit, especially in the areas closer to the coast. Prominent in the lower layer (though all are not necessarily important at all sites) are the sub-shrubs Scaevola holosericea, Acanthocarpos preissii, Rhagodia baccata and Opercularia vaginata, Lomandra maritima and Conostylis candicans and C. aculeatata (perennial herbs), Poa poiformis and Stipa flavescens (grasses) and Lepidosperma tenue, Loxocarya flexuosa and Schoenus grandiflorus (sedges). Other species recorded were Phyllanthus calycinus, Kennedia prostrata and Orobanche ? minor.

Although much of the area of this vegetation type has been burnt and slashed the sites recorded were not badly degraded and were scored as Category B on the scale given above. They have good potential for regeneration and with good management they would be able to become Category C on that scale.

Crests (cont.) **JAAl Jacksonia furcellata, Acacia saligna open shrubland over Acacia lasiocarpa low open shrubland to low shrubland**

This unit is very similar to the preceding unit, differing in the presence of the Acacia lasiocarpa (< 10-20%) and shrubs of ? Trymalium (an undescribed species), and Gompholobium tomentosum which indicate an affinity to unit OaAcl. Other species recorded were Hardenbergia comptoniana and Senecio lautus. (Sites recorded during site survey were scored as Categories C and B.)

Swales **JAH Jacksonia furcellata, Acacia saligna open shrubland over Hemiandra pungens**

This unit also has an open cover of Jacksonia furcellata and Acacia saligna over a low understorey in which Hemiandra pungens forms bright green prostrate mats against a dull background. However the understorey is less shrubby than unit JA and has more of the native grasses and sedges. There is considerable variation with some swales having dense cover of Lepidosperma tenue, others having much Stipa flavescens, or mixtures of these with Poa poiformis and Loxocarya fasicularis. Some swales have very few shrubs and are small grasslands of Stipa flavescens. (The site recorded during site survey was scored as Category B condition.)

The swales tend to have more weeds, particularly annual grasses such as Bromus but also *Romulea rosea (Guildford Grass), than the crests but most are not badly infested (those near the tracks are worst).

OaAc Olearia axillaris, Acacia cochlearis Complex

This complex occurs on N-S trending somewhat irregular relict foredunes in the very northern part of the study area, in a strip between complex JA and the narrow strip of Q2 Dunes. It extends out of the study area (to the north, onto part of the Westport development area) but is not extensive in or out of the study area.

Crests: **OaAcl Olearia axillaris, Acacia cochlearis shrubland over Acacia lasiocarpa low shrubland**

This unit has an open to moderate upper shrub layer in which Olearia axillaris (10-15%) is the most abundant species but in which Acacia saligna (to 10% on some slopes) and Spyridium globulosum (and to a lesser degree Exocarpos sparteus and Leucopogon parviflorus) can be locally common also. Acacia cochlearis varies from 1-5% cover and in the study area is only found in this unit. Beneath this there is a lower shrub layer with Acacia lasiocarpa 20-30%, Gompholobium tomentosum 2-3% and lesser amounts of ? Trymalium, Scaevola holosericea, Rhagodia baccata, Hardenbergia comptoniana, Hemiandra pungens, Rhagodia baccata, Phyllanthus calycinus and Acanthocarpos preissii. Beneath and mixed with this lower shrub layer there are Lomandra maritima to 20% and smaller amounts of Stipa flavescens, Poa poiformis, Conostylis, Dianella divaricata and Lepidosperma tenue. (The sites recorded during survey were scored as condition Category B and C.)

Swales: The swales in this complex are very similar to those in the complex above (unit JAH).

OaMa Olearia axillaris, Melaleuca acerosa Complex

This complex occurs on relict foredunes in an irregular belt paralleling the port Kennedy coastline. The relief of this group of relict foredunes drops from north to south and the vegetation of the complex changes with this change in relief. The south-west section being distinguished as complex OJ.

The area of this complex mapped does not extend out of the study area and it seems unlikely (from examination of aerial photographs) that there are other stands.

Crests: **$OaAsMa_1$ Olearia axillaris, Acacia saligna open shrubland over Melaleuca acerosa low shrubland**

This unit occurs on the crests and upper slopes of the relict foredunes. The upper shrub layer has to 15% Olearia axillaris (although in many areas this has been much reduced by fires) with 5-10% of Acacia saligna and small amounts of Leucopogon parviflorus. The lower shrub layer has Melaleuca acerosa with 15-35% cover and small amounts of Acacia lasiocarpa, Acanthocarpos preissii, Rhagodia baccata, Phyllanthus calycinus, ? Trymalium and Scaevola holosericea. In and beneath the lower shrub layer there are Stipa flavescens, Poa poiformis, Lepidosperma tenue, Lomandra maritima, Stipa sp., Loxocarya flexuosa, Opercularia vaginata, Conostylis aculeata and Schoenus grandiflorus.

Swales: **$OaAsMa_2$ Olearia axillaris, Acacia saligna open shrubland over Melaleuca acerosa low open shrubland to shrubland**

The upper shrub layer of this unit is very similar to that of the preceding unit but the lower layer had much less Melaleuca acerosa (only 5-15%) and fewer shrub species. However the sedge and grass species had increased cover with Lepidosperma tenue having 15-25% cover in some swales and Stipa flavescens having 10-15% cover in others.

OJ **Olearia axillaris, Jacksonia furcellata Complex**

This complex occurs on the south-west section of the same belt of relict foredunes as complex OaMa. However in this area the topography is lower and the swales are much damper. In these swales there is Baumea juncea (a fine sedge to 90 cm tall) growing with the Olearia, this is very unusual as the Olearia usually grows on well drained coastal dunes.

The area of this complex mapped does not extend out of the study area and it seems unlikely (from examination of aerial photographs) that there are other stands. There are no similar areas to the south of Mandurah (Trudgen 1987).

Crests: **OJ_1 Olearia axillaris, Jacksonia furcellata open heath**

This unit occurs on low dune crests in the. It has a much denser cover of Olearia than in the OaMa complex with Jacksonia and some Spyridium globulosum rather than Acacia saligna and a much more open lower shrub layer. Species in the rather than Acacia saligna and a much more open lower shrub layer. Species in the lower shrub layer are Melaleuca acerosa (1-5%), Rhagodia baccata, Acacia lasiocarpa and Scaevola holosericea. The herb layer is also very open with small amounts of Lepidosperma tenue, Lomandra maritima, Schoenus grandiflorus and Conostylis aculeata.

Swales: **OJ_2 Olearia axillaris, Jacksonia furcellata open heath**

The shrub layers in this unit are very similar to the unit above, except that it has more Melaleuca in the lower layer. However the herb layer is much more dense having large amounts (up to 80%) of Lepidosperma tenue and Lepidosperma longitudinale and 5-35% of Baumea juncea, indicating that these swales are seasonally quite damp. As noted above it is unusual to have Olearia growing in such damp areas.

Al Acacia lasiocarpa Complex

This complex occurs on NE-SW trending relict foredunes in the southern half of the study area. It is very easily distinguishable from the others by the dense layer (especially on the dune crests and slopes) of Acacia lasiocarpa a bright green shrub of 0.5-1.0 m tall related to the well known prickly moses (Acacia pulchella).

Like the preceding complex the area of this complex mapped does not extend out of the study area and it seems unlikely (from examination of aerial photographs) that there are other stands. In all the places where it was examined this stand was in Category C condition.

Crests: **Al_1 Jacksonia furcellata open shrubland over Acacia lasiocarpa low closed heath**

This unit has a very open (5-10%) layer of Jacksonia furcellatata and occassional Olearia axillaris over a very dense layer (85-95%) of Acacia lasiocarpa. Other shrubs present include Exocarpos sparteus, Leucopogon parviflorus and Rhagodia baccata. Smaller species present include Acanthocarpos preissii, Scaevola holosericea, Lepidosperma tenue, Loxocarya flexuosa, Stipa flavescens and Poa poiformis.

In the south-west corner of the stand of this complex there is a variation with Melaleuca acerosa occurring as well as the Acacia lasiocarpa (site 35). These two species total about 95% cover with the Melaleuca varying from 0-40%, however as they are both bright green shrubs (and grow tangled through each other) it is difficult to assess their contributions to the total.

Swales: **Al_2 Jacksonia furcellata, Acacia saligna open shrubland over Acacia lasiocarpa low heath**

The swales differ from the crests in the presence of slightly more Jacksonia furcellata (although it is very variable, from 2-15%) and some Acacia saligna in the emergent layer and in a thinning of the Acacia lasiocarpa layer to less than seventy percent (40-60%). In a similar fashion to all the swales in the relict foredunes in the study area the herb layer is denser in the swales

Ar Acacia rostellifera Complex

There are a number of stands in the study area dominated by Acacia rostellifera. This species is very variable in form, growing from a small shrub on the exposed windward sides of the foredunes to a small tree on sheltered sites with better soils. Stands are often low at the edges where the individuals are bushy and taller in the centre. Parts of the stands can be very like unit Ar_2 (which is found on the Q2 dunes, see above), but the stands show much more variation than this unit shows. In the study area the complex occurs on areas behind the Q4 dunes and also on areas further inland. The stands behind the Q4 dunes differ somewhat from those further inland where the Acacia rostellifera may tend to prefer the local high points (certainly some factor that does not co-incide with the distribution of the beach ridges is controlling the distribution of this species).

Inland stands of Acacia rostellifera

ArMa Acacia rostellifera open scrub over Melaleuca acerosa low shrubland

This unit occurs on the crests and slope of relict beach ridges and has a moderate to dense (35% or more) cover of Acacia rostellifera to 2-3 m tall over Melaleuca dense (35% or more) cover of Acacia rostellifera to 2-3 m tall over Melaleuca acerosa to 25% cover with other shrubs present being small amounts of Rhagodia baccata, Jacksonia furcellata, Phyllanthus calycinus, Acanthocarpos presissii and Leucopogon parviflorus. The herb layer is similar to much of the relict dunes with Stipa flavescens to 10%, Lepidosperma tenue to 5% and small amounts (1-2%) of Lomandra maritima, Conostylis candicans, C. aculeata, Poa poiformis and Loxocarya flexuosa.

SL Stipa flavescens, Lepidosperma tenue open grassland/sedgeland

This unit occurs in the swales between relict foredunes with the preceding unit, It has about 10% each of the Stipa and Lepidosperma with a few scattered shrubs of Acacia rostellifera and Rhagodia baccata and small amounts of Poa poiformis, Loxocarya flexuosa, Lomandra maritima and Schoenus grandiflorus. (Other swale units similar to those described above may also exist within this complex,)

Acacia rostellifera Stands near the Coast

High Crests: **DdAr Diplolaena dampieri, Acacia rostellifera low shrubland.**

This unit occurs on high crest in the south east part of the study area. It has a moderate cover of the Diplolaena (50 cm 15%), Acacia rostellifera (50 cm 5%), Myoporum insulare (1%) and Jacksonia furcellata (1%) over Acacia lasiocarpa (25%) and smaller amounts of Acanthocarpos (5%), Gompholobium tomentosum, Acacia saligna, Lomandra maritima, Conostylis aculeata and Lepidosperma tenue. (The site recorded during survey had condition Category C.)

Slopes and low crests: **Ar Acacia rostellifera low open heath to closed heath to open to closed scrub to low forest**

This unit occurs on moderate to steep slopes and varies in height from 1 to 2.5 metres. It is very variable and in a detailed study would undoubtedly be broken up into several units based on the height and density of the Acacia and the contribution of other species. In most areas the Acacia provides the bulk of the upper shrub layer, however in places Diplolaena dampieri reaches 60% cover, Melaleuca acerosa is often important in the understorey and in patches so is Lepidosperma gladiatum. Other species present include Acanthocarpos preissii, Gompholobium tomentosum, Acacia lasiocarpa, Leucopogon parviflorus, Rhagodia baccata, Loxocarya flexuosa, Lepidosperma tenue and Conostylis aculeata. On sheltered sites were it has escaped burning this unit can become a low forest. (The site recorded during survey had condition Category C.)

Swales: **ArSf Acacia rostellifera low open shrubland over Stipa flavescens open grassland**
For some reason (possibly waterlogging or salt accumulation) many swales have dense stands of Acacia rostellifera to there edges where it stops abruptly with only stunted individuals (50 cm, 5%) surviving in the swale. The other species present here is Stipa flavescens with cover to 10% or more. Melaleuca acerosa can form a band around the edge of these swales. (The site recorded during survey had condition Category C.)

Some swales have very different vegetation (approaching that of the wetlands complex) with dense stands of Lepidosperma gladiatum

WETLANDS

All the wetlands in the study area are seasonal wetlands with none having free water at the time of the survey, although several were very damp. All occur in swales or depressions between dunes. Most are linear in shape and have vegetation that apparently varies with the amount of available moisture, however two rounded wetlands near the Point have different vegetation (they are dominated by Juncus kraussii, which was only seen at these two swamps). For convenience in the discussion they will be referred to as linear and rounded wetlands respectively.

Rounded Wetlands

There are two of these wetlands, the one very close to the Point is the larger and better developed having a dense fringe of Juncus kraussii (= J_1) around the more open centre (= J_2) which has more Sarcocornia quinqeflora. It abuts areas of Acacia rostellifera scrub and Q4 dunes and is cut off from the ocean by one low dune which is not well stabilised (it has Spinfex longifolius and Tetragonia decumbens) and is slowly encroaching the swamp.

J_1 Juncus krausii closed sedgeland

This unit has 85-95% cover of Juncus kraussii over about 10% cover of Salicornia quinqueflora. Other species present were Rhagodia baccata, Centella asiatica, Suaeda australis, *Aster subulata and *Sonchus asper.

J_2 Juncus kraussii open sedgeland over Sarcocornia closed herbfield

This unit has 20% cover of Juncus kraussii over a dense (95% cover) of Sarcornia quinqueflora. Other species present were Atriplex prostrata, Centella asiatica, Suaeda australis and saltwater couch (Sporobolus virginicus).

Linear Wetlands

There are a number of these wetlands in the study area, most are very narrow but some are relatively broad (some were too small to map). The vegetation varies continuously, apparently with minor changes in water availability, but soil factors may also play a part. The change from the dune vegetation to the wetland vegetation is almost always very abrupt. It is possible that these wetlands are important feeding areas for birds at appropriate times of the year.

Many have been degraded more than the surrounding areas of dunes, as they have been favoured for the dumping of rubbish (which has introduced weeds) and for the location of access tracks (because of their more stable soils). However the areas where weed infestation is bad are quite limited.

The variation in the vegetation occurs in a micro-mosaic fashion with pure stands or mixtures of a number of wetland species with the following list being indicative rather than exhaustive. Stands were observed of Isolepis nodosa, Baumea juncea, Lepidosperma gladiatum, Cyperus tenuiflorus (usually with the Isolepis or

Baumea juncea), Juncus pallidus, Lepidosperma tenue, Baumea articulata, Typha, Centella asiatica (by itself or very often forming a herb layer under the sedges), Triglochin (with the Centella). (Approximately in order of frequency of occurrence.)

In some areas there are small stands of Melaleuca rhapiophylla (a paperbark) and smaller stands of Melaleuca hamulosa (a bush to a small slender tree), the distribution of these species appears to have been somewhat reduced by fire and cutting of wood and brush. However in several areas young regeneration of these species (paricularly M. hamulosa) was observed so this reduction may be reversible with good management. The understorey where the Melaleucas occur is very similar to the vegetation where they are absent.

There are two types of edges to these wetlands. Firstly (mostly in the east of the study area) there are those that have bushy edges. These have a narrow, but often quite dense band of Xanthorrhoea brunonis (a blackboy) along the edge with shrubs of Logania vaginalis amongst them and along the inner side. The other type has no special edge with the sedge species described above abruptly abutting the dune vegetation. Although in some areas where the dune slopes gradually into the wetland, there is a band with a dense cover of Lepidosperma tenue (a small sedge common in the swales between the dunes) between the wetland and dune vegetation.

Xanthorrhoea brunonis Swales

In the eastern part of the study area there are swales that are not quite damp enough to fall into the wetland types described above, these have vegetation similar to the Xanthorrhoea edges described above for some of the linear wetlands. One was recorded in detail, it had an open cover of Xanthorrhoea brunonis (others observed had more Xanthorrhoea) over25% cover of Lepidosperma gladiatum, about 5% each of Poa poiformis, Stipa flavescens and Lepidosperma tenue and small amounts of Lomandra maritima, Hemiandra pungens, Kennedia prostrata, Jacksonia furcellata, Dianella divaricata and Adriana quadripartita. This particular swale was very close to the eastern boundary of the study area and had been badly invaded by annual grasses, even so these did not seem to be seriously affecting the native perennial species present.

6.0 CONSERVATION ANALYSIS

The assessment of the value of an area for the conservation of flora and vegetation should be made in terms of the scarcity or commonness of the flora and vegetation found there and the condition the area is in. This can then be modified by other factors such as whether or not similar areas are well represented in secure reserves. This assessment should not be made from an anthropocentric viewpoint of what is aesthetically pleasing to particular individuals. This point is expressly made here because several of the units of vegetation found in the study area are low and "scrubby" and two of the most common species are often not particularly attractive.

FLORA

The flora of the study area is typical of that found along the coast between Perth and Bunbury. As such much of it is reasonably well protected in Yalgorup National Park. However this does not apply to all the species found in the current study area as several have not been recorded from Yalgorup (Trudgen, 1987) or are not common there. Also relevant however is the concept of protecting species over their range so as to avoid protecting only local variation rather than the wider variation of the species. From this point of view the study area and adjoining private land has significant potential for the conservation of the flora found there.

VEGETATION

Extent of the vegetation of the different dune types:

- Vegetation of the strand and stabilising dunes

Similar vegetation to that found on the strand in the study area is found to the south of the study area along the coast between Mandurah and Bunbury (Trudgen 1987), further south (Keating and Trudgen, 1986) and also occurs at least as far north as the Perth area. Vegetation of the stabilising dunes has similar distribution, although as noted above the stand of Olearia axillaris closed heath to closed scrub (unit Oa2) is quite unusual.

- Vegetation of the Q4 dunes

These dunes are common along the western coastline of the south west of Western Australia, however they are not well represented in National Parks as there are not many coastal National Parks in this area. Significant areas of these dunes south of Mandurah are mostly out of Yalgorup National Park as its boundary is often just inland of these dunes. The stand of these dunes in the south west part of the study area is of particularly good quality and has high conservation value. The stand along the Warnbro Sound shore is not as good in condition or development but is of interest because of its gradual drop in height and the associated gradual changes in the vegetation developed.

- Vegetation of the Q2 dunes

There is only a small area of these dunes in the study area and their development is not particularly good. The vegetation of this dune type is very well represented in Yalgorup National Park.

- Vegetation of the relict foredunes

Whereas the Q2 dunes are well developed between Mandurah and Bunbury, south of Perth the relict foredunes are restricted to the Rockingham to Mandurah area. They extend some distance inland from Rockingham to just south of the study area where they narrow and become a fairly thin coastal belt. North of the study area much of their area has been used for housing and other developments. South of the study area housing developments have broken up the thin belt leaving several small uncleared blocks. Also relevant here is that where the vegetation of these dunes has been described closer to Mandurah (Trudgen 1987) it is rather different to that described here for the study area.

From this discussion it is obvious that the area of relict foredune vegetation types in the study area and adjoining privately owned land is of very high conservation value. Additionally some units found on the relict foredunes in the study area (see above) are not known from out of the study area and from examination of aerial photographs and topographic maps probably do not occur outside the study area (Note particularly complexes Al, OaMa and OJ).

