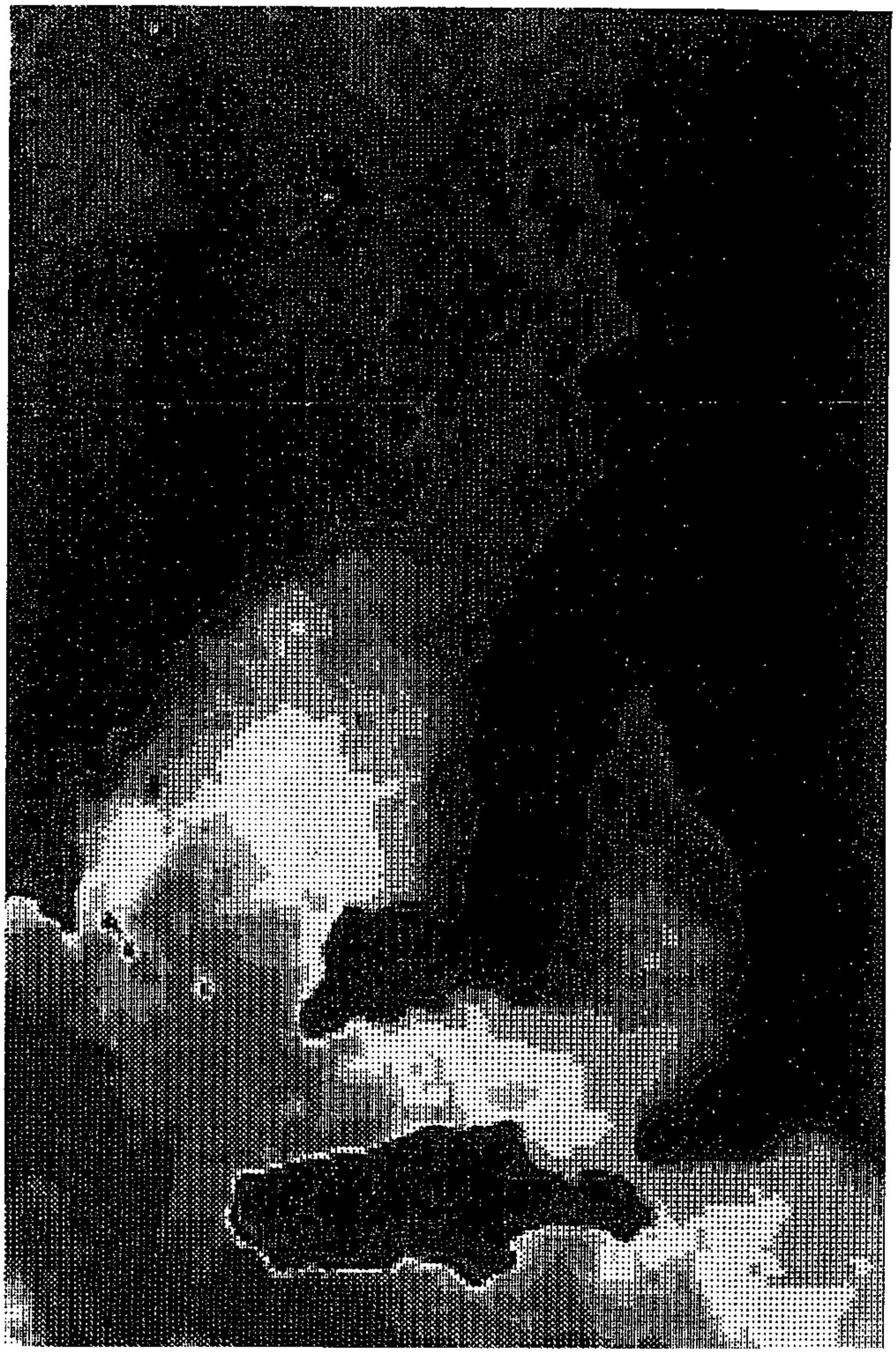
COASTAL VULNERABILITY STUDY
NORTHERN SPENCER GULF
SOUTH AUSTRALIA



A REPORT PREPARED BY THE MAWSON GRADUATE CENTRE FOR ENVIRONMENTAL STUDIES, SOUTH AUSTRALIA, FOR THE DEPARTMENT OF THE ENVIRONMENT, SPORT AND TERRITORIES.

COASTAL VULNERABILITY STUDY:

NORTHERN SPENCER GULF, SOUTH AUSTRALIA.