Wetlands

While the species found in the wetlands are typical of the species found in wetlands further south of the study area the micromosaic variation in the narrower wetlands the shape of these wetlands (and their relationship to the dunes in which they occur) is very unusual. Wetlands like this are probably restricted to the study area and adjoining private land. The circular wetlands near the Point are also very unusual in that they are so close to the ocean.

Condition of the vegetation found in the study area

It should be noted that the assessment of condition given here is from a botanical viewpoint. This places no weighting on aesthetic aspects (such as preference for tall trees rather than low shrubs or nice form rather than straggly form or bright greens rather than dull grey greens) but simply tries to assess whether or not the vegetation at a site has been adversely affected by man (or other agencies as appropriate). Inherent in this assessment are judgements as to what the vegetation at a site would be like if it were completely undisturbed, and if the vegetation has been burnt whether or not it has the capacity to regenerate to good or other condition or whether the impact of the fire(s) in interaction with other impacts such as the presence of weeds has had a permanent effect.

The condition of the vegetation was recorded using the following scale and mapped (see map one) by dividing the study area into zones with similar condition. It should be noted however that within these zones there are areas (e.g. along tracks and where rubbish has been dumped) that are in poorer condition and that the map is a generalisation.

Category A - Significant changes made by influence of man, may have significant amounts of weeds including some of the more aggressive ones.

Category B - Has definite signs of impacts by man (such as grazing) leading to some (but not substantial) changes. Weeds present but generally not aggressive species.

Category C - Shows no evidence of impact by man or shows signs of reversible impacts such as increased fire frequency, few tracks and little rubbish.

The use of this scale needs some explanation. Areas that have been recently burnt are recorded depending on their percieved ability to regain their normal ("climax") structure and density. So areas that have been frequently burnt and are not likely to regenerate well in a reasonable time would be scored lower on the scale than areas that had been burnt recently but which have not been burnt frequently. Areas with significant amounts of weeds were scored lower than areas with similar structure that had few or no weeds.

From the map it is obvious that the southern section of the study area is in the best condition. This is logical as most access to the area has been from the north and so this has suffered more. It is also apparent that the near coastal areas are generally in better condition than further inland where fire has been more frequent and more weeds have invaded (though there are local bad infestations along some tracks and in some wetlands).

Factors affecting the perception of the conservation value of the vegetation of the study area

The vegetation of the study area has some attributes that may unduly effect assessment of its conservation value by the casual observer. These are firstly the low scrubby nature of the vegetation of much of the area. Secondly the natural occurrence in the area of perennial native grasses (particularly <u>Poa poiformis</u> and <u>Stipa flavescens</u>) and the grass-like lily <u>Lomandra maritima</u>. After fire these plants give the area a weedy appearance that is in fact quite natural, but which could be mistaken for worse weed infestation than the area actually has. Thirdly the unattractive appearance referred to above of the Jacksonia furcellata and Acacia saligna. (Jacksonia furcellata holds its old foliage and older plants often look unattractive as a consequence and in the study area Acacia saligna is often attacked by the fungal pathogen Uryomycladium and as a consequence older plants of this species are also often unattractive.)

Conclusion

In conclusion the study area has very significant values for conservation of vegetation and to a lesser degree flora and these values are highest in the southern half of the study area and near Point Becher as the vegetation is less disturbed and there is less weed invasion in these areas.

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APPENDIX ONE: Flora of the Point Becher study area

An asterisk (*) before a species indicates it is introduced.

GYMNOPHYTA (Conifers)

Cupressaceae: Callitris preissii (one individual)

ANGIOPHYTA (Flowering Plants)

Monocotyledons

Typhaceae: Typha sp.

Juncaginaceae: Triglochin striata

Poaceae: *Bromus sp., *Cynodon dactylon, *Eragrostis curvula, Poa poiformis, Sporobolus virginicus, Spinifex hirsutus, Spinifex longifolius, *Stenotaphrum secondatum, Stipa flavescens, Stipa sp.

Cyperaceae: Baumea articulata, B. juncea, Cyperus tenuiformis, Isolepis nodosa, Lepidosperma effusum, L, gladiatum, L. longitudinale, L. tenue, Schoenus grandiflorus

Restionaceae: Loxocarya flexuosa, L. pubescens

Juncaceae: Juncus kraussii, J. pallidus

Dasypogonaceae: Acanthocarpos preissii, Lomandra maritima

Xanthorrhoeaceae: Xanthorrhoea brunonis

Phormiaceae: Dianella divaricata

Asphodeliaceae: *Trachyandra divaricata

Haemodoraceae: Conostylis aculeata, C. candicans

Iridaceae: *Romulea rosea

Dicotyledons

Santalaceae: Exocarpos sparteus

Chenopodiaceae: Atriplex prostrata, Rhagodia baccata, Salsola kali, Sarcocornia quinqueflora, Suaeda australis

Aizoaceae: Carpobrotus virescens, Tetragonia decumbens

Rannunculaceae: Clematis microphylla

Lauraceae: Cassytha sp.

Brassicaceae: *Cakile maritima

Mimosaceae: Acacia cochlearis, A. cyclops, A. lasiocarpa var. lasiocarpa, A. rostellifera, A. saligna.

Papilionaceae: Gompholobium tomentosum, Hardenbergia comptoniana, Jacksonia furcellata, Kennedia prostrata, *Medicago sp.

Geraniaceae: Geranium soleranderi, *Pelargonium capitatum

Rutaceae: Diplolaena dampieri

Euphorbiaceae: Adriana quadripartita, *Euphorbia terracina, Phyllanthus calycinus

Stackhousiaceae: Stackhousia pubescens

Rhamnaceae: Spyridium globulosum, ? Trymalium sp.

Dilleniaceae: Hibbertia cuneiformis

Myrtaceae: Eucalyptus gomphocephala, Melaleuca acerosa, M. hamulosa, M. huegelii, M. raphiophylla

Onagraceae: Epilobium billardierianum

Apiaceae: Centella asiatica, Trachymene caerulea (Rottnest Island Daisy)

Epacridaceae: Leucopogon parviflorus

Primulaceae: *Anagallis arvensis

Loganiaceae: Logania vaginalis

Apocynaceae: Alyxia buxifolia

Convolvulaceae: *Cuscuta epithymum

Lamiacaeae: Hemiandra pungens

Solanacaeae: * Solanum nigrum, *S. sodomaeum (one seedling)

Scrophulariaceae: *Phyla nodiflora (The status of this species is uncertian, it may be native.)

Orobanchaceae: Orobanche ? minor (above ground part dead)

Myoporaceae: Eremophila glabra, Myoporum insulare, M. caprarioides

Rubiacaeae: Opercularia vaginata

Lobelia alata: Lobelia alata

Goodeniaceae: Scaevola crassifolia, S. holosericea

Asteraceae: *Arctotheca calendula,*Aster subulata, Olearia axillaris, Senecio lautus, *Sonchus oleraceus, *Sonchus asper.

APPENDIX E: MARINE ENVIRONMENTAL INVESTIGATIONS

BOWMAN BISHAW & ASSOCIATES

APPENDIX E
MARINE INVESTIGATIONS FOR THE PORT KENNEDY REGIONAL RECREATION CENTRE
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TABLE OF CONTENTS

		Page No.
SUMMARY		E4
1.0	INTRODUCTION	E7
2.0	DESCRIPTION OF IMPORTANT ASPECTS OF THE MARINE ENVIRONMENT	E9
	2.1 Regional Perspective	E9
	2.2 Local Geomorphology and Marine Habitats	E11
	2.3 Marine Communities	E14
	2.4 Overview of the Marine Ecosystem	E17
	2.5 Scientific Research - M101 Area	E23
3.0	EVALUATION OF POTENTIAL MARINE BIOLOGICAL IMPACTS	E25
	3.1 Impacts of Marina Construction	E25
	3.2 Water Quality Issues	E26
	3.3 Recreational Impacts	E29
	3.4 Overall Assessment of Project	E34
4.0	OVERVIEW OF EXISTING AND FUTURE UTILIZATION OF THE M101 AREA	E35
	4.1 Existing Recreational Use	E35
	4.2 Population and Boating Trends	E36
	4.3 Development Proposals	E39
5.0	MANAGEMENT IMPLICATIONS	E42
	5.1 The Need for a Management Plan	E42
	5.2 Implementation of a Management Plan	E44
	5.3 Monitoring and Research Requirements	E45
	5.4 Role of the Port Kennedy Development	E45
BIBLIOGRAPHY		E47

LIST OF FIGURES

Figure No.		Page No.
1	Regional Geomorphic Elements	E10
2	Broad Scale Marine Habitats	E13
3	Existing Boat Ramps and Proposed Boating Facilities	E37
4	Recent Population Trends and Projected Growth	E38
5	Trends in Boat Ownership	E40

SUMMARY

1. The proposed Port Kennedy Regional Recreation Centre includes a marina development with capacity for 250 boats associated with tourist accommodation plus provision for a further 130 boat pens. It is anticipated that a significant proportion of future recreational activities will focus on the nearshore and offshore marine environments. The marina site is located at the southern end of Warnbro Sound and approximately 2.5 km from the eastern boundary of a proposed Marine National Park.

2. Potential impacts arise from the development in terms of marina construction, nutrient enrichment of groundwaters and increased recreational use. The following conclusions have been drawn:-

   (i) the permanent loss of a small area of seagrass meadow at Bridport Point, due to construction of the marina, is considered to be an acceptable environmental cost;

   (ii) consideration of the potential avenues for entry of contaminants to the marina, such as from anti-fouling paints, indicates that the degree of water contamination will be extremely low;

   (iii) addition of nutrient to groundwater through fertilizer application is considered to be too low to create potential for subsequent nutrient enrichment of marine waters, when the groundwater ultimately discharges to the ocean;

   (iv) the development will contribute to existing fishing and harvesting pressure, particularly on the shallow, offshore reefs.

3. Despite the proximity of this development to a proposed Marine National Park, the potential impacts should also be considered in the context of the entire Metropolitan coastal waters. Some mitigating factors are highlighted below.

(i) There are no onshore intertidal limestone platforms at Port Kennedy; these habitats are known to be suffering from intense recreational pressure elsewhere (e.g. Northern Metropolitan coast and Rottnest Island).

(ii) Warnbro Sound is noted for good water quality, especially in comparison to Cockburn Sound with its industrial discharges. Consequently, the nearshore waters would appear to have high assimilation capacity for the minor perturbations which may be expected from planned development of the Rockingham-Port Kennedy coastline.

(iii) The degree of endemism in marine biota is not considered significant on a localised basis.

(iv) There is considered to be high potential for recovery of disturbed and locally depleted habitats/biota, once identified, through the process of natural recruitment if these areas are granted sanctuary status.

4. This investigation has recognized at outset that there is increasing concern at the number of large water-based developments proposed for the area. Three projects have been approved in recent years without addressing or contributing to management requirements in relation to the nearby Marine Park proposal. Secret Harbour (1,000 - 1,200 boats), Rockingham Marina (330 boats) and Westport (572 waterfront lots) are all moderately large in terms of potential recreational impacts. It is also significant that none of these proposals has commenced development.

5. Assessment of population growth along with trends in boat size and usage, indicates that small boats launched from boat ramps in Rockingham and Safety Bay are potentially the greatest source of recreational impact in the shallow nearshore waters of the M101 area. Many boats moored in the proposed marina will tend to be larger craft that are restricted in shallower

waters because of their size and, by definition, have enhanced ability to utilize offshore oceanic waters.

6. Consideration of the long history of the M101 Marine Park proposal and the increasing levels of use emphasizes that a formal management plan is overdue. Formalisation of a plan would assist on-going management planning for the Port Kennedy proposal. The structured nature of the tourist development and associated activities that are offered, will be amenable to implementation of initiatives that are consistent with the philosophies of a Marine Park.

1.0 INTRODUCTION

Stage I of the proposed Port Kennedy Regional Recreation Centre involves construction of a marina, catering for about 380 boats and associated water-oriented tourist accommodation. Consequently, the relatively protected waters of Warnbro Sound and the offshore chain of shallow limestone reefs and occasional islands, will be a focal point for water-based recreational activities from the development.

For many years now, the offshore reefs in particular have been widely recognized as having high educational, recreational and conservation potential. This was formally acknowledged during the System 6 Study, in which a large expanse of waters, offshore from Becher Point and stretching north to Cape Peron, became the subject of System 6 Recommendations for protection. These recommendations were endorsed by the State Government Cabinet in 1983. A Marine National Park is now proposed for the area, with the implication that it will be managed for sustainable public recreation. The park has not been formally named, and is commonly referred to as the M101 area (the number of the System 6 Recommendation).

In accordance with statutory requirements, the Environmental Protection Authority has requested that the proponent for the Port Kennedy proposal evaluates, among other things, the perceived impacts on the marine environment which may result from the development. This report has been commissioned by Binnie and Partners, as principal consultants to Fleuris Pty Ltd, for inclusion in the ERMP for the development. It is a desk study based on published information and discussions with relevant personnel. No field work was conducted.

This report concentrates on the marine biological issues associated with the development proposal. Initial considerations suggest that there are three main aspects which require evaluation, as follows:-

(i) the direct impacts of marina construction;

(ii) the issues associated with water quality in the marina and also the potential changes to shallow groundwater quality, which ultimately discharges to the marine environment, and

(iii) the indirect impacts associated with additional people attracted to the area and their utilisation of the marine environment.

The study not only assesses the impacts of activities associated with the recreation centre, but also considers the broader issues in relation to existing and future levels of use. In this context, the need for management is discussed, along with the role of the proponent. Obviously, management commitments must recognize equity of responsibility, and an appropriate management approach is suggested.

2.0 DESCRIPTION OF IMPORTANT ASPECTS OF THE MARINE ENVIRONMENT

Before describing the marine environment adjacent to Port Kennedy (Becher Point), a brief regional perspective is given below in terms of the inherent suitability and attractions of nearshore waters for recreational use. More detailed and technical descriptions of the regional setting of Becher Point and the whole Metropolitan coast have been compiled in previous studies, for example the Westport ERMP and Mindarie Keys ERMP (Delta Holdings Pty Ltd, 1986 and Smith Corporation, 1985).

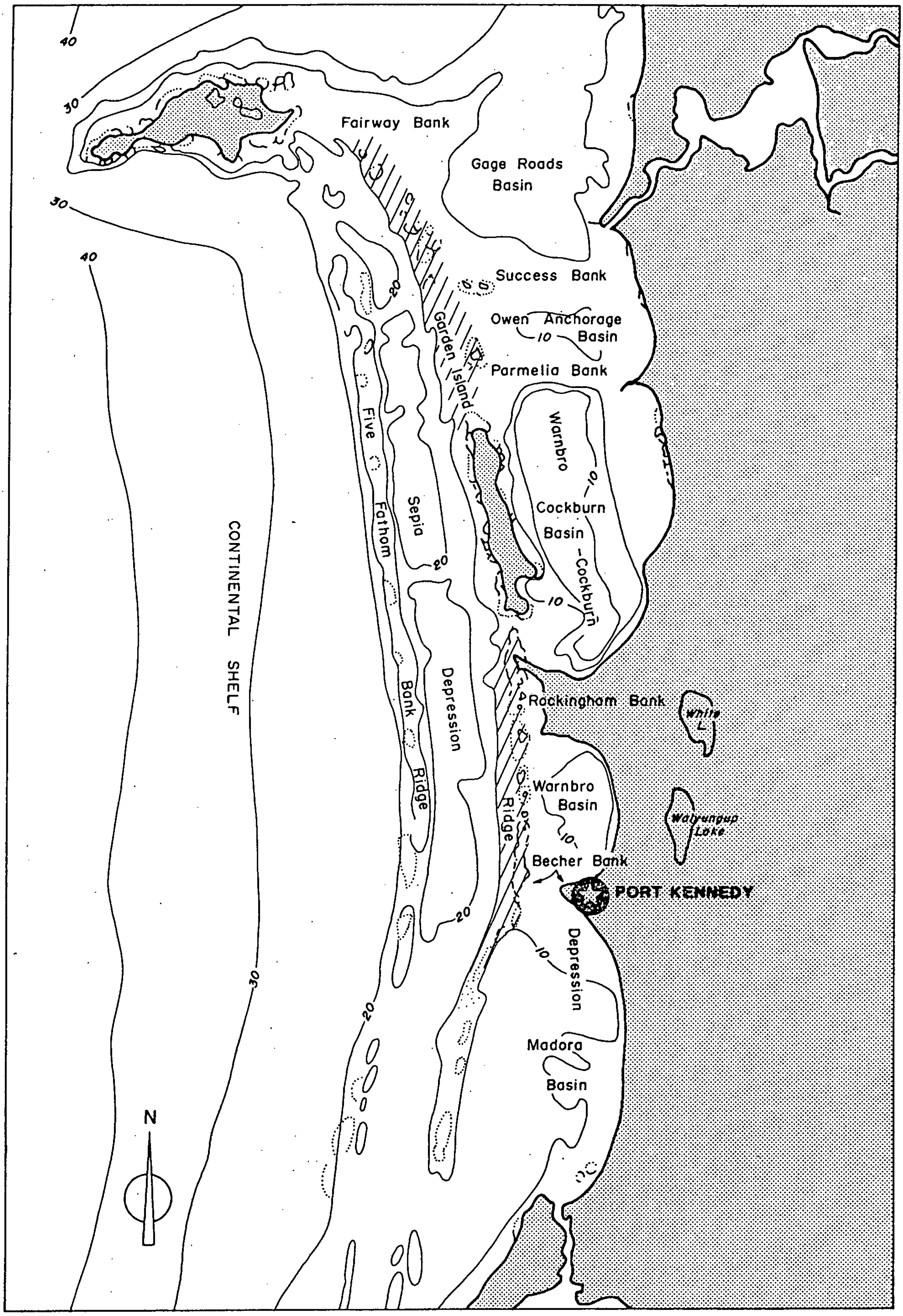
2.1 Regional Perspective

Recreation and tourist activities in the highly urbanized Rockingham area focus on the foreshore and nearshore marine environments. The large variety of environmental characteristics provide opportunities for a wide range of uses. The proposed Port Kennedy Recreation Centre lies approximately 9 km south of Rockingham and it will also focus activities on these marine environments.

A short distance to the west of Port Kennedy some limestone islets and emergent pinnacles may be observed. These mark the crest of the so-called "Garden Island Ridge", which has more prominent and well-known exposures further to the north (e.g. Penguin Island, Cape Peron, Garden Island and Carnac Island). The Garden Island Ridge may be described as an almost continuous, submarine to emergent limestone ridge, lying parallel to the mainland and extending from just north of Mandurah to Rottnest Island. This ridge, along with some other regional geomorphic and bathymetric elements, is illustrated on Figure 1.

From the perspective of recreational use, the Garden Island Ridge has three important functions, which are listed below.

(i) It provides habitats for a wide range of marine plants and animals, including fish and rock lobster, thus catering for the interests of fishing



Crest of Garden Island Ridge

0 2 4 6 8 10 km

REGIONAL GEOMORPHIC ELEMENTS

FIGURE 1

enthusiasts.

(ii) The limestone ridge characteristically provides an highly variable seafloor topography, such as caves, trenches and pinnacles, which are interesting underwater features for recreational divers.

(iii) The combination of shallow water, 'roughness' of the seafloor and the islands act to dissipate wave energy from the prevailing west to south-west swells and therefore, the ridge represents the western boundary of the nearshore waters that are most suited to recreational boating.

It can be seen on Figure 1, that the protection offered by the Garden Island Ridge provides relatively safe boating in the extensive nearshore 'lagoons', such as Warnbro Sound, Cockburn Sound and Owen Anchorage. These are complementary to the sheltered embayments of Rottnest Island, which tend to become very congested in the summer months.

It should be noted that Becher Point approximates the southern boundary of these protected waters. To the south, the Garden Island Ridge becomes a less prominent and more discontinuous feature. The shelter it provides is substantially reduced in this area in comparison to further north. Consequently, the shores of Becher Point facing to the south-west and the adjacent waters of Madora Bay are more exposed and subject to higher levels of wave energy. This suggests that boating and other recreational activity from Port Kennedy will tend to concentrate on the protected waters of Warnbro Sound and the offshore reefs in the north-west sector. Some characteristics of these marine environments are described in the sections which follow.

2.2 Local Geomorphology and Marine Habitats

2.2.1 Geomorphic Units

Becher Point lies within the geomorphic unit known as the Warnbro-Cockburn

Depression. The point itself represents the terrestrial component of a sand barrier that extends across the Depression to the Garden Island Ridge. The submarine portion of this barrier is a shallow (2 - 5 m) sand bank that is typical of other banks to the north (e.g. Parmelia and Success Banks).

North and south of this barrier there are sandy embayments which vary in depth and may have shallow sand bars in places. The embayment to the north has been substantially infilled in recent geological times, leaving the relatively small, but deep (up to 20 m) basin of Warnbro Sound.

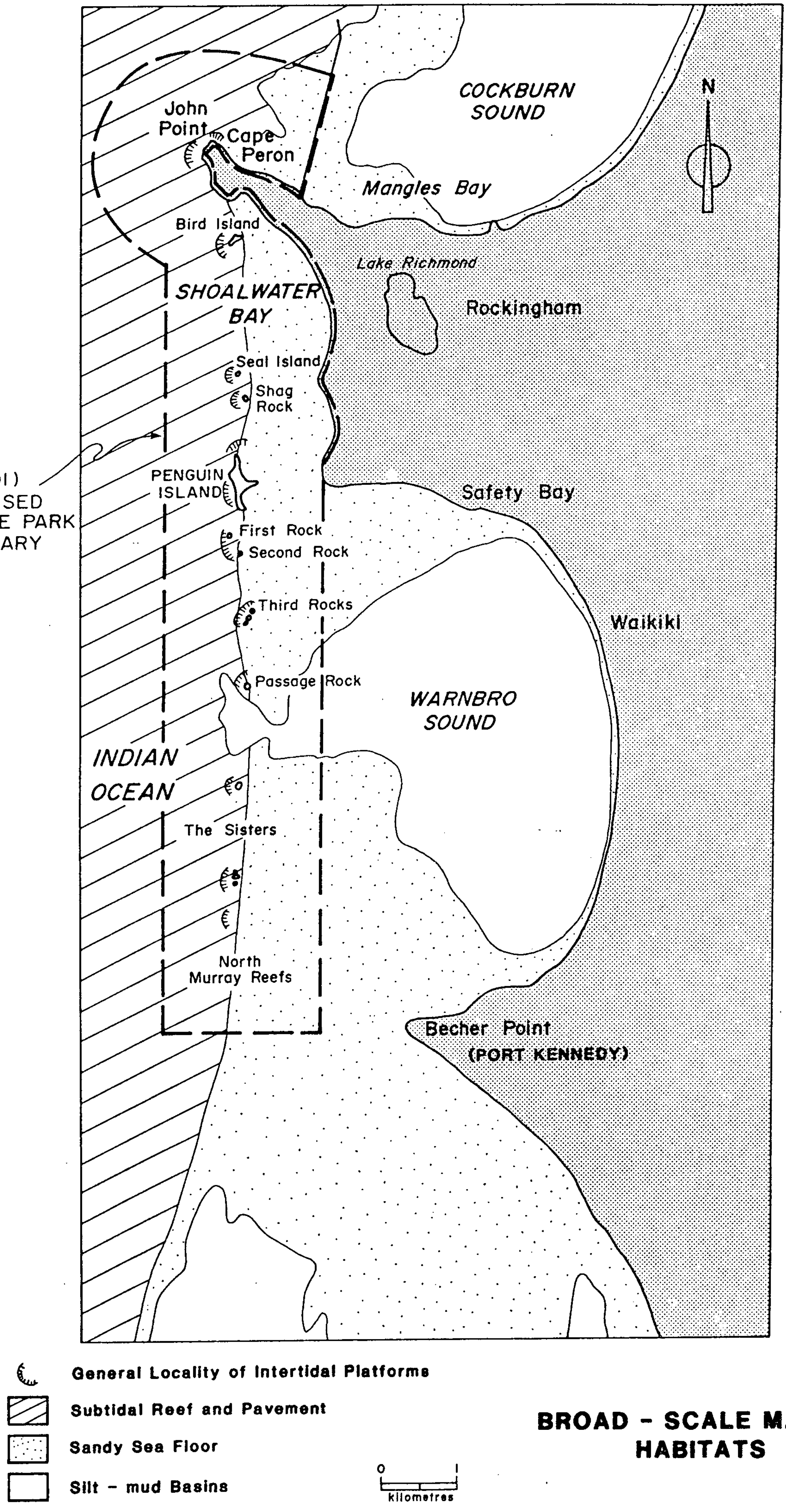
Westwards from Becher Point, there are five broad geomorphic units which lie parallel to the Warnbro-Cockburn Depression. These have been well-described in previous studies and are simply listed here, along with brief topographic information and the typical range of water depths within each unit. The units are delineated on Figure 1.

Geomorphic Unit	Topography and Water Depths	
. Garden Island Ridge	Irregular, rugged reef	(0 - 10 m)
. Parallel Ridge System	Variable, but low relief	(10 - 15 m)
. Sepia Depression	Gently sloping	(15 - 24 m)
. Five Fathom Bank	Rugged limestone reef	(mostly 10 m+)
. Offshore Continental Shelf	Gently sloping	(20 - 300 m)

2.2.2 Marine Habitats

Marine habitats may be broadly defined in relation to the geomorphic units, seafloor type (substrate) and other physical factors. The broad marine habitats that have been identified are listed below and their distribution is shown on Figure 2.

- Intertidal high reef platforms.
- Subtidal reefs and limestone pavement.
- Sandy seafloor (including seagrass meadows and shoreline zones).



BROAD - SCALE MARINE HABITATS

FIGURE 2

- Silt-mud basins.

It is obvious from Figure 2 that sandy seafloor is the dominant habitat type in the vicinity of Becher Point. Seagrass meadow is a conspicuous element on this substrate, although it is often patchy in occurrence. Another feature of Becher Point is the total absence of onshore, intertidal limestone platforms. These platforms are subject to intense recreational pressure elsewhere on the Metropolitan coast.

2.3 Marine Communities

A survey of plant and animal communities in the area was conducted by the Department of Conservation and Environment (now Environmental Protection Authority) in 1985. The area surveyed was primarily within the proposed M101 Marine Park boundary, although some work was conducted inshore from the eastern boundary. Subsequently, a report was produced which described the marine communities in some detail, and included the results of other studies and scientific research (Gordon, 1986).

A brief summary is given below in terms of each of the broad habitat types identified in the area and where possible, the relative significance of the habitats closest to Becher Point is addressed.

2.3.1 Intertidal High Reef Platforms

These platforms are close to sea-level at low tide and represent a harsh environment for biota due to high summer dessication rates. There is a proliferation of turf algae rather than macrophytes, and there are large seasonal changes in community structure. The communities of algae observed on the reef platforms near to Becher Point (i.e. Murray Reefs and The Sisters) are apparently similar to those further north.

The dominant animals observed are common to most local reefs, including the commercially important abalone and common whelk. The Sisters reef flats appeared to contain the most diverse animal life of the platforms surveyed.

The islands and rock pinnacles associated with these intertidal reef platforms are valuable as resting, breeding and nursery sites for a variety of mammals and birds. Whilst none of the fauna are endemic to the islands, 18 species of birds use the islands for breeding. Pied cormorants breed on The Sisters.

2.3.2 Subtidal Reefs and Limestone Pavement

The subtidal reefs which form the Garden Island Ridge are dominated by brown algae such as kelp and Sargassum, with a variety of red algae (coralline and non-calcareous species). Biomass varies largely due to seasonal growth of kelp, which 'hides' much of the reef in summer. Superficial appraisal suggests the dominant species may be similar throughout the reef.

Attached animals include colonial and solitary ascidians, sponges, featherstars, hydroids and corals. The distribution of these fauna is patchy, although the diversity of many animals, such as the sponges, is believed to be very high. These reefs are nursery grounds for rock lobster, and abalone are also present.

2.3.3 Sandy Seafloor and Seagrass Meadow

Eight species of seagrass are known to occur in the area and none of them are unique to this location. There are extensive, healthy meadows of seagrass on the sand bank west of Becher Point, whilst the seagrass at Bridport Point is relatively isolated and patchy in occurrence. Seagrass meadows are host to numerous fish and invertebrates and there is normally a wide range of epiphytic plants and animals on the leaf stalks.

The fauna of bare sandy seafloor usually comprises burrowing animals such as molluscs. Demersal fish, including sole and flounder may occur, as well as pelagic species such as skipjack trevally.

2.3.4 Silt-mud Basin

The deep basin of Warnbro Sound has very little plant life due to the lack of light. However, animals are abundant. Anemones, sea-stars, holothurians and other echinoderms are conspicuous. Despite the sometimes high density of animals, the overall diversity is low.

2.3.5 Implications for Impact Assessment

The above description is a substantially abbreviated account from the investigations reported by Gordon (1986). These investigations were conducted in November of one year only. A complete description of the marine biota, on a seasonal basis, has yet to be compiled.

Whilst knowledge of the seasonal species composition is an advantage, it does not provide a sufficient basis to predict impacts from potential stresses, such as intense recreational fishing. To predict how communities may respond to human interference, some knowledge of the dynamics of the local populations would be required. For example, quantitative estimates of patterns of distribution and abundance on a temporal basis would be required to make more accurate impact assessment, and (say) to define the sustainable yield of an amateur fishery. The research effort and time required to obtain a data base of this nature is enormous.

Despite the above disadvantages, a relatively superficial assessment of the impact of a disturbance may be conducted through the application of general ecological principles. In addition, an appreciation of the significance of a community, or component of the community, to the overall stability of an ecosystem is an important basis on which judgements can be made. Therefore, a broad overview of pertinent aspects of the marine ecosystem offshore from Port Kennedy is given in the section below. This provides the background for impact assessments conducted in subsequent sections.

2.4 Overview of the Marine Ecosystem

2.4.1 Regional Zonation and Recruitment

Biologically, the marine environment adjacent to the Metropolitan area is known to be part of a zone of overlap between the northern coast, with its characteristic tropical species and the southern coast, with its temperate species. Therefore on a broad scale, the plant and animal species along the south-west coast are a mixture of both temperate species and representatives of the sub-tropical and tropical biota. Temperate species tend to dominate along the Metropolitan coast, especially the algal assemblages. In the zone of overlap there are, of course, endemic species which are not found along the southern coast or in tropical waters. However, the degree of endemism is not considered significant locally i.e. the number of species that are restricted solely to an area the size of M101 is likely to be small.

The oceanography of the south-west coast plays a significant role in the maintenance of the zone of biological overlap. Many marine species have a life cycle which includes a planktonic larval stage. The larvae essentially drift in the water, although they often possess small-scale locomotive ability. Therefore, water currents are indirectly responsible for recruitment (i.e. replacement or colonization) of species to particular habitats. In the case of the M101 area, for example, planktonic larvae may originate from local reproductive activity or from communities much further away.

Recruitment of temperate and tropical species is therefore, influenced by northerly and southerly currents. North flowing currents apparently dominate in nearshore waters. As previously mentioned, the flora and particularly the reef-algal communities, tend to be more typical of the south coast temperate region. This also applies to the animal life, although there are interesting tropical and sub-tropical elements which have been documented in some areas.

The Leeuwin current, which flows southward from the tropics sometime between March and September most years, is strongly implicated in recruitment of planktonic larvae from tropical waters. This warm current flows further offshore above the true continental shelf and has a sufficient driving force to flow southwards against the prevailing winds. It is probably responsible for the extensive coral communities at the Abrolhos Islands, offshore from Geraldton. In addition, both the characteristically warmer waters at Rottnest Island during winter and its prominent tropical coral communities, are due to the Leeuwin current. Rottnest has about 19 species of hard corals, with most diversity on the southern side of the island (Marsh, 1985).

In view of its offshore flow path, the Leeuwin current influences species composition at Rottnest more so than the mainland. Two demonstrable examples are the comparative distributions of fish fauna and marine molluscs.

(i) Fish (Hutchins, 1985):

Location	No. of Species	Affinity		
		Temperate	Subtropical	Tropical
Rottnest Island	360+	54%	16%	27%
Inshore Coastal	202	72%	15%	11%

The proportion of tropical species in nearshore waters is less than half of the proportion observed at Rottnest. In addition, most of the tropical species recorded near the mainland have low abundance.

(ii) Molluscs (Wells, 1985):

A comparison of the affinity of 373 species of molluscs was conducted in three areas; inshore localities, eastern Rottnest and the west end of Rottnest.

Location	Affinity		
	Temperate	Tropical	Endemic
Inshore and Eastern Rottnest	67%	18%	15%
West End, Rottnest	52%	33%	15%

Tropical species are nearly twice as important at the west end of Rottnest Island, in comparison to temperate species.

The major recruitment of tropical species at Rottnest Island arises from eddies associated with the offshore Leeuwin current. These eddies may sometimes influence recruitment at the mainland, hence the patchy appearance of tropical species in areas such as M101. Many of these species are near to the southern limit of their range. There is a significantly reduced likelihood that they will establish breeding populations. Therefore, the tropical species in M101 are viewed more as ecological oddities of scientific interest, rather than communities with high, intrinsic conservation potential, as is the case at Rottnest.

Overall, the level of recruitment is a primary factor in determining the susceptibility of a population to over-exploitation. Recruitment is likely to vary spatially and from year to year. Therefore, information on recruitment levels for a particular species over an extended time period would be a valuable management tool. For example, management decisions for the rock lobster industry rely to a large extent on monitoring of recruitment in nearshore nursery waters, by the Department of Fisheries and CSIRO. Some monitoring sites have been deployed for 16 years.

2.4.2 Water Quality Considerations

Water quality is a major determinant of ecosystem stability and two of the more important parameters are turbidity and nutrient concentration.

(i) Turbidity

Water turbidity, a measure of the clarity of the water column, determines the degree of light penetration. Light availability has a strong influence on the distribution of photosynthetic plants. There is a high degree of temporal variability in turbidity in nearshore, shallow waters such as the M101 area. Wind-induced turbulence through wave action (both local sea-waves and oceanic swell-waves) is the principal cause of turbidity fluctuation; via the re-suspension of fine particulate matter. (Phytoplankton growth is another primary cause of turbidity increase, but this mechanism is not as important as wind and wave action in M101.)

In the context of the natural, large variations in turbidity, most concern with human disturbances arises when there is likely to be a sustained increase in turbidity generation. Long term reductions in the clarity of the water column may have a marked impact on the ecosystem. Productivity of the benthic algae and seagrass communities would decrease with a consequent reduction in the primary food chain. Colonisation of benthic substrates and other habitats may be reduced. Overall, there may be marked changes in species composition and community structure.

(ii) Nutrients

There is a fundamental necessity for nutrients within any ecosystem, and the marine environment of M101 is no exception. Nutrients are one of the prerequisites for biological productivity. Whilst nutrient concentrations in the water column are characteristically low, there is a vast quantity of nutrient 'held' in plants, animals and sedimentary detritus. Efficient recycling of nutrients occurs between these various components of the system.

A complex equilibrium exists between biological productivity, nutrient availability and other factors. The availability of nutrients within a system is a function of the various nutrient inputs, the extent of internal recycling and the degree of nutrient loss from the system.

New inputs of nutrients to Warnbro Sound and the M101 area, as a result of human activities, can stimulate primary productivity. This is not necessarily a problem and, in fact, could be perceived to be beneficial in some instances. However, excessive nutrient input can cause a shift in productivity to different species. These species are generally more opportunistic and tend to reduce the level of diversity within an ecosystem. There are well-known, local case studies of nutrient enrichment at Cockburn Sound and the Peel-Harvey Estuary, which will not be repeated here.

In assessing the likely impact of external nutrient addition to M101, factors to consider include the following:-

- the comparative magnitude of the new nutrient source with respect to existing nutrient flows in the system;

- the assimilation capacity of the existing biota and nutrient 'sinks'.

In the above context, 'assimilation capacity' refers to the ability of the existing biota to be more productive, without resulting in a shift to more undesirable species.

The desirability of some of the existing ecosystem components is addressed in the next section.

2.4.3 Significance of Ecosystem Components

Whilst the detailed ecology of the area is poorly understood, the importance of certain ecosystem components is well known. Two of these components are briefly discussed below, viz: algal assemblages and seagrass meadow.

(i) Algal Assemblages:

The algal assemblages, particularly on areas of limestone reef in shallow water, are important primary producers in the ecosystem. Species such as kelp and Sargassum are highly productive at certain times of the year. This production is utilized by grazing organisms and supports a variety of intricate food chains. The algae are capable of occupying many different micro-habitats within the reef structure and provide refuges for fish. They are rapid colonizers of hard substrates and form the basis of reef communities.

The large quantities of macrophytic growth that are detached from reefs during winter storms, provide a mobile food source and shelter for juvenile fish, as the material drifts with longshore currents. Detached algae that accumulate in nearshore basins contribute to nutrient recycling.

The diversity of algal assemblages and the depth at which species common to high reefs are observed to grow, are reliable indicators of good water quality.

(ii) Seagrass Meadows:

The seagrass meadows on the sand banks surrounding Warnbro Sound and adjacent to Becher Point are important for a number of reasons, as outlined below.

- Seagrasses stabilize sand banks by dissipating wave energy and slowing the rates of current flow.

- The seagrass leaves provide a relatively stable substrate for specialized epibiota.

- They are important contributors to primary productivity within the ecosystem.

- Seagrass meadows provide nursery areas for juvenile fish, as well as habitat for many adult fish species and invertebrates.

- The stabilizing effect of seagrasses acts to trap organic material within the beds, thus contributing to nutrient recycling in shallow water areas.

- Dislodged seagrass leaves contribute to detrital food chains.

The presently healthy seagrass meadows near Warnbro Sound may be easily monitored to indicate long term changes in water quality. Evidence obtained during the Cockburn Sound study demonstrated that changes to epiphytic plant growth occur as the waters become enriched with nutrients.

2.5 Scientific Research - M101 Area

Most recent studies have focussed on the onshore platforms at Cape Peron and reef and seagrass communities around Penguin Island. The reef areas south of Penguin Island, such as The Sisters and Murray Reefs, have been barely studied.

The varied habitats, particularly on the intertidal and subtidal reefs, are known to support large populations of animals and a diverse range of flora. There may be hundreds of different species of algae, many of which could be undescribed and represent new records of marine life. The same applies to much of the animal life, such as the sponges and numerous cryptic species. A complete inventory of the marine species would take many years to compile and would present arduous taxonomic problems. Interestingly, the distribution of the diverse biota appears to be patchy and highly variable and the complex interactions within and between the marine communities is poorly understood. Research on the detailed ecology of the area has been minimal. (Note: these comments are equally relevant to most sections of the Western Australian coast).

Whilst it may be suggested that the marine plants and animals of the M101 area are generally typical of the Metropolitan coastal waters, this area has been nominated since the early 1970's as a representative portion of marine ecosystem that is worthy of preservation. The area also has high recreational value due, in part, to the diversity of communities present. For the same reasons, the area is a natural laboratory for scientific research, and has the convenience of good accessibility to the Metropolitan area.