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THIS STUDY HAS BEEN CARRIED OUT FOR THE DEPARTMENT OF THE ENVIRONMENT, SPORT AND TERRITORIES THROUGH THE SOUTH AUSTRALIAN DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES BY THE

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(cover illustration: NOAA satellite image of sea-surface temperature, South Australian Gulfs, July 1994)

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EXECUTIVE SUMMARY

The South Australian Coastal Vulnerability Assessment Study was conducted in one of Australia's few inverse estuaries, the Northern Spencer Gulf. The region is in an arid environment with a relatively sheltered coast, unaffected by swell waves. There are wide mudflats, sand and sea-grass banks, mangroves and extensive supratidal areas subject to tidal flooding. Potential sea-level changes are important for the area given existing flooding problems in two of the three cities in the region.

The study produced an overview of the biophysical and socio-economic characteristics of the region drawing on aspects of regional strategic studies funded by the Commonwealth and State governments. In particular, it noted the dominance of industrial and economic activity in the three cities, Whyalla, Port Pirie and Port Augusta. The study examined coastal vulnerability using existing contour data, flooding data, tidal studies, and biophysical information stored on GIS databases.

Further vulnerability data were collected from four coastal sites; two industrial cities with sheltered coastal environments and extensive intertidal and supratidal deposits in the north and eastern part of the Gulf; one less developed holiday shack area on the north-western side of the Gulf; and a south facing bay of conservation value and low scale industrial usage.

First, at Port Pirie, an industrial city with a flood history, flooding studies had resulted in construction of protective works across the supratidal flats. A detailed levelling and vegetation survey provided an insight into the potential effects of sea-level change on vegetation communities in the area. Second, at Port Augusta, a flood hazard study had been conducted following previous coastal flooding problems. The response in that city, like Port Pirie is to construct protective works.

Third, Blanche Harbour on the northwestern side of the Gulf has extensive holiday shack development where building levels are inconsistent with State government coastal hazard policies. Options for relocation are too expensive and private protection works may cause future problems.

Fourth, False Bay, near Whyalla is flanked by industrial development but is an important conservation area for prawn larvae. At this site aerial photogrammetry together with ground based survey was used to produce a detailed contour map with 0.5m intervals. Results indicated the restricted areas, caused by levee construction for salt production, available for mangrove and samphire migration in the event of sea-level rise. This technique was relatively expensive.

Another technique investigated was the use of detailed GIS based Holocene geological maps, to identify levels of susceptibility to coastal flooding. This technique could be relatively inexpensive, accessible and useful for coastal managers around Australia, where there are low gradient intertidal and supratidal deposits.

The four sites indicated issues of protection, relocation and adaptation in response to sea-level rise. Interaction with community groups and local government, indicated pockets of expertise which would benefit from further interaction with State and Commonwealth coastal programs. Existing State coastal policies appear appropriate for responding to sea-level rise scenarios but in some areas are compromised by conflicting policy decisions on shack freeholding. In addition, the success of the policies rely to a large extent on implementation and monitoring by local councils.

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CHAPTER 1: BACKGROUND

1.1 THE COMMON METHODOLOGY FOR COASTAL VULNERABILITY ASSESSMENT

As an international response to adaptation to climate change the Intergovernmental Panel on Climate Change (IPCC) charged the Coastal Zone Management Sub-Group (CZMS) to develop a "Common Methodology" for coastal vulnerability assessment (CVA) in 1991. The aim of the "Common Methodology" was to " Identify the types of problems that a country will have to face and, if necessary, the types of assistance which are most needed to overcome these problems". The assessment was to "serve as a preparatory study, identifying priority regions and priority sectors and to provide a first reconnaissance and screening of possible measures" (IPCC, 1992).

Three boundary conditions and scenarios were used for the assessment:

1) impacts on socio-economic developments
2) impacts on the natural coastal systems and
3) implications of possible response strategies for adaptation.

The scenarios to be considered were:

1)The reference (present) situation,
2) A 30 cm to 1 metre sea-level rise by 2100 which were the high and low scenarios of the 1990 Working Party 1, predictions.

The methodology recommended that the full range of response options be considered from the extreme options of complete retreat and total protection. However, the methodology did not consider coastal evolution other than that caused by climate change, nor did it consider progressive adaptation at the local scale such as the raising of dykes.

The seven steps to be included in the coastal vulnerability assessment were:

1. Delineation of case study area and specification of accelerated sea level rise (ASLR) boundary conditions.
2. Inventory of study area characteristics.
3. Identification of relevant development factors.
4. Assessment of physical changes and natural system responses.
5. The assessment of the vulnerability profile and interpretation of results.
6. Assess the vulnerability profile and interpret results.
7. Identification of actions to develop a long-tem coastal zone management planning.

Data requirements and data processing steps are further elaborated in a number of tables to be used for guidance and a checklist for the execution of VA case studies (IPCC, 1992).