Most of the research into the marine environment of Warnbro Sound and surrounding reefs is being undertaken by Murdoch University. Current research projects include:

- continuing investigations into seagrass meadows and productivity (Murdoch/CSIRO);
- waterflow characteristics in seagrass meadows (Murdoch/CSIRO);
- utilization of seagrass meadows by crustaceans and their importance to the food chain;
- studies of the seagull populations of Penguin Island and nearby breeding areas, and
- study of sea lion populations along the Metropolitan coast, including Seal Island.

Future research proposals hope to focus on fisheries in the M101 area and, in particular, seagrass meadows and their role as breeding grounds and nurseries.

Note that there is no present research under way in the area of recreational impacts on the marine environment.

3.0 EVALUATION OF POTENTIAL MARINE BIOLOGICAL IMPACTS

The proposed Port Kennedy development may potentially impact on the marine environment in relation to the three aspects listed below.

(i) Direct impact of marina construction.

(ii) Water quality impacts, both direct (marina) and indirect (groundwater).

(iii) Indirect impacts arising from increased recreational/tourist activities.

The impacts are defined and evaluated in the sections which follow.

3.1 Impacts of Marina Construction

The major construction impacts on the biological environment will occur during the dredging and rock back-fill phase. The nearshore biota at Bridport Point consists of discontinuous seagrass meadow, comprising mainly <u>Posidonia</u> <u>sp.</u> with patches of <u>Amphibolus</u> <u>sp.</u> Construction of the marina will necessitate removal of the majority of seagrass present within the area encompassed by the breakwater.

The significance of this loss is minimal. Both seagrass species are well represented in the area and elsewhere along the Metropolitan coast. The area affected represents a very small proportion of the total seagrass meadow on adjacent sand banks. No further offshore construction activity is proposed during the life of the development.

Disturbance of the sediments will cause elevated water turbidity during construction. This temporary phenomenon is not considered to have significant impact. Smothering or significant shading of nearby seagrass meadow should not occur as there is a buffer zone of essentially bare sand, west and north-west of the marina site. Suspended sediment influx to the adjacent Warnbro Sound is considered acceptable because it acts as a natural sedimentation basin to the present biophysical environment (i.e.) the existing biota within Warnbro Sound are adapted to low light conditions and relatively high sedimentation rates.

3.2 Water Quality Issues

There are two principal avenues for the potential discharge of water-borne contaminants to the marine environment. These are:-

- direct contamination of water inside the marina, which is subsequently flushed into Warnbro Sound, and

- indirect contamination of the superficial groundwater on the landward side of the development, which eventually discharges into nearshore waters.

There is little doubt that some contaminants will be released to the marine ecosystem via the avenues described. In this regard, the development will be no different to other marinas and near-coastal subdivisions in the Metropolitan area. However, the risk that serious degradation of the marine environment will occur is considered to be negligible. Potential sources of contaminants and assessment of impacts are addressed below.

3.2.1 Marina Water Quality

There will be no inputs of poor quality water to the marina from the associated accommodation development and harbour facilities. Sewage and other wastewaters will be pumped from the site to a package treatment plant operated by the Water Authority. Deliberate discharge of hydrocarbons or boat sullage into the marina will not be allowed. Standard facilities for disposal of boat wastes will be provided. Apart from accidental fuel spills and bilge water releases, the discharge of contaminants to the marina waters will be very low.

Minor heavy metal contamination will occur due to the mooring of boats within the marina. The main sources of metals are antifouling paints, which may contain copper and/or tin, and sacrificial anodes which release aluminium or zinc. The quantity of metals released to the environment from these sources is believed to be very low, although to our knowledge no rigorous investigations have been conducted.

Consideration of the fate of these contaminants suggests that the environmental impact will be minimal. Slow accumulation of some of the material will occur in the sediments of the marina. The organisms which colonize these sediments may also accumulate metals, but they are not anticipated to be an important component of the environmental food chains in the peripheral environment.

The metals that do not accumulate in the marina's sediments will be flushed into adjacent waters. The proposed marina entrance is favourably aligned to enable exchange into the deeper waters of Warnbro Sound. Substantial dilution and dispersal of these contaminants will occur over a relatively short distance.

3.2.2 Potential Groundwater Contamination and Discharge to Nearshore Waters

Groundwater discharge has recently been implicated as a substantial source of nutrient to nearshore waters in the Marmion area (Johannes and Hearn, 1985). Nitrogen, in the form of nitrate, was identified as the most important nutrient in this source. Other nutrients, such as phosphorus and ammonia, were found not to be significant.

Subsequent to the Port Kennedy development, (see Volume II) nitrogen concentrations in the underlying groundwater will increase, primarily as a result of fertilizer application to landscaped areas such as the golf courses. The increase in nitrogen concentrations is extremely difficult to predict at this early stage of the project. It will occur gradually over several years.

A case study of environmental problems caused by nutrient enrichment exists at the nearby Cockburn Sound. The discharge of industrial effluent to Cockburn

Sound was estimated to contribute up to 5 t/day of nitrogen compounds during the mid-1970's. This resulted in a major nutrient enrichment problem. Detailed studies were conducted and to overcome the problem, interim management objectives were proposed for the Sound which would limit nitrogen inputs to more sustainable levels. Nitrogen input into Cockburn Sound is currently approximately 1500 kg/day. Although this has reduced the major problems of ten years ago, algal blooms still occur which would seem to indicate that further reductions are desirable. On the basis of the substantial improvements to water quality in Cockburn Sound that have occurred, it is reasonable to suggest that only marginal decreases in the current loading may now be required and that the input of nitrogen should be in the order of 1000 kg/day.

Comparison of the volumes of Cockburn Sound and Warnbro Sound, and interpolation of the suggested sustainable loading relative to the differences in volume, indicates that 200 kg/day may be the appropriate limit for external nitrogen inputs to Warnbro Sound. Other factors would also need to be considered, such as the difference in flushing characteristics of the two water bodies. The presence of Garden Island and the causeway would mean that the rate of flushing within Cockburn Sound would be much less than Warnbro Sound. Given that Warnbro Sound undergoes more efficient flushing, it seems unlikely that the sustainable nitrogen loading would be less than 200 kg/day.

Assessment of the significance of nutrient discharge in groundwater to Warnbro Sound must rely on more general comparisons. The following pertinent points are noted:

- no gross biological evidence of nutrient enrichment has been observed anywhere along the Metropolitan coast, as a result of 'contaminated' groundwater discharge;

- water quality surveys conducted in the vicinity of the Beenyup treated sewage outfall, offshore from Ocean Reef, have not detected responses typical of nutrient enrichment, despite the high nutrient output;

- nutrient addition to groundwater undergoes dilution and dispersion within the aquifer prior to entering the marine environment at the discharge boundary;

- groundwater discharges along a broad 'front', thus providing an enormous and effective mixing zone in comparison to sewage outfalls and the industrial discharges of Cockburn Sound, which are more concentrated point sources;

- Warnbro Sound and the nearshore waters of Becher Point do not have any industrial or other significant point source discharges of nutrient.

In view of the above, it may be concluded that the input of nutrients via groundwater at the Port Kennedy development will not result in nuisance phytoplankton blooms or epiphytic algal growth. The inherent stability of the marine ecosystem should be unaffected by the development.

3.3 Recreational Impacts

The Port Kennedy proposal is solely a recreational/tourist development and the marina will be the focal point of Stage I. Therefore, water-based recreation is expected to be a primary component of activities pursued by visitors to the area. Assessment of the likely impacts and the significance of recreational use of the marine environment is a difficult task. The degree of impact will depend on such factors as the type of activity, the intensity of use and the sensitivity of a specific habitat or biota to a particular disturbance.

However, practical consideration of potential impacts, based on existing knowledge and experience of the nearshore Metropolitan environment and its utilization, enables some broad conclusions to be drawn. Obviously, some form of management guidance would be sensible in those areas where the degree of impact may be potentially higher. An assessment is conducted below in terms of the following categories of recreational activities:-

- beach activities (i.e. use of onshore intertidal areas);
- general use of power boats;
- collecting on islands and shallow platforms;
- offshore amateur fishing.

3.3.1 Beach Activities

The beaches at Becher Point are attractive for line fishing, swimming and general beachcombing.

(i) Evaluation of Impacts

The intertidal area of Becher Point is continuous sandy shore; there are no limestone platforms where reef harvesting may have been of concern. In the zone of nearshore waters where beach-related activities would be concentrated, there is no risk of deleterious habitat disturbance. For example, people will tend to avoid the seagrass meadows at the western tip, especially for swimming. This is the only area of relatively significant nearshore marine life.

Beach fishing is the only activity perceived to directly affect biota. The main recreational fish of the nearshore waters are migratory species such as Australian herring, southern sea garfish, salmon, skipjack trevally and tailor. These species all have wide distributions, extending across southern Australia, and their population status is not considered to be threatened. Other popular species such as whiting, sea mullet and yelloweye mullet are considered to be locally abundant.

(ii) Conclusion

Beach-related recreation activities are considered to have negligible potential impact on the nearshore marine environment at Becher Point.

3.3.2 Boating

The marina will cater for approximately 380 boats and boating activity is expected to be high in the summer months.

(i) Evaluation of Impacts

The main potential impacts of boating activity arise from waste discharges and accidental fuel spillages from the boats, and anchor damage.

Provided that there are adequate facilities at the marina for sullage pump-out and ancillary waste disposal, the discharge of wastes from boats is not considered an environmental problem. There is a growing awareness in the community with respect to waste disposal, particularly in heavily utilized areas. Of course, there will always be individuals who do not conform to accepted practice, but the associated impacts are considered to be minimal.

With respect to anchor damage, the marina solves a recognized problem with the mooring of boats in areas of seagrass meadow. The provision of fixed mooring facilities within the marina means that ad-hoc mooring of boats on swing-moorings around Becher Point will not occur. Swing-moorings are known to have resulted in widespread damage to seagrass meadows in the Mangles Bay area, near Rockingham.

Boat excursions from the marina will invariably involve short-term anchoring at specific localities. The random nature of this phenomenon suggests that there will be no noticeable impacts, in comparison to (say) a designated swing-mooring zone. Random anchor damage is an unavoidable consequence of boating activity.

(ii) Conclusion

The perceived impacts of boating activity on the marine environment near Port Kennedy are considered to be environmentally acceptable.

3.3.3 Harvesting on Islands and Offshore Reefs

The high reef platforms associated with the offshore chain of islands and limestone pinnacles support a wide range of animals that are an attraction for people interested in harvesting and collecting.

(i) Evaluation of Impacts

Whilst there are no high reef platforms in the vicinity of Becher Point that are accessible on foot, boat access is relatively easy. However, not only is it difficult to predict the degree of reef harvesting that will occur as a result of the development, but the ecological consequences are also largely speculative.

There are likely to be a range of edible and collector's species of animals inhabiting the offshore rock platforms. For example, sea urchins, turbo shells, mussels and Roe's abalone are known to occur. Indiscriminate and uncontrolled harvesting can significantly reduce the abundance of target biota and cause alterations to the species composition. However, the local animal populations have not been studied in detail and a statement regarding their status is not possible.

Studies conducted in the Marmion marine park indicate that it is the onshore intertidal reef platforms that are most susceptible to harvesting pressure. This is obviously related to the easy accessibility of the onshore platforms. The nearest onshore platforms to Port Kennedy occur at Cape Peron; these are apparently intensely harvested over the summer months. There are mitigating factors which will tend to reduce harvesting pressure on the high reef platforms offshore from Becher Point. Periods of moderate swell and/or fresh breezes significantly reduce the accessibility of these platforms relative to onshore areas.

(ii) Conclusion

Whilst it is recognized that reef harvesting activities have the potential to reduce the abundance of certain organisms, the ecological significance is difficult to quantify.

3.3.4 Offshore Fishing and Diving

Line fishing and spearfishing are popular activities wherever limestone reef occurs. In addition to fin fish, the reefs are also a rock lobster fishery and a source of cowries and other shellfish for collectors.

(i) Evaluation of Impacts

Reef fish that are commonly sought by recreational anglers and divers include dhufish, tarwhine, breaksea cod, blue groper, baldchin groper, queen snapper, harlequin fish and banded sweep. As recreational fishing pressure increases, catch rates may decline and the size of fish taken may be reduced. However, it is recognized that a decline in the catch rates may largely be due to greater numbers of people fishing, rather than a reduction in fish populations. There is a notable lack of scientific information regarding the present status of reef fish in the M101 area.

Anecdotal evidence collected in the area of the Marmion Marine Park strongly suggests that some fish species are significantly depleted and may be overfished. Species such as blue groper and baldchin groper may have markedly decreased population stocks in local areas. It is also clear from the anecdotal evidence that the resident populations of reef fish are more likely to have suffered changes in population structure, in comparison to pelagic and migratory species.

With respect to rock lobsters, there is a great deal of research information which suggests that this species is very resilient and able to withstand high rates of harvesting. The productivity of the lobsters and existing management controls on the commercial fishery indicate that they are not in danger of extinction. However, excessive fishing by amateurs in shallow water areas, including the taking of undersize individuals, can denude lobster stocks in areas of locally restricted habitat, especially on a seasonal basis.

(ii) Conclusions

The Port Kennedy development will naturally result in increased fishing pressure on nearby reefs. A consequence of this greater pressure will be a decline in catch rates per unit effort and a reduction in the mean size of animals caught. Whilst the sustainable yield of local populations of reef fish and shellfish is not known, it is considered that there is little risk of species extinction.

3.4 Overall Assessment

The perceived impacts of the proposal on the marine biological environment are minor and not considered to be an impediment to the development. Consideration of the available data base and experience elsewhere suggests that the inherent uncertainty in some areas of evaluation does not affect the environmental acceptability of the project. During the conduct of the evaluation phase a requirement for management has emerged, particularly in regard to recreational use of the proposed M101 Marine National Park. (see Section 5.0.)

4.0 OVERVIEW OF EXISTING AND FUTURE UTILIZATION OF THE M101 AREA

Assessment of the Port Kennedy proposal should recognize that the development is superimposed on an existing base level of use, particularly with regard to recreational activity. In addition, the long term nature of the project means that management flexibility should be maintained in relation to future trends in the area. Accordingly, this section gives a brief overview of the existing and future levels of use of the M101 area, to provide an appropriate perspective to the assessment process and to emphasize the need for management, particularly with respect to the Marine Park.

4.1 Existing Recreational Use

4.1.1 Port Kennedy

At present, Port Kennedy contains an illegal squatter settlement that has built up over at least the previous 30 to 40 years. Numerous shacks have been erected by holiday makers and/or professional fishermen. There are an estimated 20 to 30 boat moorings in the relative sheltered waters around Bridport Point. The beach is also considered to be firm enough to launch small boats from trailers. Whilst a detailed survey has not been conducted, factors such as the 50 or more shacks, numerous boat moorings and accessibility to the Metropolitan area, suggests that Port Kennedy already sustains a moderate level of recreational activity. Utilization of the offshore reefs would also appear to be common practice.

4.1.2 Regional

On a regional basis, Warnbro Sound, the M101 area and Cockburn Sound are known to be popular destinations for boating and fishing enthusiasts. Regional tourism studies and recreational usage surveys have consistently highlighted the value of these marine areas for recreation. Cockburn Sound in particular, has been identified as being particularly overcrowded. Surveys conducted during the

Cockburn Sound Study demonstrated that on peak days, more than 600 boats could be expected on the waters of the Sound.

In terms of non-boating activity, visitor numbers to Penguin Island also give some idea of the numbers of people utilising the area. A recent survey, conducted over 3 months of the summer period, revealed that approximately 60,000 people walked the sand bar to Penguin Island and an additional 16,000 travelled by the local ferry service (Haswell, pers. comm.). Obviously, recreational pressure on the shoreline intertidal platforms at Cape Peron must be intense at times.

The available information on boat usage clearly demonstrates that moored craft, i.e. on swing moorings and in pens, are only a minor component of total boat numbers. Provision of launching ramps is the dominant factor in heavy boat usage of an area. For example, as far back as 1978 a boat census was conducted in the Mandurah area which revealed the following statistics for a five day summer period (which included a long weekend):

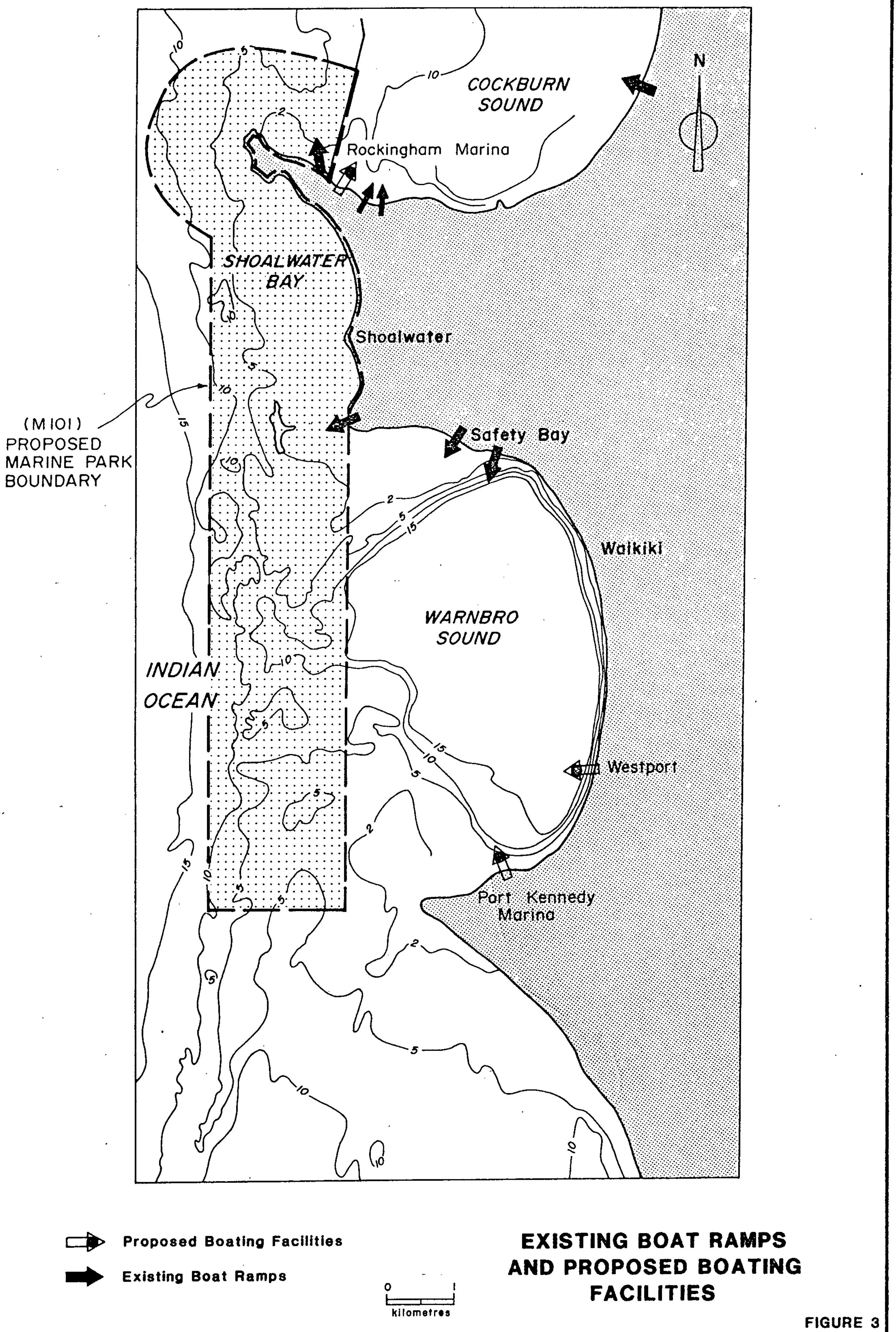
- 2,232 boats were launched from the six major boat ramps in the Peel-Harvey area,

- an additional 2,670 boats were estimated to be launched from the minor ramps not surveyed in detail. (Schwinghammer, 1978.)

There are currently about seven boat ramps in the Rockingham/Safety Bay area, with the implication that the northern sector of the M101 area in particular, is heavily used. (The locations of these boat ramps are illustrated on Figure 3.)

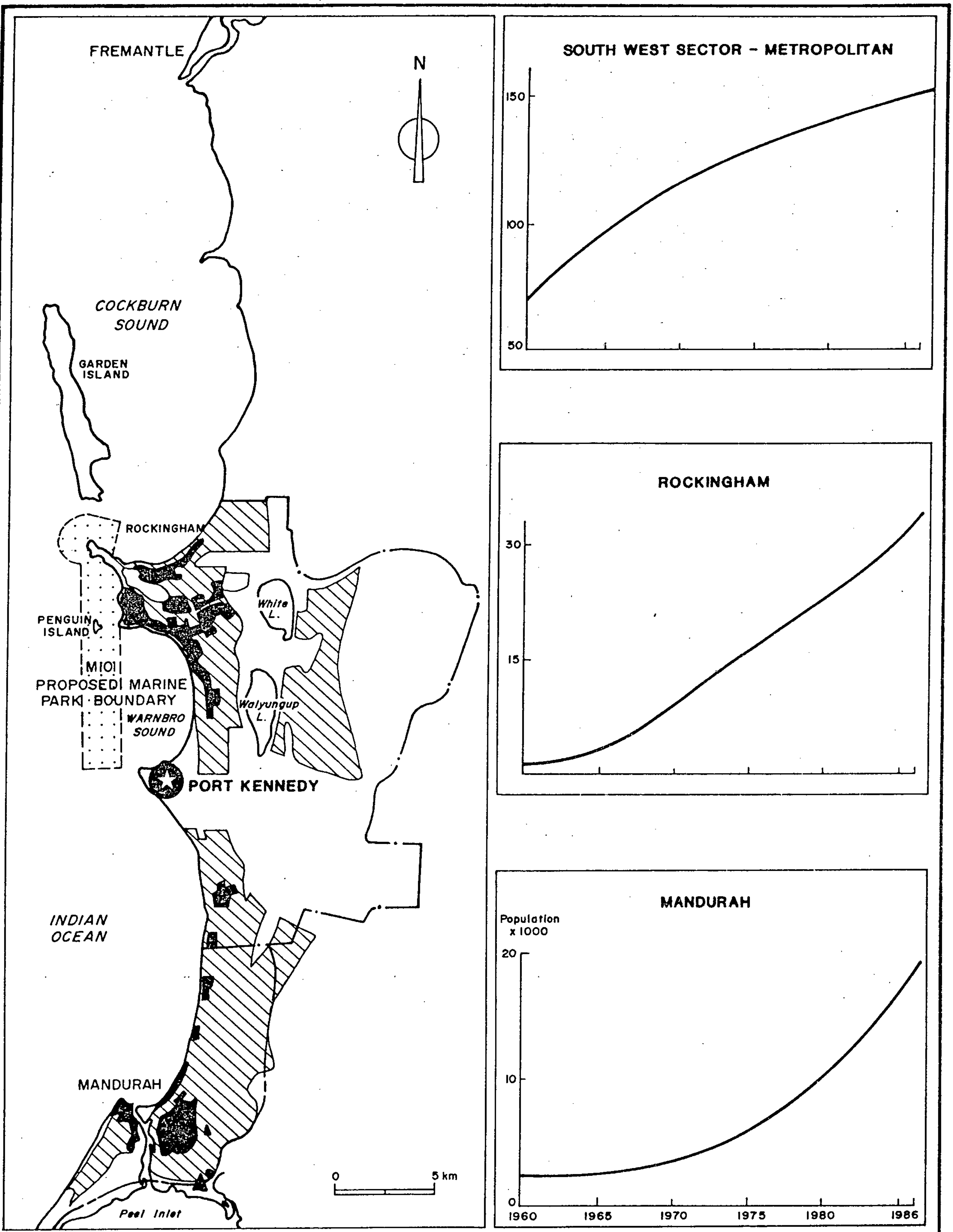
4.2 Population and Boating Trends

Port Kennedy is ideally located as a regional recreation centre especially in relation to the urban centres of Rockingham and Mandurah. Recent population trends for both centres are given in Figure 4. These communities have experienced above average populaton growth in the last 10 to 12 years. Whilst less importance can be



EXISTING BOAT RAMPS AND PROPOSED BOATING FACILITIES

FIGURE 3



Shire of Rockingham

Shire of Mandurah

Existing Urban Areas

Projected Urban Growth 2021

RECENT POPULATION TRENDS AND PROJECTED GROWTH

ROCKINGHAM - MANDURAH

FIGURE 4

placed on long term projections, the illustration of projected urban growth highlights the future potential of the Port Kennedy location (Figure 4.).

There is little information on participation rates in recreation activities for centres such as Rockingham and Mandurah. However, broad trends may be identified, including:

- factors such as shorter working hours, early retirement, increasing affluence, health awareness and growth in part-time employment support a steadily growing demand for outdoor activities;

- water-based activities are increasingly popular;

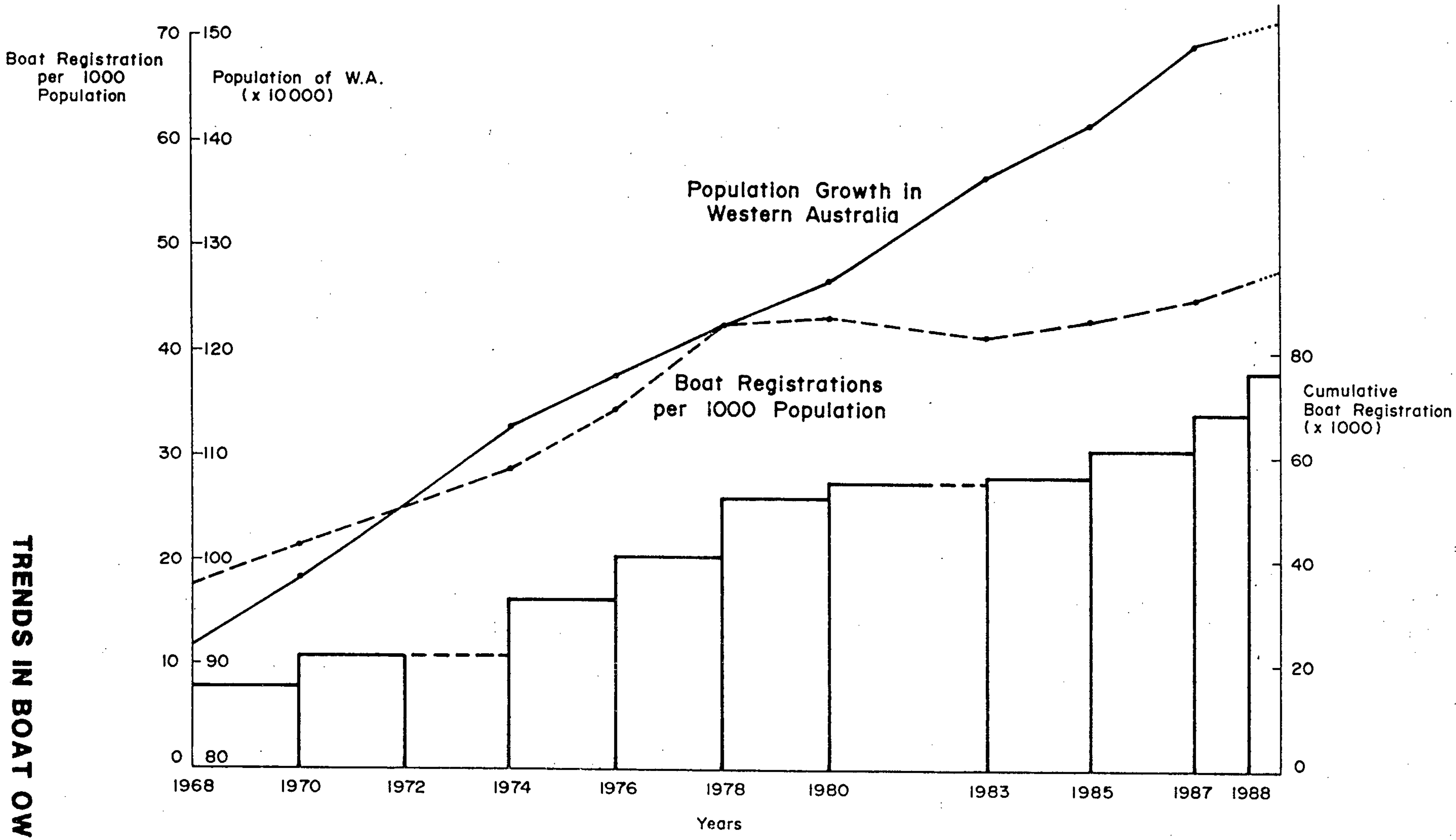
- with respect to tourism, the average annual rate of increase in total visitor numbers to Perth in the last five years has been approximately 7%. (State Planning Commission, 1987).

Perhaps one of the best indicators of recreational trends is in the data on boat registrations. Some historical data for the whole of Western Australia is provided in Figure 5. The proportion of boat registrations per 1000 population has fluctuated but noticeably, has continued to increase. There is apparently a sustained increase in the level of boat ownership.

The Department of Marine and Harbours has estimated that between 60% and 70% of the total boats registered are within the Metropolitan area. Significantly, 85 - 90% of the boats are less than 6 m in length (Thurlow et al 1986). Hence there is a marked dominance in small, trailerable craft, which utilize the boat ramps and would tend to utilize the nearshore shallow waters in preference to areas such as Five Fathom Bank and beyond.

4.3 Development Proposals

A number of water-oriented developments have been proposed in the



TRENDS IN BOAT OWNERSHIP

FIGURE 5

Bowman Bishop & Assoc

Rockingham-Mandurah region in recent years. These include:

- Secret Harbour residential, recreational and tourist community (1982) - capacity for 1,000 - 1,200 boats;

- Rockingham Marina (1985) - capacity for 330 boats, and

- Westport Inland Waterway (1986) - 572 single residential waterfront lots.

None of these proposals have yet commenced construction, and it is believed that the Secret Harbour proposal is highly unlikely to proceed. The future status of the latter two projects has not been investigated. (The locations of these two proposals relative to Port Kennedy are included on Figure 3.)

5.0 MANAGEMENT IMPLICATIONS

The principal management implications of the Port Kennedy Regional Recreation Centre relate to recreational use of the adjacent marine environment, in particular the area proposed as a Marine National Park. Before discussing some potential management strategies for the development, the overall management planning for the area is addressed.

5.1 The Need for a Management Plan

5.1.1 Rationale

The concept of the M101 area being granted official protective sanctions arose in 1972 and was reinforced by 2 recommendations of the System 6 Study (Red Book) in 1983. During the sixteen year period 1972 - 1988, the original aim of the proposed 'reserve' designation has altered slightly, but more importantly, the requirement for implementation of a formal protective mechanism has achieved a more urgent status. This urgency arises from the continued increases in recreational use and fishing/harvesting/collecting pressure on the nearshore marine environment. Whilst there are no definitive figures available on recreational use of the area, it is believed that the broad population and boat registration statistics presented in Section 4, along with other well-known trends in water-based recreational activities, can be readily extrapolated into use pressures in the M101 area.

Formal designation of the M101 area as Marine National Park is therefore endorsed. This endorsement does not solely arise on environmental grounds. Creation of a National Park will improve the status of the Rockingham - Port Kennedy area as a tourist and recreational attraction, which will be beneficial to developments such as the proposal examined herein. By definition, gazettal of the Marine National Park means that a detailed management plan should be prepared.

5.1.2 Existing Management

It is noted that very little attention has been devoted to consideration of management requirements for the proposed M101 area. This is particularly the case for the variety of coastal development projects that have been proposed in recent years. The earliest of these projects was the Secret Harbour proposal, which perhaps could be excused for not considering recreational impacts on the relatively distant M101 area; especially given the more important perceived impacts of the development itself. However, there has been a noticeable absence of recreational impact assessment in documents for proposals such as the Westport development and Rockingham marina. No management initiatives were proposed in relation to their potential interaction with M101.

Essentially, the only management of the area at present is via the regulations in relation to recreational and commercial fishing. These are administered by the Fisheries Department on a broad scale i.e. there are only opportunistic enforcement patrols in a particular locality. In addition, there are specific areal restrictions on the use of set lines, on net fishing and on the use of crab pots in the Shoalwater Bay and Warnbro Sound areas.

There are management initiatives being progressed for the so-called Shoalwater Bay islands. A Draft Management Plan is currently in preparation by the Department of Conservation and Land Management (CALM). This plan will supersede a draft plan prepared for Penguin Island only, by the (then) Department of Conservation and Environment in 1984. CALM's Draft Management Plan for all the islands north of, and including, Penguin Island is expected to be released for public comment in about September/October 1988 (Haswell pers. comm.)

Despite this forthcoming document there is still perceived to be a need for an overall plan for the M101 area. Development proposals, such as at Port Kennedy, and steadily increasing urbanisation in the south-west Metropolitan sector, puts the M101 proposal in a similar scenario to the Marmion Marine Park just a few years ago. Development of the Hillarys Boat Harbour in the proposed M10 area was the catalyst for subsequent proclamation of the Marmion Marine Park in May, 1987.

5.2 Implementation of a Management Plan

5.2.1 Responsibility

Proclamation of the CALM Act (1984) in March, 1985 gave CALM statutory authority to reserve any part of Western Australian waters as a marine nature reserve or a marine park. Therefore, CALM is ultimately responsible for implementation of the management plans for these areas. Development of specific management plans is conducted on a priority basis in line with the availability of Departmental resources.

5.2.2 Timing

At present, CALM has no specific schedule to commence work on a detailed Draft Management Plan for M101. It is recognized that the statutory procedures to be followed sets a time frame of about 12 to 18 months, from the decision to proceed with a plan to release of the final document. In reality, many of the proposed management strategies may be wholly or partly implemented as the need arises. CALM are not restricted to awaiting the final document before management initiatives can be advanced.

A delay in the implementation of a management plan and indeed, proclamation of the M101 area as a Marine Park, is not considered an impediment to the Port Kennedy development proposal. This development will not directly impinge on the M101 area. Also, the indirect effects of increased recreational pressure will occur gradually over a number of years. Maximum utilization of the marina may not occur for several years.

5.3 Monitoring and Research Requirements

During the evaluation of this project, the deficiencies in base-line data prevented rigorous assessment of long term potential impacts. Reasoned judgements have been made without the benefit of supporting scientific data. The greatest level of uncertainty is in relation to the long term impact of fishing and other forms of reef harvesting.

In broad terms, the information requirements are quite simply stated. If the proposed National Park is to support the amateur fishery which is now in place and likely to increase, the sustainable yield of the fishery needs to be determined. When the catch rate of a particular species exceeds the reproductive capacity of the population, abundance can be reduced to extremely low levels. Definition of sustainable yield would require long term monitoring of annual catches from the entire breeding stock and monitoring of annual recruitment; this is a demanding and expensive exercise.

It is believed that investigations should be conducted into the feasibility of obtaining data to support particular management strategies. For example, will regulations on total catch and species size be an adequate management strategy for reef fish, or would complete closure of a section of reef be a more workable approach?

Routine monitoring of recreational use and fish catches would be valuable information to management. The potential for periodic creel surveys should be assessed. Research in the area should be encouraged to be management oriented.

5.4 Role of the Port Kennedy Development

In this instance, it is not the role of a private sector developer to become involved in the direct management of a nearby National Park. It would also be difficult to determine accountability in relation to recreational impacts apportioned to the development. Consequently, no attempt has been made to determine a formula or relationship between the proponent and future management structure for the proposed marine park.

However, it is considered that the proponent could play a role in influencing the behaviour of people utilizing the development, to help minimize activities which are incompatible with the aims of the National Park. The following preliminary list is suggested as a basis for discussion with respect to on-going planning for the development.

(i) Development plans for the marina will incorporate an office to be utilized by inspectors or rangers from the Fisheries Department and CALM. The need for a permanent ranger presence at the marina is not considered a prerequisite to the development. Maximum ranger presence would be most beneficial in the zone of greatest accessibility to the M101 area, i.e. in the Cape Peron area.

(ii) A programme of education, including information displays (etc) would be an important technique in raising visitor awareness of both the opportunities for recreation in the Marine Park and the limitations which need to be imposed. Aspects to be considered for an education programme would be determined in liaison with CALM.

(iii) The facilities and services provided could be modified in recognition of the more sensitive aspects of the marine environment. The degree to which some potential activities will be structured is not known at this stage. However, for the sake of examples, activities such as spearfishing competitions on the Murray Reefs, or the establishment of water skiing circuits over shallow seagrass meadow, should be discouraged.

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APPENDIX F: HARBOUR FLUSHING

CENTRE FOR WATER RESEARCH, UNIVERSITY OF WESTERN AUSTRALIA

AN ASSESSMENT OF HARBOUR EXCHANGE

FOR THE

PORT KENNEDY REGIONAL RECREATION CENTRE ERMP

Client:

Binnie and Partners

July 1988

D.P. Lewis and J. Imberger

Coastal and Hydraulic Engineering Laboratory
Centre for Water Research
The University of Western Australia
Nedlands Western Australia 6009

Report Number WP-88-039

CONTENTS

		Page
1.	INTRODUCTION	1
2.	ENVIRONMENTAL PARAMETERS	2
	2.1 Tidal fluctuations	2
	2.2 Meteorological conditions	2
	2.3 Freshwater inflow	3
	2.4 Harbour layout	3
3.	EXCHANGE MECHANISMS	4
	3.1 Tidal exchange - Astronomical tides	4
	3.2 Tidal exchange - Barometric tides	5
	3.3 Wind induced flushing due to shear dispersion	5
	3.4 Wind mixing due to eddy dispersion	7
	3.5 Gravitational flushing	9
4.	DISCUSSION AND SUMMARY	13
REFERENCES		15

1. INTRODUCTION

The proposed Port Kennedy Regional Recreation Centre is to be located on Becher Point at the southern end of Warnbro Sound, as shown in Figure 1.

This report was commissioned in April 1988 by Binnie and Partners Pty Ltd to assess the exchange mechanisms within the proposed marina associated with the Recreation Centre. The brief entailed an investigation of the flushing rates between the marina and ocean waters.

2. ENVIRONMENTAL PARAMETERS

2.1 Tidal Fluctuations

The astronomical tidal fluctuation at Port Kennedy may be approximated by the tidal variations measured at the Port of Fremantle. The tidal oscillation of the sea water surface at Fremantle is dominated by a diurnal component, of period 24 hours, and a barometric component of period from 5 to 9 days. The mean range of the diurnal tide is approximately 0.4 m. The barometric tide is estimated to range between 0.2 and 0.3 m (Hunter 1987; Imberger and Associates 1982).

2.2 Meteorological Conditions

Wind data has been collected in the region by Steedman and Associates at Cape Peron (Buchan 1981), approximately 10 km north of Port Kennedy; by the Fremantle Port Authority at the Port of Fremantle; and by Steedman Limited off Fremantle between November 1984 and October 1985.