WORLD COAST CONFERENCE AND REASSESSMENT OF THE COMMON METHODOLOGY

In 1993 a World Coast Conference (WCC) was held in the Netherlands to provide an opportunity for nations to exchange information in assessing vulnerability to climate change by reviewing the 46 case studies which had been completed and the ways to utilise this information to develop coastal zone management plans (WCC, 1993). This follows from the requirements of the Convention on Climate Change and Chapter 17 of United Nations Conference on Environment and Development's Agenda 21 which requires new approaches to marine and coastal zone management that are precautionary and fully integrated. Such management involves assessment, setting of objectives, planning and management of coastal systems and resources that take into account traditional, cultural and historical perspectives plus conflicting interests and uses. It also recognises that this is a continuous and evolutionary process for the achievement of sustainable development. There was an emphasis at the conference on the urgency for the accelerated development of such plans so they take account of the long-term impacts of global climate change (WCC, 1993).

Of the 46 case studies reviewed in at the WCC only 18 country case studies contained enough information to estimate a vulnerability profile using the vulnerability classification of five impact categories using 1 metre sea-level rise. Only three countries, the Marshall Islands, Poland and the Netherlands were able to fully completed all steps.

From these studies it appears that small islands, deltaic settings and coastal ecosystems are particularly vulnerable to ASLR. Also, beach-based tourism may be vulnerable due to the large investment and significant sand resources required to maintain beaches and protect adjoining infrastructure in the face of sea level rise (IPCC, 1995). The potential loss of wetlands has also been highlighted, with these losses being 10 times greater than dry land loss in some cases. However, it must be remembered that the present direct human reclamation of wetlands for a range of purposes is a much bigger threat to these areas than sea-level rise (IPCC, 1995).

The common scenarios in these case studies were limited to a one metre sea-level rise over 100 years and the current pattern and level of development. The results therefore overstate the potential impacts of climate changes and underestimate the other implications of pressures and development due to socio-economic trends. Only eight studies completed Step 3 which required a consideration of the socio-economic scenario 30 years into the future. Damage cost estimates will also be underestimates because they neglect non-market values such as the cost of resettlement of coastal populations. Also, the studies did not capture the risks posed by combined sea-level rise (SLR) and possible changing frequencies, intensities and distributions of extreme weather events. The studies also assumed a slow gradual sea-level rise which may not be the case (WCC, 1993).

While vulnerability has focussed attention on climate change and long term thinking in the coastal zone there are several criticisms that have been raised with regard to the "Common Methodology".

The main criticisms raised at the World Coast Conference and the Preparatory Workshops were:

- The shortage of accurate and complete data. It was found to be especially difficult to accurately determine the impact zone due to lack of basic coastal topography. Therefore, there is a need to improve information management.

- Many studies carried out simple linear, first order assessment by vertically shifting the coastline landward by an amount corresponding with a sea-level rise of 30 cm and 1 metre. Due to the lack of data and operational technical capacity it was not possible to describe the more complicated non-linear coastal processes.

- There is a need for more attention to be given to the impacts of climate change such as extreme events

- While the "Common Methodology" does give some guidance by semi-quantitative vulnerability profiles it is less effective in assessing a wide range of technical, institutional, economic and cultural elements present in different localities. Therefore, more attention should be paid to the broader socio-economic needs, including traditional aesthetic and cultural values such as those of subsistence economies and traditional land tenure systems.

- As most studies only used the single global estimate of 1 metre, the spatial distribution of relative sea-level rise and other coastal implications were ignored due to a lack of regional climate scenarios. So, assessments would be improved if regional climate scenarios were used that included reference to both low and high scenarios.

- Vulnerability assessments also need to take into account the concept of the resilience of coastal systems to the various stresses. Areas with greater diversity and flexibility will be more resilient whether these occur by natural or managerial adaptation.

- There is a need to integrate CVA into the approaches taken for CZMP. Therefore, the assessment needs to incorporate a bottom up approach which is more consistent with coastal zone management (CZM).

- The "Common Methodology" adopts a static view of the state of the environment, not recognising the dynamics and interconnectedness of the subsystems and the impracticability of forecasting their responses (IPCC, 1995).

At a National level, the "Common Methodology" was tested through a case study of Geographe Bay, Western Australia (Kay et al. 1992) and the Cocos Islands (MacLean and Woodroffe, 1993). The Australian government through the Department of the Environment, Sports and Territories also funded a preliminary study of Kiribati. This lead to several of the criticisms of the methodology at the WCC'93 as outlined above, from the Australian authors. The "Common Methodology" was not seen as being appropriate to the Australian situation as the economic based assessment technique is not consistent with the planning approaches used. The method was viewed as being too general to isolate the preferred responses and the failure to include time dependencies and social and cultural factors was also a concern.