Typical wind data collected by Steedman Limited off Fremantle in 1984-85 are presented in Figures 2 and 3. The data was analysed by the Department of Marine and Harbours (1988) and presented as percentage wind speed occurrence versus wind direction (refer Table 1).

Wind data was also collected at Fremantle by the FPA from January 1, 1981 to June 30, 1982. This consisted of a continuous record of wind speed and direction measured atop the FPA building at an elevation of 60 m. D'Adamo (1983) reduced this data to equivalent wind speeds at an elevation of 3 m. Typical reduced data are presented in Figure 4. The mean wind speed at Fremantle was determined to be approximately 4.5 m s^{-1} with the dominant directions being from the southwest, south and east (Figure 5).

Buchan (1981) has shown that a high correlation exists between wind data recorded at Cape Peron and Fremantle (Figure 6). Halpern and Glick (1983) have indicated that for all practical purposes the wind climate near Becher Point may be assumed identical to that recorded at Fremantle.

2.3 Freshwater Inflow

Numerical modelling of the groundwater flow in the Port Kennedy area was completed by Mackie Martin and Associates (1988). A coastal groundwater flux of approximately 250 m^3 per day was predicted along the length of the shoreline adjacent to the proposed marina. This result was based on long term drawdown predictions. It has been assumed that the groundwater flux is uniformly distributed along the landward boundary of the marina.

2.4 Harbour Layout

The layout of the Port Kennedy Marina is illustrated in Figure 7. For the purposes of estimating harbour exchange, the basin has been assumed to comprise an area of 96 000 m^2 at a level of -4 m (AHD) and an area of 32 000 m^2 at -3 m (AHD). The entrance channel is approximately 60 m wide at an average depth of -4 m (AHD).

3. EXCHANGE MECHANISMS

Flushing of small harbours along the southwest Australian coastline may be dominated by any of the following mechanisms:

- tidal exchange
- wind-induced mixing and flushing
- gravitational circulation.

Each mechanism will be described separately with specific reference to the marina proposed at the Port Kennedy Regional Recreation Centre. A preliminary prediction of flushing times will be based on calculations assuming a relatively open and unobstructed basin layout. The effect of the three island structures within the marina, as illustrated in Figure 7, will be addressed in each case.

3.1 Tidal Exchange - Astronomical Tides

Flushing of the marina basin by tides can be calculated using the tidal prism method. During a complete tidal cycle, a volume of harbour water will be removed and replaced with water from outside the harbour on the subsequent flood tide. Assuming complete mixing both within and outside the harbour, the tidal exchange or flushing time is given by:

$$\text{Flushing time} = \frac{V_B \times TP}{V_P} \qquad (1)$$

where V_B is the harbour basin volume at low water; TP, the tidal period; and V_P, the tidal prism volume.

Assuming a flat-bottomed basin and level water surface, the exchange can be approximated by:

$$\text{Flushing time} = \frac{h_{LW} \times TP}{TR} \qquad (2)$$

where h_{LW} is the average basin water depth at low water and TR is the tidal range.

Substituting the relevant parameters for the Port Kennedy Marina, that is $V_B \approx 4.54 \times 10^5$ m^3, TP = 24 hours, and $V_P \approx 5.12 \times 10^4$ m^3, gives a flushing time, due to astronomical tides, of 9 days. This result could be viewed as optimistic as complete mixing has been assumed to take place inside and outside the harbour during each periodic tidal exchange. This mixing, however, will be facilitated by wind-induced turbulence and shear and is addressed in detail in sections 3.3 and 3.4 of this report.

The effect of the non-uniform layout of the marina will have little impact on tide generated exchange. The provision for continuous flow around the island structures will aid mixing between the harbour and ocean waters within the basin.

3.2 Tidal Exchange - Barometric Tides

Meteorological forcing generates barometric tides in this region of approximately 0.2 m range. The mean tidal velocities induced by this barometric oscillation will be so small that the exchange rate will be very slow. For example,

$$\bar{V} = \frac{TR \times L_B}{{}^1/_2\ TP \times h_m} \tag{3}$$

where $\bar{V}$ is the mean tidal velocity induced within the basin by the barometric oscillation; L_B, is the typical basin length; and h_m, is the mean water depth. Substituting typical values for the Port Kennedy marina, that is, $L_B \approx 400$ m, TP $\approx$ 5 days, and $h_m \approx 4.0$ m, yields $\bar{V} \approx 4.6 \times 10^{-4}$ m s^{-1}. This velocity is so small that it would have negligible influence on longitudinal mixing.

3.3 Wind-Induced Flushing due to Shear Dispersion

Wind shear acting on the water surface will generate circulation currents within the enclosed basin. The stress developed on the water surface of the basin results in a return shear flow at depth which in turn leads to longitudinal mixing within the basin. This shear flow is maximised when the wind is blowing from, or towards, the harbour entrance along one of the basin's long axes. In basins of non-uniform bottom geometry lateral circulations may also be induced resulting in enhanced longitudinal flushing (see Csanady 1966).

The wind shear stress at the water surface is given by τ where:

$$\tau = C_D \rho_A U_W^2 = \rho_W u_*^2 \tag{4}$$

and C_D is a drag coefficient (taken to be approximately 1.3×10^{-3}); ρ_A and ρ_W are the air and water densities respectively; U_W is the free wind velocity and u_* is the shear velocity.

Imberger and Monismith (1986) have experimentally determined the water surface drift velocity U_D to be of the order of 10 to 20 u_*. This corresponds to around 1 to 2% of the free wind speed. They have also measured a peak return flow velocity (i.e. propagating into the wind direction) of approximately 2 u_* or 0.25% of the free wind speed. This recirculating flow generates longitudinal mixing through shear dispersion. The longitudinal dispersion coefficient, K_x, was defined as

$$K_x = C_2 h_m u_* \tag{5}$$

where C_2 was of the order of 10. The mixing or flushing time scale is then defined as

$$T_x = L_B^2 / K_x \tag{6}$$

Substituting values for the proposed marina gives a flushing time of the order $8^1/2$ days for winds blowing from the southwest at a mean speed of 4.5 m s^{-1}. This result, however, should be viewed in light of the following limitations:

a) Vertical density stratification of the water column, which may suppress the wind-induced shear, has been assumed to be negligible.

b) The vertical overturning will not flush floating debris or contaminants from the harbour. Some form of surface maintenance may be required near enclosed regions of the basin.

c) The wind fetch has been assumed to be relatively unobstructed.

The third limitation is of considerable importance. From site inspections it is apparent that Becher Point provides substantial shelter from the south-westerly prevailing wind. The islands within the proposed marina will further reduce the surface shear. For example, assuming a surface wind speed of the order of 2 m s^{-1} increases the flushing time to around 19 days. Wind shear therefore becomes less dominant than tide generated exchange. Orienting the islands within the harbour basin to be parallel with the dominant wind direction would optimise the flushing due to the reduced wind-induced shear.

3.4 Wind Mixing due to Eddy Dispersion

Wind-induced mixing in a homogeneous water column takes place by longitudinal turbulent dispersion. This effect will lead to internal mixing within the harbour thus complementing tide and density generated exchange with the ocean.

The turbulent horizontal dispersion coefficient, ε_x, scales as

$$\varepsilon_x \sim \varepsilon^{1/3}\, \ell^{4/3} \qquad (m^2\ s^{-1}) \qquad (7)$$

where ε is defined as the rate of energy dissipation and ℓ is a typical eddy length scale. The rate of energy dissipation scales as

$$\varepsilon \sim U^3/\ell \qquad (m^2\ s^{-3}) \qquad (8)$$

where U is a typical velocity scale. For this situation, U is given by the free wind speed U_w.

Oakey and Elliott (1982), derived a term ε_1, dependent upon the free wind speed U_w, such that

$$\varepsilon_1 = \rho_w h_m \varepsilon \qquad (\text{Watts } m^{-2}) \qquad (9)$$

where h_m is the mean water depth of the basin. Assuming U_w to be of the order of 4.5 m s^{-1} and with reference to Figure 8:

$$\varepsilon_1 \simeq 2 \times 10^{-3} \text{ Watts m}^{-2}$$

and therefore

$$\varepsilon = 4.9 \times 10^{-7} \text{ m}^2 \text{ s}^{-3}$$

Schwartz (1988) measured ε in Hillarys Boat Harbour, Western Australia, and found for wind speeds of approximately 6 m s^{-1}, ε was of the order of 3×10^{-6} m^2 s^{-3}.

Fischer et al. (1979) described experiments by Okubo (1974) making it possible to estimate the dispersion coefficient, ε_x, given the length scale of the mixing zone. It was shown that (Figure 9)

$$\varepsilon_x \simeq 0.01\ \varepsilon^{1/3}\ \ell^{4/3} \tag{10}$$

The time scale to longitudinally mix some contaminant through a vertically homogeneous basin can then be defined as

$$T_x = \frac{L_B^2}{\varepsilon_x} = \frac{100\ L_B^2}{\varepsilon^{1/3}\ell^{4/3}} \tag{11}$$

For a relatively open and unobstructed basin, the eddy length scale ℓ is equivalent to the basin length scale, L_B. Equation (11) therefore becomes:

$$T_x = \frac{L_B^2}{\varepsilon_x} = \frac{100\ L_B^{2/3}}{\varepsilon^{1/3}} \tag{12}$$

Assuming $L_B \simeq \ell \simeq 400$ m gives a wind induced horizontal mixing period due to eddy dispersion of around 8 days.

The proposed marina layout, however, incorporates three significant island structures within the basin. The eddy length scale, ℓ, will be limited to the typical channel length of around 200 m. Equation (11) then gives a wind induced flushing period due to eddy dispersion within the basin of the order of 20 days. Again, orienting the islands to be parallel with the dominant wind direction will maximise the flushing due to wind-induced turbulent dispersion.

3.5 Gravitational Flushing

Harbour flushing may also be induced by gravitational circulations resulting from density variations within the water body. These density variations may be the result of differential heating or cooling within the basin, fresh water inflow or surface evaporation.

Imberger and Associates (1982) examined the effects of strong surface heating on the gravitational mixing within a narrow canal system. In the absence of strong stratification, however, it may be assumed that mixing in this manner within the Port Kennedy Marina will be weak.

Schwartz (1988) has estimated the flushing induced by fresh water inflow to Hillarys Boat Harbour. In this specific instance, the presence of the Gnangara Mound to the east produced a substantial inflow to the Hillarys Harbour which in turn led to gravitational flushing in the order of 5 days. The work followed the two-layer flow theory, described by Armi (1986) and Armi and Farmer (1986) in predicting the flushing rate driven by density variations within the harbour. The calculations were derived from field density measurements within the two separate layers, observed both in the entrance channel and the harbour basin.

The analysis was based on the concept of critical flow in a two-layer system, as described by Stommel and Farmer (1952), where two fluid layers of slightly differing density exist at the entrance to a water body. It can be shown that the discharge at the mouth of an estuary, or harbour, with freshwater inflow, can be limited when the interfacial Froude number, F_i, equals unity, where

$$F_i = v_i/(g'y_i)^{1/2} \tag{13}$$

and the subscript i denotes either the upper layer (1) or the lower layer flow (2). Should the flow in the upper layer be critical, thus maintaining a critical depth, then the compensating lower layer inflow to the harbour will be controlled.

Armi (1986) defined a non-dimensional layer flow rate U_0 such that

$$U_0 = \frac{Q_i}{(g')^{1/2}\, b_0 (y_1 + y_2)^{3/2}} \tag{14}$$

where Q_i is the barometric flow rate through layer i; b_0 is the channel width at the entrance; y_1 and y_2 are the depths of layers 1 and 2 respectively; and

$$g' = \frac{\Delta\rho}{\rho_0} g \tag{15}$$

Assuming an exchange rate R (days) for the Port Kennedy Marina, it is possible to estimate the change in salinity, and therefore density, within the harbour during one flushing cycle. That is,

$$\frac{S}{S_0} \simeq \frac{V_B - RQ}{V_B} \tag{16}$$

where V_B, is the volume of the harbour basin; Q, is the freshwater inflow; S_0, is the oceanic salinity; and S, is the average basin salinity over the entire flushing time, Q. Assuming a flushing period of around 3 days gives $(S/S_0) \simeq 0.9984$. Fischer et al. (1979) describes a method for calculating density from salinity, so that assuming an oceanic salinity of 34 ppt,

$$\rho_0 \simeq 1024.02 \text{ kg m}^{-3}$$

$$\rho \simeq 1023.98 \text{ kg m}^{-3}$$

and

$$g' = (\Delta\rho/\rho_0)g = 3.8 \times 10^{-4} \text{ m s}^{-2}$$

The total barometric flow Q_i may be approximated by

$$Q_i = \frac{V_P}{1/2(TP)} \tag{17}$$

where V_P, is the tidal prism volume; and TP, is the tidal period. This gives an average flow rate of around 1.18 $m^3\ s^{-1}$. Substituting this result into equation (14), and setting $b_0 \simeq 60$ m and $(y_1 + y_2) = h_m = 4.0$ m, yields

$U_o = 0.127$

Armi and Farmer (1986) describe a method for determining the flow rate in each layer given the non-dimensional barotropic flow component U_o. The method is summarised in Figures 10, 11 and 12. From these plots the following dimensionless parameters were determined for the Port Kennedy Marina, assuming critical two-layer flow:

$$y_{20} = 0.47$$
$$y_{10} = 0.53$$
$$b_v = 1.10$$

$$u_{10} = 0.59$$
$$u_{20} = -0.39$$

The dimensionalised velocities may then be determined using the result:

$$u_{10} = \frac{u_i}{(g')^{1/2}(y_1 + y_2)^{1/2}} \qquad (18)$$

so that

$$u_1 = 0.023 \text{ m s}^{-1}$$

$$u_2 = -0.015 \text{ m s}^{-1}$$

Using the lower layer to estimate the baroclinic exchange rate:

$$R = \frac{V_B}{Q_2} = \frac{V_B}{u_2\, b_o\, y_2} \qquad (19)$$

where

$$u_2 = -0.015 \text{ m s}^{-1}$$
$$b_o = 60 \text{ m}$$
$$y_2 = 0.47(4.0) = 1.88 \text{ m}$$
$$V_B = 4.54 \times 10^5 \text{ m}^3$$

so that $R \approx 3.1$ days. This result indicates a flushing time due to two-layer baroclinic flow of the order of 3 days.

It is important to remember that this two-layer gravitational exchange analysis is based upon density differences existing within the harbour as a result of freshwater inflow. The theory has been verified under relatively strongly stratified conditions through field measurements within Hillarys Boat Harbour. Further verification of the theory, through field experimentation, is required in less strongly stratified harbours, such as the Port Kennedy Marina.

It should also be recognised that a reduction in freshwater inflow to the harbour through groundwater drawdown would limit the gravitationally induced flushing of the basin. The groundwater flux predicted by Mackie Martin & Associates (1988) has, however, accounted for long term groundwater utilisation and is considered a reliable estimate of the freshwater inflow.

4. DISCUSSION AND SUMMARY

In the majority of relatively enclosed southwest Australian coastal waterways and harbours the principal water quality problem likely to be encountered is that of nutrient enrichment, leading to the formation of algal blooms, the generation of organic detritus and consequent oxygen depletion (Hunter 1987; Imberger and Associates 1982).

Nutrient enrichment, and the subsequent algal bloom, can be avoided by maintaining nutrient concentrations in the water body at levels below that at which the blooms may develop. This may be achieved by:

1. restricting the nutrient supply to the water body; and/or

2. ensuring adequate flushing of the water body.

This report has detailed the effects of tidal flushing, wind circulation and internal mixing, and gravitational flushing within the proposed marina associated with the Port Kennedy Regional Recreation Centre. Exchange rates have been predicted for each mechanism. It has been shown that gravitational exchange is potentially the dominant flushing mechanism yielding an exchange rate of the order of 3 days. Field verification of this estimate would be warranted under the relatively weakly stratified conditions in the proposed marina.

In the absence of significant sheltering, wind-induced shear and eddy dispersion would flush the harbour basin in around 9 days. However, the shelter provided by Becher Point and the structures associated with the marina development will tend to limit this wind generated exchange. A flushing period of the order of 20 days has been estimated when these sheltering effects have been considered. Orienting the structures within the harbour basin parallel to the predominant wind direction would maximise this wind-induced flushing, however, since the dominant flushing mechanisms have been shown to be gravitational and tidally driven exchange, this requirement is not critical.

Astronomical tidal exchange within the basin was predicted at 9 days. This result should ensure adequate flushing of the water body provided nutrient supply to the marina is controlled. Barometric tidal exchange has been shown to be insignificant. Gravitational exchange is likely to reduce the overall flushing period to less than 9 days.

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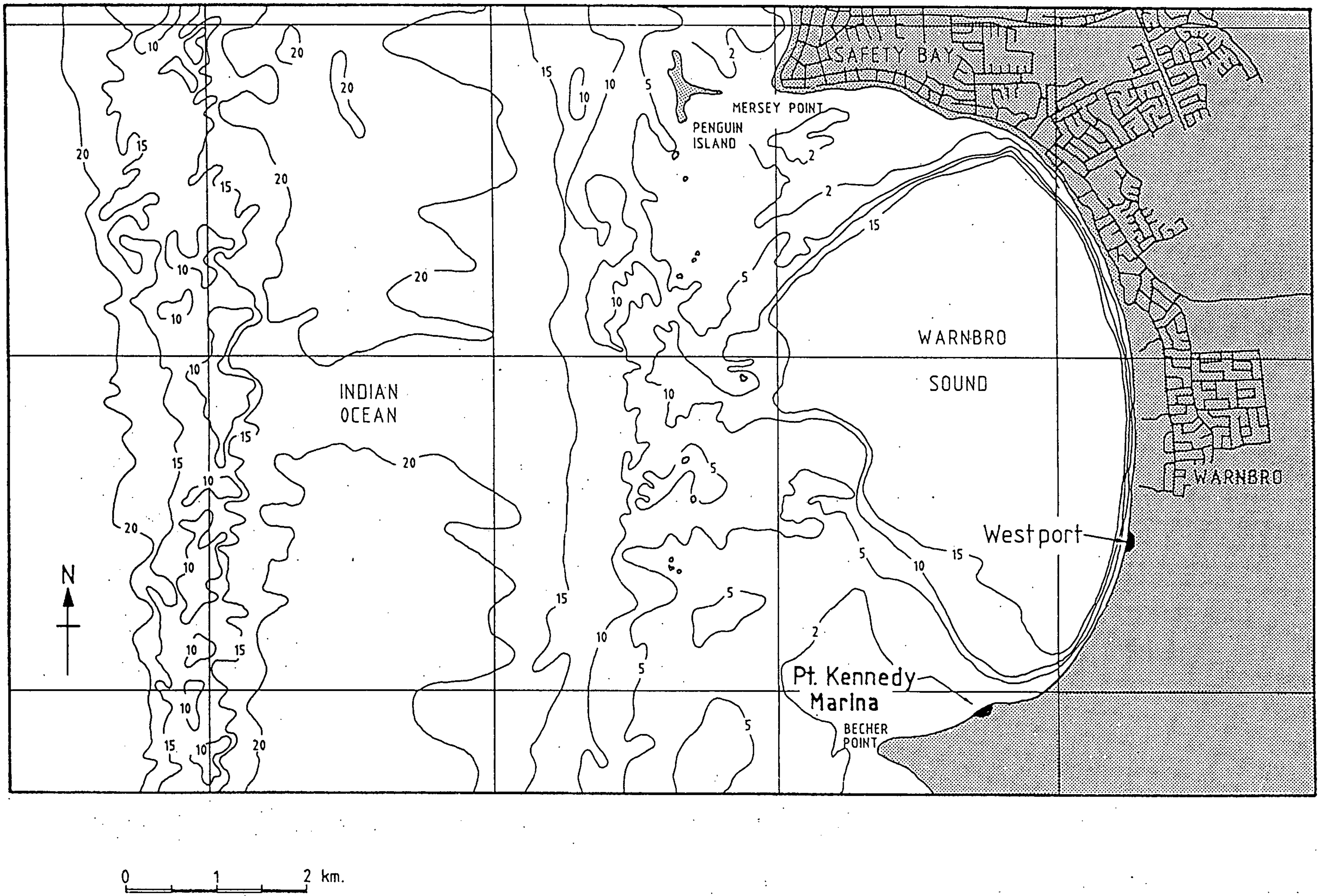


Source: Riedel & Byrne Pty Ltd

Figure 1: Site Location

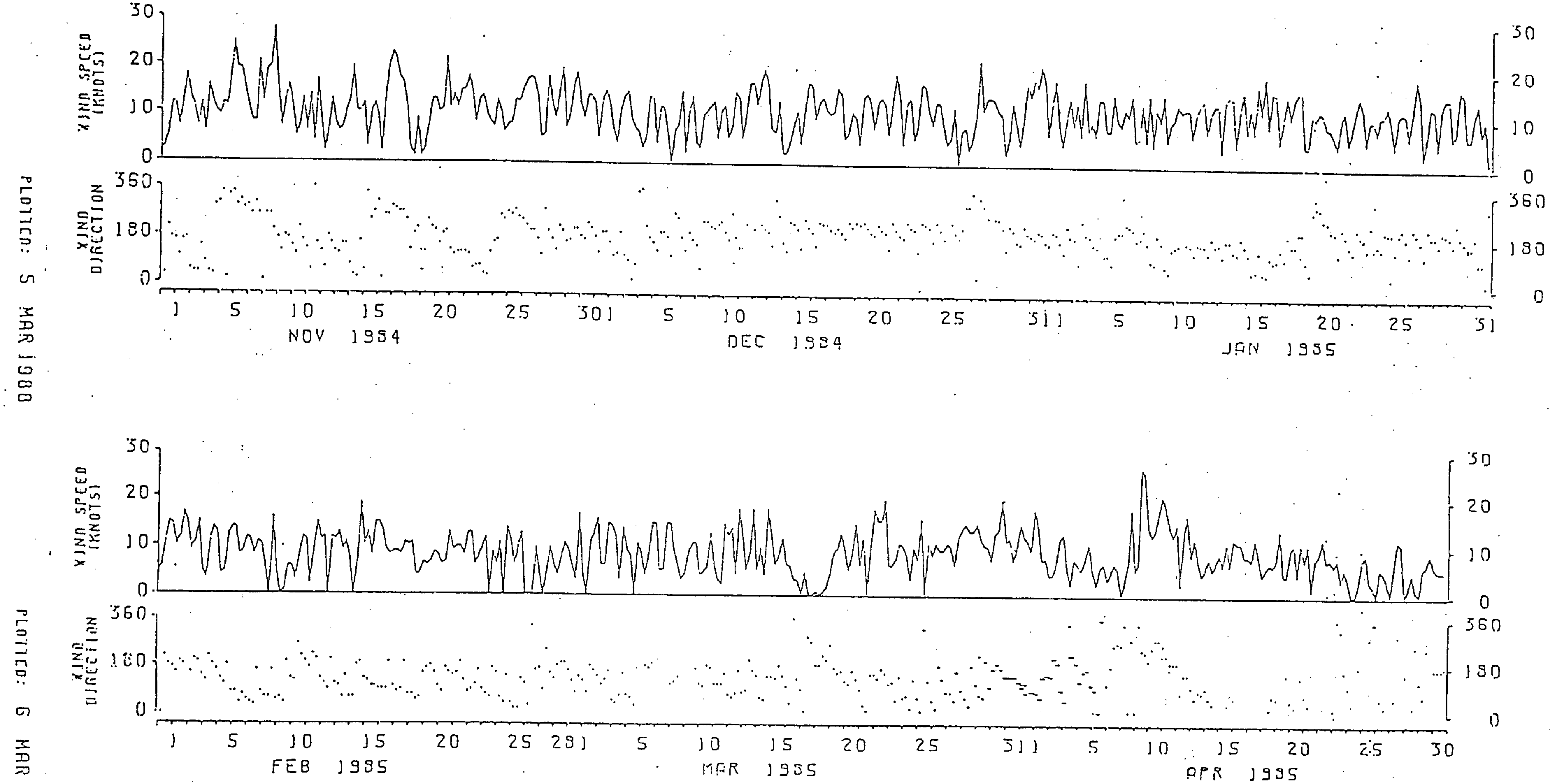


Figure 2 : Time history plot of wind field off Fremantle (DMH 1988).

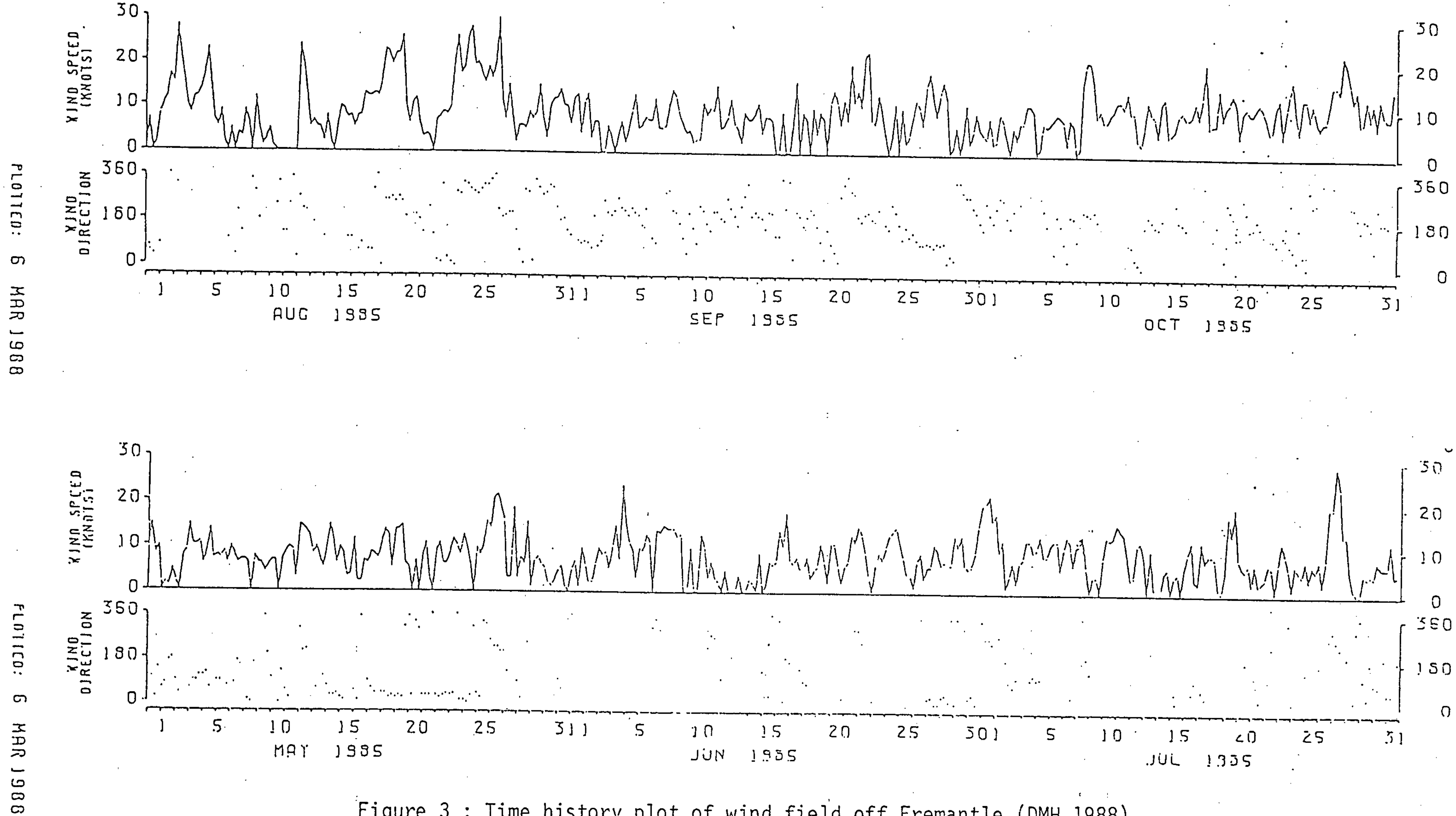


Figure 3 : Time history plot of wind field off Fremantle (DMH 1988).

OFF FREMANTLE PORT
NOV 84 TO OCT 85

PERCENTAGE OCCURRENCE OF WIND SPEED (KTS) VS. DIRECTION

ANNUAL

	0 (0-2)	5 (3-7)	10 (8-12)	15 (13-17)	20 (18-22)	25 (23-27)	30 (28-32)	35 (33-37)	40 (38-42)	45 (43-47)	50 (>47)	TOTAL
NNE		2.43	2.33	.72	.03	.03	.00	.00	.00	.00	.00	5.55
NE		1.82	2.47	.75	.07	.00	.00	.00	.00	.00	.00	5.10
ENE		2.12	2.74	.68	.14	.03	.00	.00	.00	.00	.00	5.72
E		3.22	3.94	1.68	.10	.00	.00	.00	.00	.00	.00	8.94
ESE		2.74	1.88	.68	.07	.00	.00	.00	.00	.00	.00	5.38
SE		2.91	2.26	.62	.07	.00	.00	.00	.00	.00	.00	5.86
SSE		2.64	2.53	1.34	.14	.00	.00	.00	.00	.00	.00	6.64
S		3.32	5.14	2.81	.58	.03	.00	.00	.00	.00	.00	11.88
SSW		1.61	2.67	2.84	.89	.07	.07	.00	.00	.00	.00	8.15
SW		.79	2.50	1.61	.62	.10	.03	.00	.00	.00	.00	5.65
WSW		.89	1.61	.96	.17	.17	.03	.00	.00	.00	.00	3.84
W		.99	1.54	1.27	.79	.24	.03	.00	.00	.00	.00	4.86
WNW		.51	1.27	.65	.31	.17	.07	.00	.00	.00	.00	2.98
NW		.45	.79	.68	.27	.03	.03	.00	.00	.00	.00	2.26
NNW		.51	.45	.38	.24	.14	.00	.00	.00	.00	.00	1.71
N		1.40	1.37	.45	.17	.00	.00	.00	.00	.00	.00	3.39
CALM	12.09											12.09
TOTAL	12.09	28.36	35.48	18.12	4.66	1.03	.27	.00	.00	.00	.00	

NUMBER OF OBSERVATIONS 2920

Table 1 : Annual percentage occurrence of wind speed (kt) versus direction. Based on 3 hourly wind speed and direction measurements for the period November 1984 to October 1985 (DMH 1988).

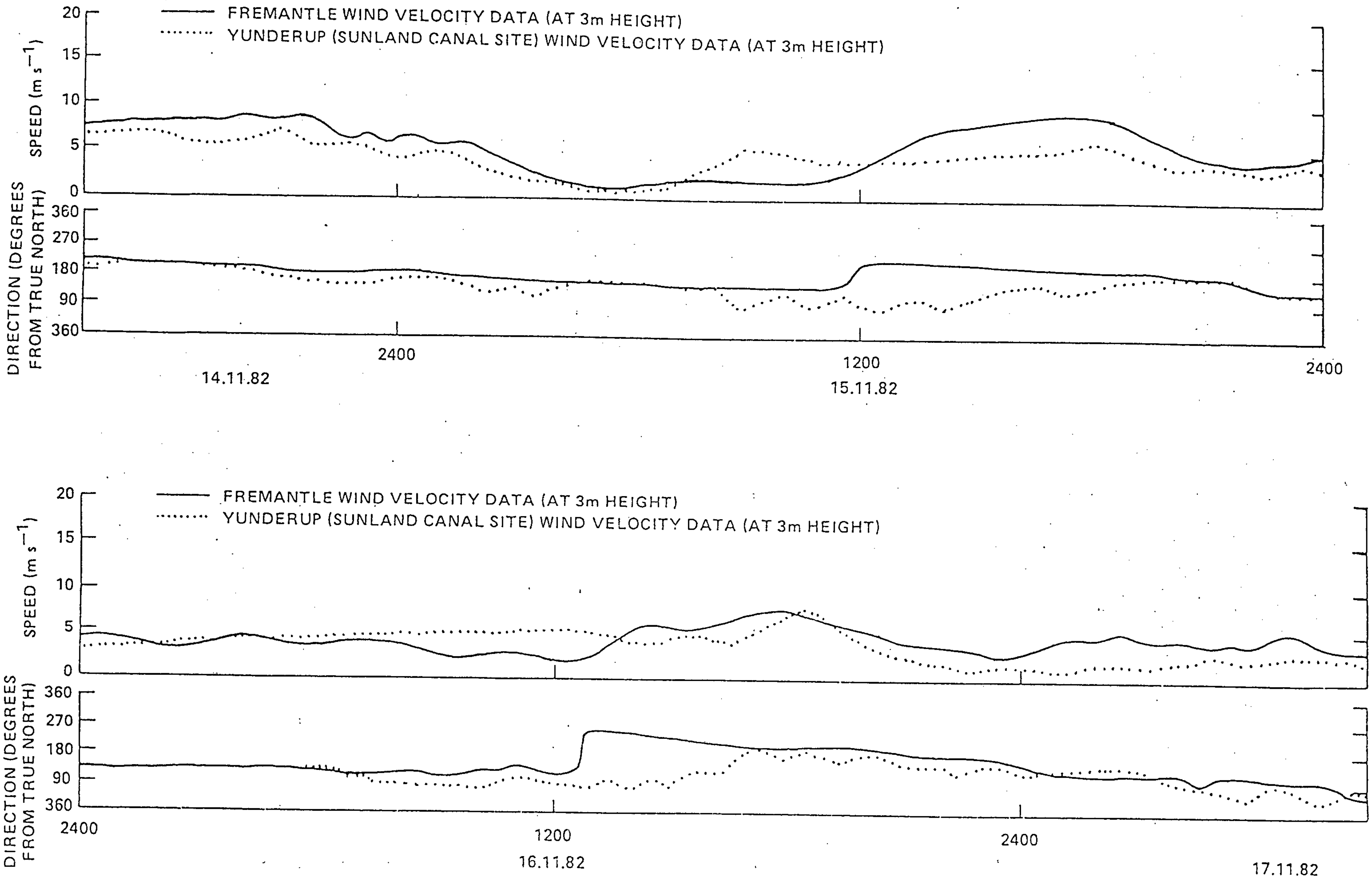


Figure 4 : Reduced wind data for Fremantle and Yunderup (D'Adamo 1983).

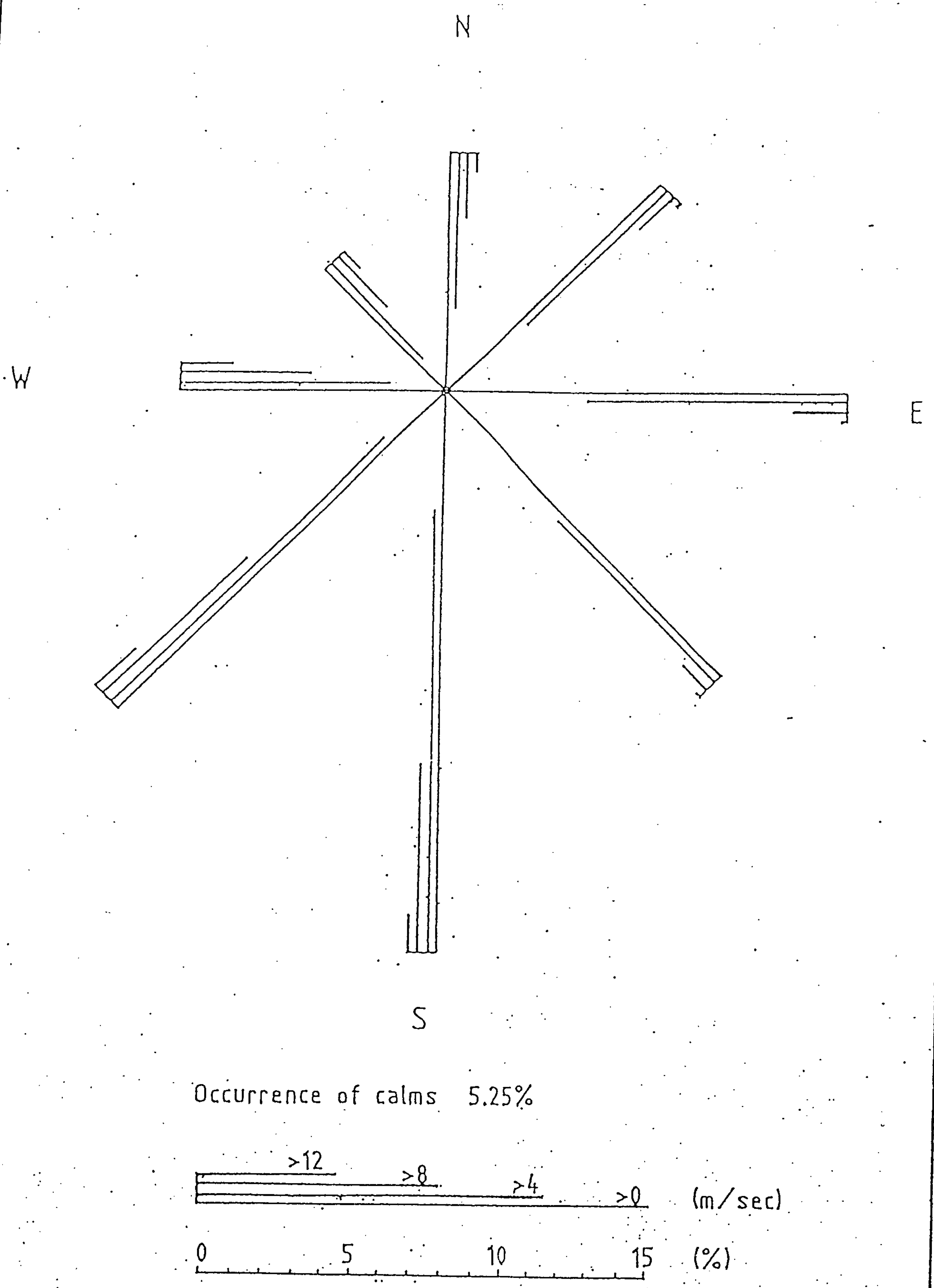


Figure 5 : Wind rose for Fremantle 1979-84 (Riedel & Byrne 1988).