The preferred approach, as proposed by Kay and Waterman (1993) considers both the vulnerability and resilience of separate but interacting coastal systems to both internal and external stresses in a time dependent framework. It adopts a planning and environmental management approach so assessments of the capacity of institutional and decision making systems for implementing mitigating impacts are an integral part of the methodology. The experience of the authors demonstrated the need to involve all levels of government in a meaningful way (Kay and Waterman, 1993). To utilise coastal vulnerability assessment as a starting point for integrated coastal zone management it needs to take into such considerations as the bio-physical processes at work, the socio-economic setting of the zone, areas of heritage significance, community responses, the linkages outside the study area and the legislative, jurisdictional and planning framework. It is also necessary to take account of the predicted impacts of climate change.

1.2 CLIMATE CHANGE PREDICTIONS

There continues to be considerable uncertainty about the predicted effects of greenhouse warming and climate change. Most vulnerability assessments have utilised values of sea- level rise of 30 cms to 2040 and 1 metre to 2100. Although these values are higher than those now predicted they can still be considered useful, "especially because sea level rise is expected to continue beyond 2100" (IPCC, 1995,p.2). Beyond 2100 the model predicts a rise of at least one metre due to lags in climate response, even with assumed stabilisation of global carbon dioxide emissions.

Therefore, projected sea-level rises still present a potential threat to coastal zones (IPCC, 1995, p.7).

Predictions for global warming are now 0.2°C compared with the IPCC 1990 prediction of 0.3°C per decade averaged over the next century. There is still a high range of uncertainty. Changes in sea-surface temperatures (SST) are predicted to be lower but are not less significant. For example, changes in SSTs in tropical and subtropical oceans are in the order of 1-2°C by the year 2100. "Such warming would be unprecedented in the recent geological past" (IPCC, 1995, p.8).

There has been a downward revision for the predicted rise in sea level. It now ranges from 25 to 80 cms for the year 2100, with a best estimate of 50 cms. This is ±25% lower than the best estimate of 1990 which was 66 cms by 2100. However, it should be noted that this represents a rate that is two to four times that experienced during the last 100 years (IPCC, 1995, p.2). One certainty regarding climate change is that the atmospheric concentration of carbon dioxide, now about 360 ppmv, has increased by about 29% over the pre-industrial concentration and will continue to increase in the future, even if stringent policies on emissions were adopted (IPCC, 1995, p.8).

Added to the uncertainty of these predictions are regional and local neotectonic and anthropocentric impacts on relative sea level rise (Harvey and Belperio, 1994). There are also the dynamic effects resulting from oceanic circulation, wind and pressure patterns and ocean density which cause variation in the level of the sea- surface. Global warming may cause regional oceanic changes which will alter the dynamic effects of sea-surface "topography".

In Australia, Whetton et al, (1994) have developed scenarios of regional climate change from general circulation models (GCM's). The authors stress that these scenarios are a description of a range of plausible future climates for a region for guidance in impact studies. Three important areas of uncertainty in these models are the range of greenhouse gas emission scenarios considered by IPCC, the range of uncertainty regarding the sensitivity of global climate to increased greenhouse forcing and the differences between GCM's in the simulated regional climate change per °C of global warming (Whetton et al, 1994, p.1). In the models explored, the scenarios of global warming used were the highest emission scenarios combined with the greatest climate sensitivity (4.5°C) and the lower limit based on a climate sensitivity of 1.5°C. These curves indicate an average global warming in the range 0.6-1.7°C by 2030 and 1.0-3.9°C by 2070 (Whetton et al., 1994,p.3).

The 2030 warming scenarios used in the Australia model are 0.5 -2.5°C for inland areas, 0-1.5°C for northern coastal areas, and 0.5-2.0°C for southern coastal areas. There is a predicted change in summer rainfall from little change to as much as 20% increase by 2030 and a 40% increase by 2070.

Winter rainfall changes may be as much as 10% by 2030 and 20% by 2070. There is considerable evidence pointing to a future increase in rainfall intensity and in the frequency of heavy rainfall events. Scenarios are suggested of up to a halving of the return period of heavy rainfall events by 2030 and up to a fourfold reduction by 2070 (Whetton et al., 1994, p.1). In general an increase in evaporation is expected to be associated with higher temperatures.

Figure 1.1 gives maps by season of the local warming per degree of global (annual) warming for a low (1a) and high (1b) regional temperature response. In general the maps show that warming over Australia is about, or a little less than, the global average in the low response case and greater than the global average throughout inland areas in the high case. Warming is also larger in the south than it is in the north, and larger in winter and spring than it is in summer and autumn. There is also a general tendency for overnight minimum temperatures to increase a little more than daytime maxima (Whetton et al., 1994, p.7).

Increases in daily mean temperature, without changes in daily temperature standard deviation, would imply a much greater frequency of high temperature extremes and a reduced frequency of frosts for Australia. It has been found the frequency of summer daily temperatures greater than 40°C may increase by 50-100% in parts of Australia for increases in mean temperature of around 2°C (Hennessy and Pittock in press as quoted in Whetton et al, 1994, p.8).

The model shows an increase in rainfall in summer over most of Australia in both the high and low cases. However, the pattern is more complex for the winter half year. Models agree with a rainfall decrease in inland southern areas. For the southern Ocean and Tasmania, models agree on increasing rainfall and both the high and low cases are positive. However for southern coastal Australia the models disagree. In Figure 1.2, three separate regions are used to correspond to these regions. Table 1.1 contains ranges of percentage precipitation change scaled for 2030 and 2070. These scenarios suggest changes over broad areas. At local scales when local topography exerts a strong climatic effect, changes outside the ranges given would be expected to occur (Whetton et al., 1994, p.9).

1.3 POTENTIAL COASTAL IMPACTS

Although it is hard to quantify the predicted changes, it is agreed that the combination of climate extremes - temperature, precipitation, winds, sea-levels - and how they are affected by longer-term changes that are important for the future effects of global warming on coastal zones and small islands (IPCC, 1995, p.9).

Storm surges, if they are severe, can flood low-lying coastal areas, reduce the drainage rates of rivers and if accompanied by strong winds, enable

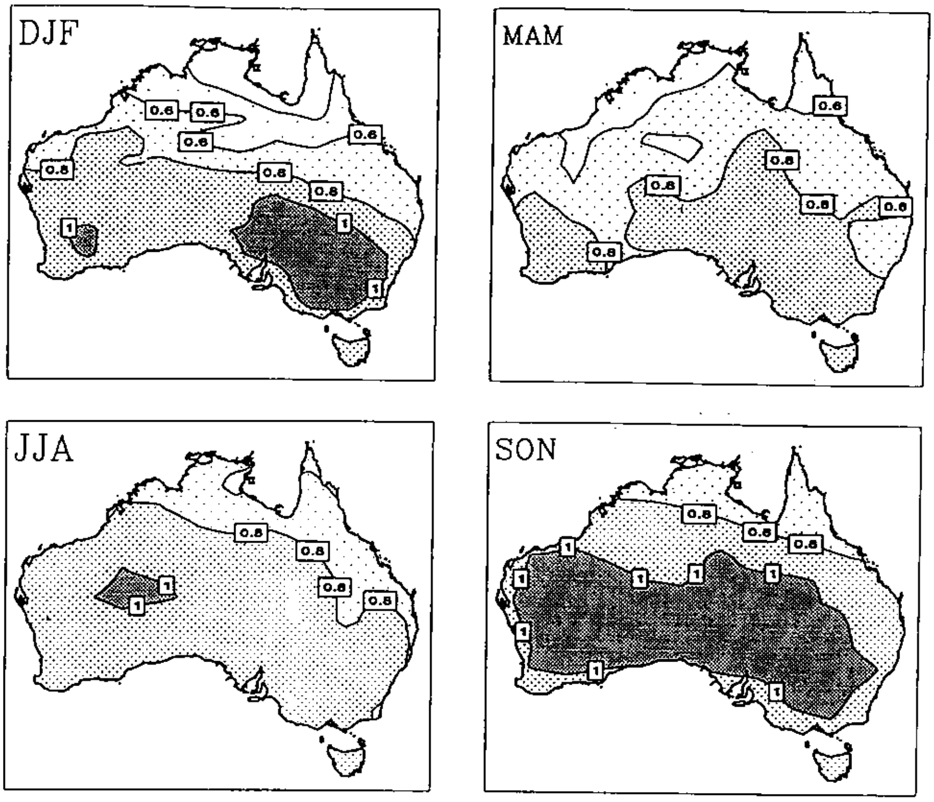


Figure 1.1 (a) The low case response for seasonal warming per degree global warming over Australia. Contour interval 0.2°C. (source: Whetton et al, 1994, p.24)