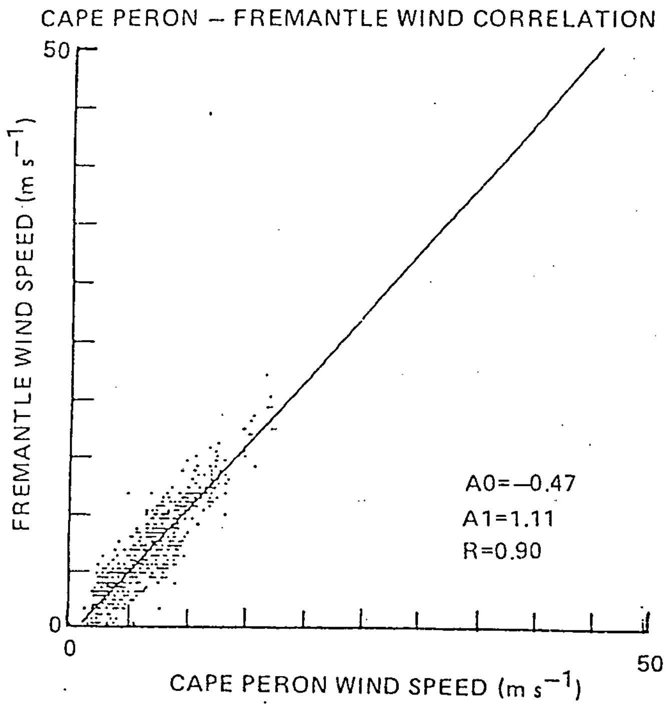
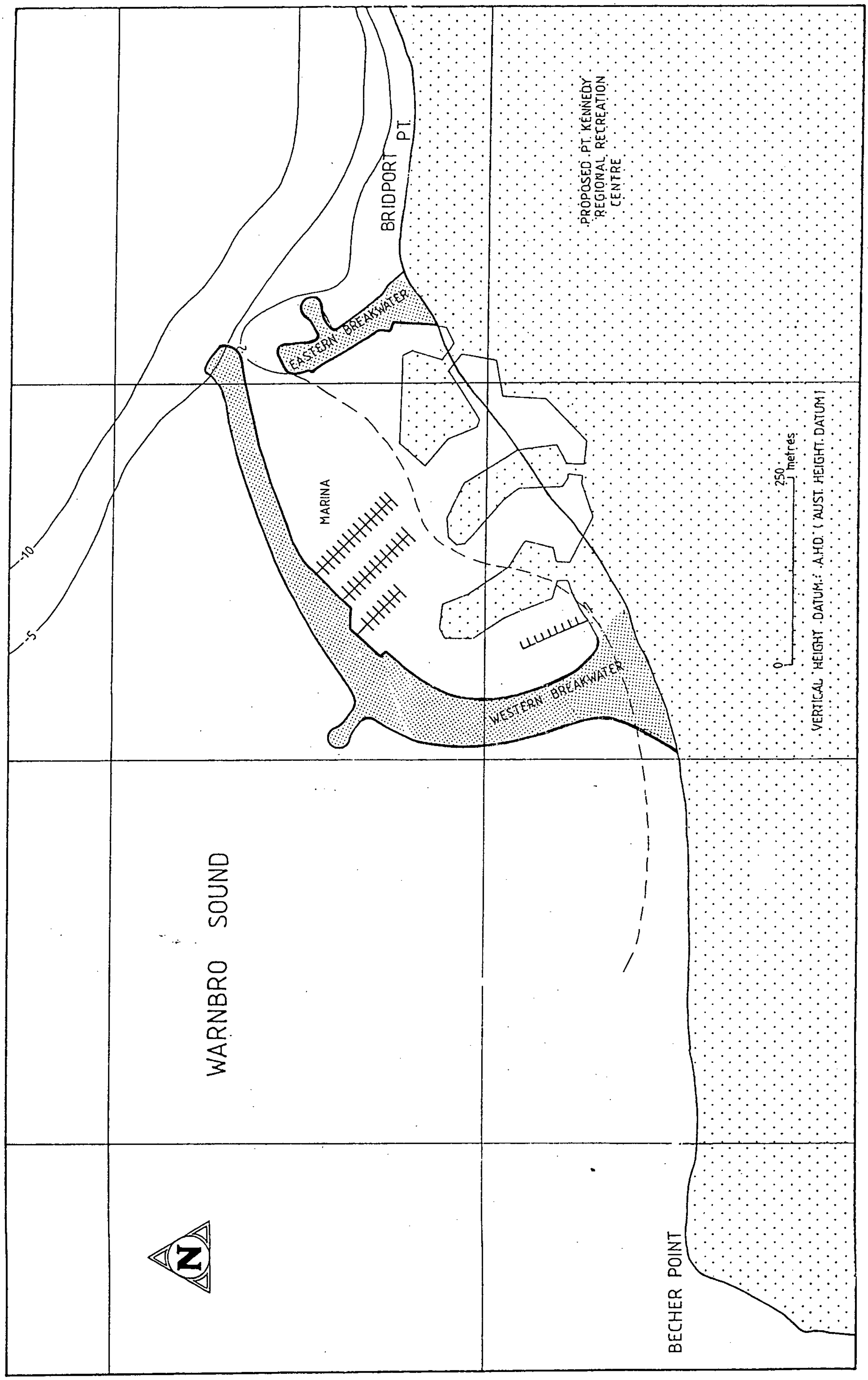


Figure 6 : Correlation of Cape Peron and Fremantle wind speeds. Fremantle data obtained from the FPA tower (60 m ASL) and corrected to 10 m ASL (from Buchen 1981).



Source: Riedel & Byrne Pty Ltd

Figure 7: Marina Layout

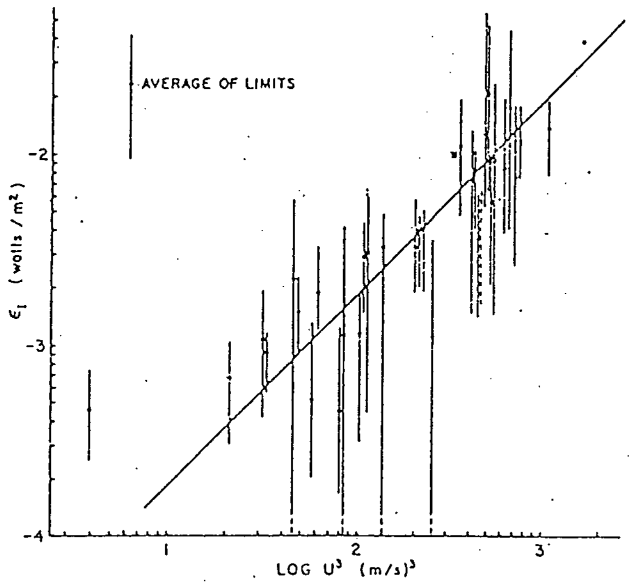


Figure 8 : Dissipation rate V wind speed cubed (Oakey & Elliott 1982).

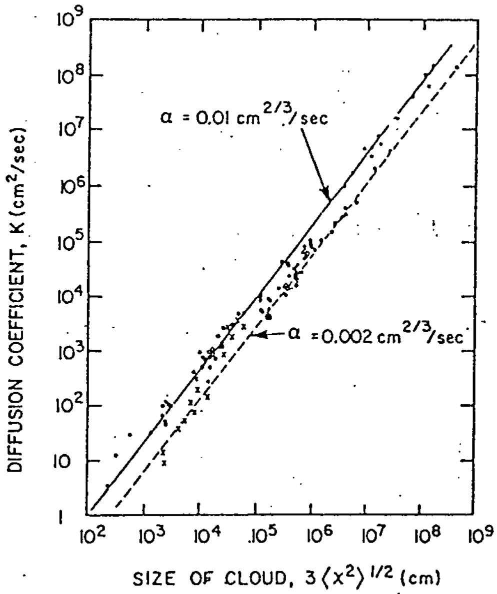


Figure 9 : Unified diagram of cloud diffusion (after Fischer et al, 1979).

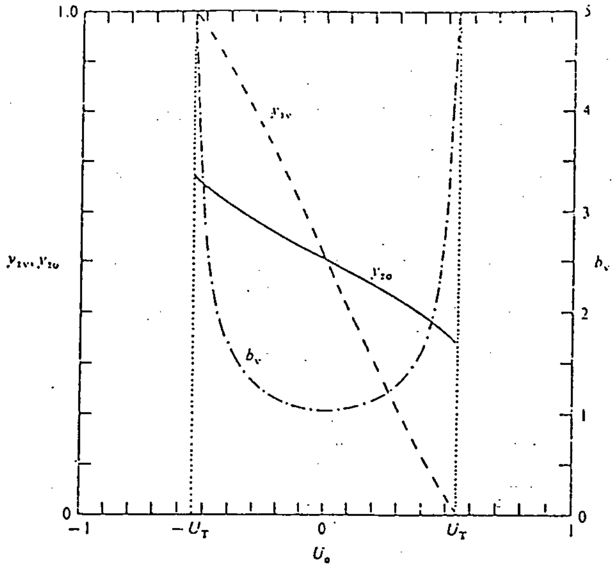


Figure 10 : Interfacial depth y_{20} in the channel versus the barometric flow component U_0 (Armi & Farmer 1986).

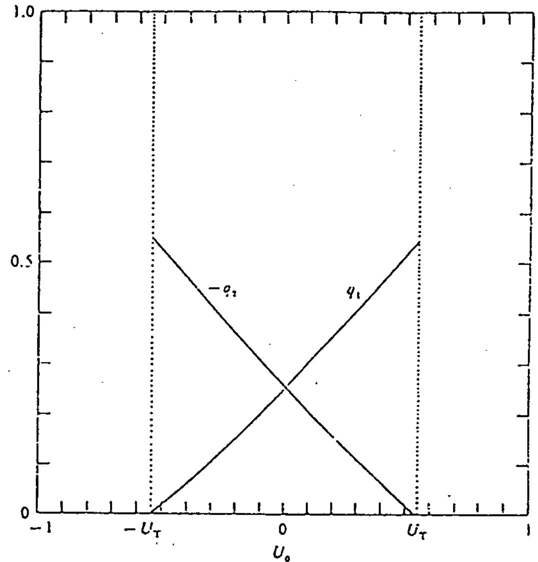


Figure 11 : Layer flow rates q_1 and q_2 versus the barometric flow component U_0 (Armi & Farmer 1986).

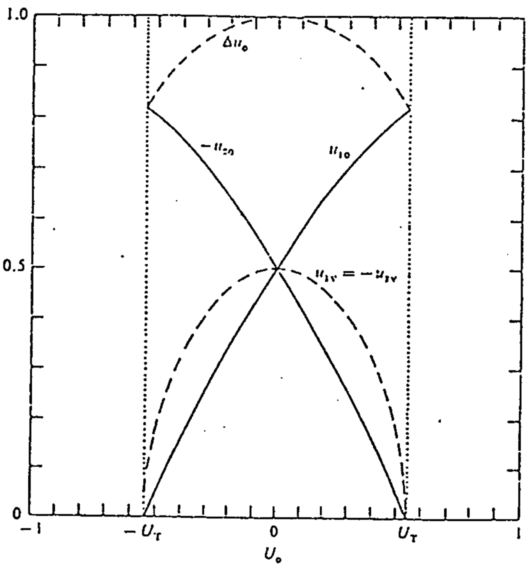


Figure 12 : Layer velocities u_{10} and u_{20} versus the barometric flow component U_0 (Armi & Farmer 1986).

APPENDIX G: GREENHOUSE EFFECT

COLIN PORTER

THE GREENHOUSE EFFECT AND OTHER CAUSES OF CLIMATIC CHANGE

Climatic change resulting from an overall warming or cooling of the earth's surface has followed a complex cyclic pattern for many hundreds of thousands of years, with major peaks occurring roughly every 100,000 years and minor variations lasting between 300 and 400 years. Since the 'little ice-age' between 1430 and 1850 AD the earth has been in a consistently warming trend.

These long term changes are believed to be due to variations in the earth's orbit round the sun (Milankovich Theory) and occur so slowly that the effects are masked by short term and regional variations. Nevertheless they have caused the sea level to rise and fall many metres due to the thermal expansion of the oceans and melting of the polar ice.

Recently, predictions have been made of much more rapid changes due to the 'greenhouse effect'. This is based on measurements of carbon dioxide in the atmosphere which have shown a consistently increasing trend since monitoring began in the early 1950's. It can be shown in the laboratory that radiated energy of short wave length, like that emitted by the sun, passes more easily through gases with higher levels of carbon dioxide and certain other gases, than the longer wavelength energy reflected back into space from the surface of the earth. The steadily increasing levels of carbon dioxide, methane and the other greenhouse gases, resulting largely from the burning of fossil fuels, should therefore encourage greater heat retention at the earth's surface.

Increasing international concern over the greenhouse effect resulted in a conference held at Villach, Austria in October 1985. This conference concluded, among other findings, that past climatic changes were no longer a reliable guide to the future since the increasing concentrations of greenhouse gases are expected to cause a significant warming of the global climate in the next century. It pointed out that energy conservation programmes and a reduction in the use of chloro-fluorocarbons would slow the rate of climate change, and it confirmed that the other greenhouse gases were collectively as important as the contribution to warming from carbon dioxide alone.

While the increase in temperature of between 1.5°C and 4.5°C is anticipated from a doubling of atmospheric carbon dioxide based on global modelling, the conference concluded that values outside this range could not be excluded due to imperfections in the models and uncertainties over ocean-atmosphere interactions. Based on observed changes since the beginning of the century, temperature increases of this order would produce rises in sea level of between 20 and 140 cms by the middle of the 21st century, due to thermal expansion of the oceans.

Villach also pointed out that the estimated increase in global mean temperature during the last one hundred years of between 0.3 and 0.7°C was consistent with the calculated temperature increase due to rising levels of the greenhouse gases. However it agreed that the increase could not be ascribed in a scientifically rigorous manner to these factors alone. Presumably this was in recognition of the long term climatic changes referred to earlier.

However while that rate of increase in greenhouse gases concentrations has been relatively uniform, the rate of increase in surface temperature has not been so. Indeed between 1940 and 1965 it appeared to be declining. This can only be due to other factors affecting climatic change, of which the most significant one appears to be the amount of the sun's radiation actually reaching the surface of the earth.

Dramatic changes in climate have followed major volcanic eruptions when large quantities of fine particulate matter are discharged into the upper atmosphere. These aerosols blanket the earth's surface from the sun's radiation and reduce surface temperature, but the effects are believed to last for only a few years. Gravity slowly brings these particles down towards the surface until they enter the lower atmosphere where they are rapidly purged by rain.

Dr Pearman of CSIRO, one of Australia's leading atmospheric scientists, stated, after a recent seminar held at Murdoch University, that it was believed that increased volcanic activity in the northern hemisphere was the cause of this inconsistency between global temperature and atmospheric carbon dioxide concentration.

Not all climatologists accept the Villach conclusions in respect of forecast temperature increases, because they believe other factors are leading to a reduction in the sun's warming capacity. Following the eruption of the Mexican volcano El Chichon in 1981, N.A.S.A's Aerosol Climatic Effects Programme conducted a dust sampling programme using very high flying U2 aircraft. They found an aerosol of water vapour droplets fused with sulphuric acid which, unlike volcanic ash, could remain in the upper part of the atmosphere for many years, and reduce sunlight penetration.

So, while the greenhouse gases will increase global temperatures, other man-made pollutants like sulphur dioxide and particulates, may be leading to a lowering of the sun's heating effect. The astrophysicist Dr Gribbin in a 1982 article argued that there had been a 5% reduction in the amount of heat arriving from the sun. Unfortunately these figures, like those of surface temperature change are harder to substantiate on a global scale than the easily measured atmospheric level of carbon dioxide.

Even more dramatic in its impact on climate than either the greenhouse effect, or a reduction in the sunlight intensity, is the warm Peruvian ocean current, known as El Nino, which can cause a dislocation of the world's largest weather system. Occurring on average every five or six years an exceptional El Nino has the capacity to devastate much of the southern hemisphere, like that of 1983 which left more than 1100 dead, caused drought in Australia, south east Asia, India and South Africa, but produced torrential rains and flooding on the west coast of the United States, the Gulf Coast and northern Peru. In that year the equatorial current reversed direction across the entire Pacific, sea surface temperatures rose as much as 14°F and a great tongue of warm water stretched 5,000 miles along the Equator. Unfortunately the cause of this ocean current aberration is not yet understood.

While the extent and rate of climatic change due to the greenhouse effect may be hedged with uncertainty, it is clearly prudent to examine the possible effects of global warming on mankind's activities. A number of conferences have been held since Villach for this purpose. One, organised jointly by the U.S.E.D.A. and U.N.E.P. was held in Washington D.C. in June 1986, and dealt with "The Effects of Changing the Atmosphere on the Stability of Sea Level and Shore Stability".

Even allowing for the large variation in possible temperature increases due to the greenhouse effect, a further unknown is the possible delay in the conversion of air temperature changes into sea temperature changes. While the Villach conference estimated a sea level rise of between 20 and 140 cms, Thomas in his paper "Future sea level rise and its early detection by satellite remote sensing" projected a worldwide rise in sea level of 90 to 170 cms by the year 2100 with a 'best guess' of 110 cms. His prediction for the middle of the 21st Century comes close to the bottom end of the Villach range, however he also draws attention to the effects of thermal lag and suggests that the actual rate of sea level rise may be only half. This would result in a rise in mean sea level of about 18 cms by the year 2050.

Because of the unevenness of warming, regional changes have been the subject of modelling in a number of countries in an attempt to predict weather patterns resulting from a warmer climate. Dr Pittock of C.S.I.R.O. has pointed out that tropical cyclones could form 200-400 kms further south following an overall increase in sea-surface temperature of 2-3°C. Dr Chittleborough, in a review paper published in 1985, has suggested that northern Australia will be wetter, but that the south west may well be drier than at present.

A further conference - Greenhouse 87 - was held at Monash University in early December 1987 and brought together those scientists engaged in atmospheric research and planners, engineers and government scientists who have the task of making long term decisions affecting the community. Since then a number of seminars have been held around Australia to inform the public about the predicted changes. Most State governments have now established lead agencies and advisory committees to review further information on the greenhouse effect, as it becomes available, and to advise on the public policy implications.

Clearly the most significant aspects of a warming climate are the prospective increases in sea level, and the potential for increasing or reducing rainfall. Neither are particularly easy to predict because of the complexity of the models and assumptions that must be made. As stated in the working papers for the National Conference held in 1987. "The uncertainties present in any prediction of future regional climate are very large". However the importance for the people of Western Australia, most of whom live on or close to the coast, and where water resources are scarce because of a dry climate, cannot be overestimated.

CONCLUSION

The steady increase in atmospheric levels of carbon dioxide and the other greenhouse gases is evident, and is unlikely to change significantly in a civilisation built on the burning of fossil fuels as the principal energy source. The greenhouse effect is a calculated change in surface temperature based on laboratory scale measurements of radiation transmitted through gases, magnified to a global scale by the use of complex models.

While the long-term temperature changes to date are largely consistent with overall temperature increases to be expected from past increases in greenhouse gas concentrations, they are small and cannot yet be used to substantiate the model predictions. Indeed, the rate at which temperatures have increased over the past 50 years has varied in a way that is not consistent with greenhouse gas concentrations, showing other factors are involved.

While it is important that research into the greenhouse effect continues, it is equally vital that measurements of solar radiation penetration to the earth's surface are carried out on a long term basis. This will substantiate or disprove the theory that concentrations of aerosols resulting from polluting emissions are filtering out some of the sun's radiation, leading to an overall cooling effect.

Of the two major impacts on Western Australia, that of sea level rise has the potential to cause flooding of low lying coastal areas and increased erosion of the coast due to increasing wave activity. Thermal lag, or the delay in transmission of air surface temperature increases to the main water body of the oceans, remains a major uncertainty in the prediction of sea level rise.

Changing rainfall patterns also have the potential to seriously effect a community which does not enjoy an abundant rainfall. Further reductions in annual precipitation will lead to the earlier harnessing of remote water resources and possibly to expensive salinity reduction programmes. Such reductions could have serious economic implications for all water users. The modelling of these microclimates is hedged with uncertainty, nevertheless the reliability of the prediction can only improve with time.

Fortunately these changes are likely to occur slowly and at a rate which will allow public policies to be developed as monitoring allows the theory to be substantiated.

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