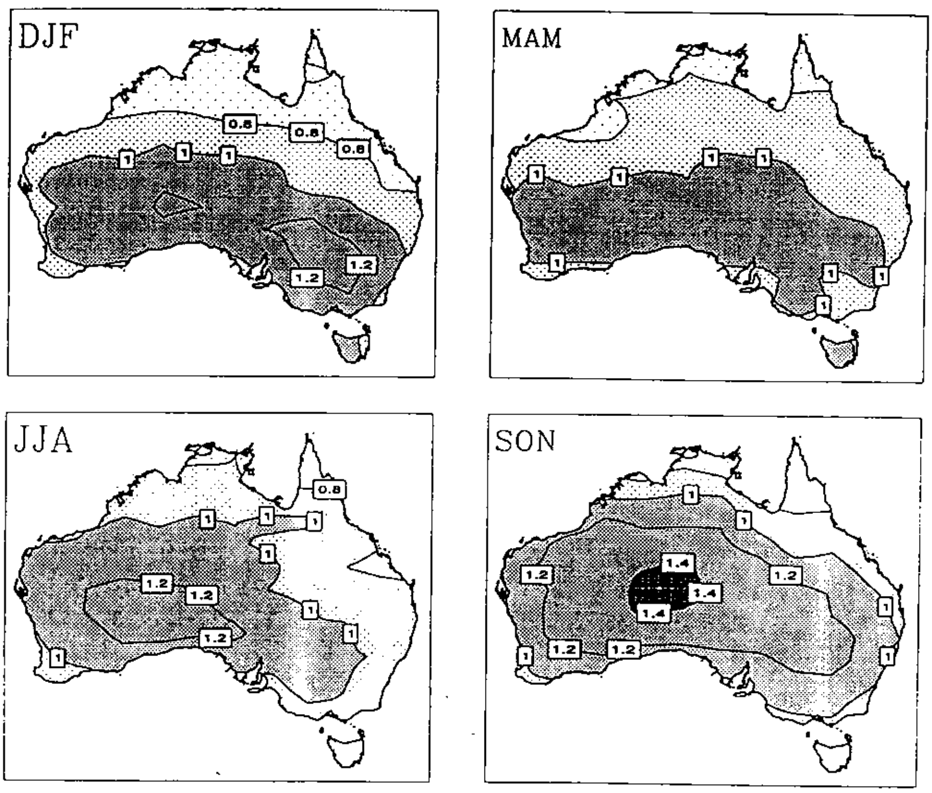


Figure 1.1 (b): High case response for seasonal warming per degree global warming over Australia. Contour interval 0.2°C. (source: Whetton et al, 1994, p.25)

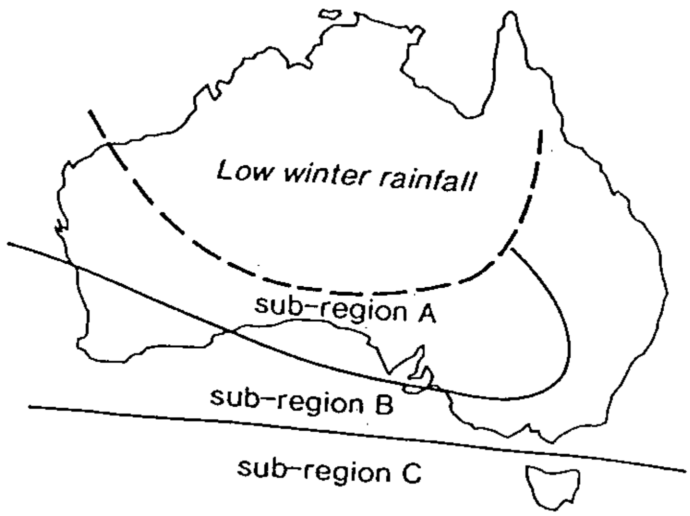


Figure 1.2: Sub-regions used for winter rainfall change over Australia. (source: Whetton et al, 1994, p.29)

Table 1.1 Scenarios of rainfall change for locations in the Australian region. Sub-regions are defined in Figure 1.2. 2030 and 2070 values are rounded to the nearest 10%. (source: Whetton et al, 1994, p.21)

Season	Region	Response per degree global warming	Change in 2030	Change in 2070
Summer half year (Nov. to April)	Any location	0 to +10%	0 to +20%	0 to +40%
Winter half year (May to Oct.)	sub-region A	0 to -5%	0 to -10%	0 to -20%
	sub-region B	-5 to +5%	-10 to +10%	-20 to 20%
	sub region C	0 to +5%	0 to +10%	0 to +20%

wave action to penetrate further on shore. It is still unsure how climate change will affect the frequency, location and intensity of severe storms (IPCC, 1995,p.9). However, modelling work done by McInnes and Hubbert (1995) in Victoria, Australia shows that the intense low pressure systems which occasionally effect the south-east coast of Australia may become significantly more intense, both in winds and rainfall, under a regime of higher sea surface temperature (Whetton et al., 1994 p.12).

While earlier studies of sea level rise used simple models of shifting the land-sea boundary inward by the amount of the projected global rise it is now clear that the geomorphological and ecological impacts of rising sea level will be complex. Coastal landforms and ecosystems both respond to and modify the processes which impact on the coastlines and will vary according to local conditions. Models for coastal recession suggest that with future sea-level rise currently eroding shorelines should erode further, stable shoreline should begin to erode, and advancing or accreting coasts should wane or stabilise, although local changes in wave energy and direction as well as sediment supply may modify these results (IPCC, 1995, p.10).

The effect of sea-level rise on estuaries has also been examined and it is suggested that hydraulic processes such as tidal range, prism and currents, salinity intrusion and sedimentation would be modified but changes will vary widely according to local topography and tidal range (IPCC, 1995,p.11). Bird (1993 in IPCC, 1995) has suggested that estuaries will tend to widen and deepen. Another serious effect will be the intrusion of saline water into groundwater aquifers. This will be exacerbated by the withdrawal of freshwater which may result in either subsidence and/or replacement by sea water.

Geomorphic and hydrological changes resulting from sea-level rise will have important effects on coastal wetlands. Salt marshes have the ability to respond to sea-level rise as long as sedimentation and internal biomass production processes keep pace and as long as the entire marsh can move to higher shore levels or inland. That is provided they are not restricted by infrastructure, protective sea walls etc., in which case they will progressively decline and ultimately disappear (IPCC, 1995, p.12). For, mangroves there has been conflicting evidence (Ellison 1993, Snedaker et al, 1995 in IPCC, 1995) as to whether they are able to accrete vertically as fast as the projected rate of se-level rise. Sediment supply, shoreline erosion and species robustness, along with the lack of restriction in landward migration will result in varying regional responses to sea level rise. While some marshes and mangroves may be threatened by sea-level rise the greatest threat at present is from human impact.

Sea grasses which extend subtidally to depths of several tens of meters are of considerable economic importance and generally serve as natural coastal protection agents. Edwards (1995 in IPCC, 1995) argues that intertidal and shallow seagrass beds (<5 metres depth) are most vulnerable to climate change impacts particularly increases in sea temperature and freshwater run-off. However, like the mangroves the greatest risk comes from anthropogenic pressures, such as dredging and pollution (IPCC, 1995, p.13).

Impact studies also need to take account of the fact that the scenarios do not encompass all possible future climates for 2030 and 2070, just those considered plausible given present knowledge and assumptions (Whetton et al, 1994, p.13).

1.4 CURRENT PROJECT OUTLINE

In order to respond to the potential impacts of climate change in regard to marine and coastal environments, Australia has a research and governmental infrastructure in place which resides within the United Nations Framework Convention on Climate Change (UNFCCC), the Intergovernmental Panel on Climate Change (IPCC) and the National Greenhouse Response Strategy (NGRS) (Morvell, 1993).

Much of the administration and policy requirements are conducted through the Climate Change and Environmental Liaison Branch of the Department of the Environment, Sport and Territories (DEST). DEST also has the charter of assessing climate change impacts on the coastal zone and evaluating the mechanisms for managing their effects. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is involved in climate change research, and DEST has agreed with CSIRO to participate until at least 1996 in the Global Change and Terrestrial Ecosystems Core Project, part of the International Geosphere Biosphere Progamme (IGBP) (Morvell, 1993).

This current study is part of a DEST initiative providing funding for all the States and the Northern Territory to conduct Coastal Vulnerability Assessments of selected case studies using the Kay and Waterman methodology. This revised approach to the Common Methodology will enable spheres of Government and communities of interest to respond to hazards and climate-induced change in the coastal zone. It is hoped the outcome will then form the bases of an Australian common framework to vulnerability assessment and coastal zone management.

1.5 SELECTION OF STUDY AREA: THE NORTHERN SPENCER GULF

The Northern Spencer Gulf, (Figure 1.3) was selected by the Coastal Management Section of the Department of Environment and Natural Resources as the South Australia case study area for vulnerability assessment. The area was chosen due to its unique bio-physical characteristics and its changing socio-economic structure. The northern part of the Spencer Gulf is a marine protrusion into arid Australia situated between the uplifted Flinders Ranges to the east and flat topped hills to the

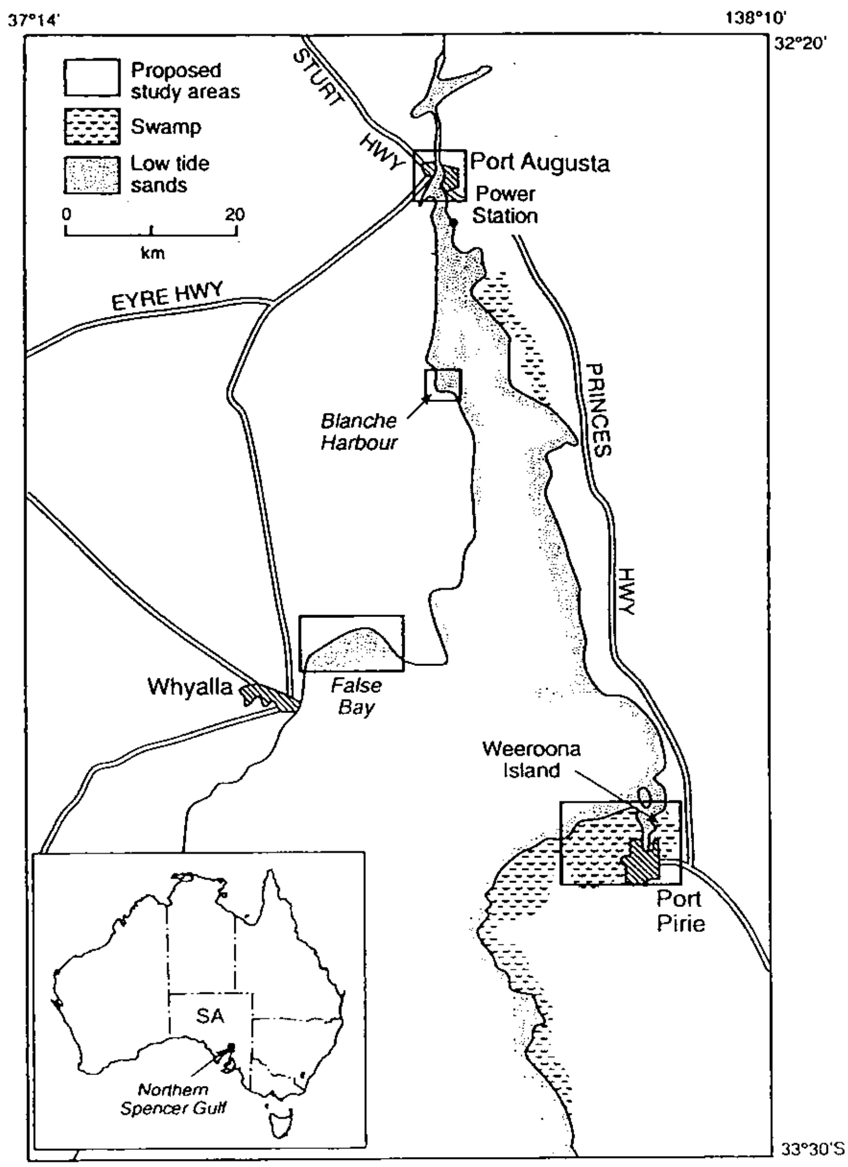


Figure 1.3: The Northern Spencer Gulf.

west. The study area is bordered by the industrial towns of Whyalla, Port Augusta and Port Pirie.

The upper area of the Gulf is shallow, experiences high summer temperatures and an high evaporation rate. There is little or no fresh water inflow due to the restricted water exchange with the open sea thus it can be considered to be one of the three inverse estuaries in Australia. The tolerance of marine organisms to such extremes is unique in world marine systems. The area also covers part of the transitional zone between the agricultural zone of the state and the arid interior so there are marked changes in the vegetation, landscapes and landuses across the region.

Four selected study sites, False Bay, Port Pirie, Port Augusta and Blanche Harbour have been chosen for a more detailed analysis to illustrate the effects of potential climate change on the above characteristics.

It was also hoped that the assessment could be carried out within the wider context of the Spencer Gulf and Flinders Ranges Regional Development Strategy which was being prepared for South Australia. A major goal of the strategy was to create economic development and employment in the region within the criteria of Ecological Sustainable Development. The development of such a strategy provides an opportunity to include the potential coastal impacts of climate change into both regional and local planning. However, during the course of the project the strategy took on a much larger focus including most of the north and west of South Australia and the Department of Premier and Cabinet, the co-ordinating government department felt that the results of the vulnerability assessment were not relevant to the economic focus of the strategy.

CHAPTER 2: METHODOLOGY FOR APPLYING THE REVISED COMMON METHODOLOGY TO THE STUDY AREA

As a result of the criticism of the "Common Methodology" the vulnerability assessment of Kay and Waterman has been adapted for use as a methodology for coastal vulnerability assessment of the Northern Spencer Gulf. The conceptual framework for climate change impact assessment is shown in Table 2.1. Tables were developed that outlined the factors that need to be considered, again using an adaptation from those suggested by Kay and Waterman. See Table 2.2.

The four stages of the revised CVA are as follows:

STAGE 1: DELINEATION OF THE IMPACT ZONE

This stage focuses on the physical and biological conditions of the study area and delineates those areas of potential coastal hazard.

To obtain the relevant known physical and biological conditions of the Northern Spencer Gulf a literature review was undertaken. Sources of information were found in academic journals, university theses, government publications, consultants reports, Environmental Impact Statements and feasibility studies. The latter publications were found to be the most useful in providing information required for this stage. The flooding studies for Port Pirie (1991) and Port Augusta (1991) from the consultants Lange Dames and Campbell Australia also provided a basis for this information.

In order to delineate the impact zone, information was sought on the topography of the Northern Spencer Gulf. As the two scenarios prescribed in the study brief were an 18 cm sea-level rise to 2030 and 44 cm to 2070 it was desirable to find information that would provide the necessary level of detail to illustrate potentially vulnerable areas. However, as in the case of many rural vulnerability assessments, this information was not readily available. Therefore, several other techniques for obtaining information on coastal vulnerability were investigated.

Table 2.1: Conceptual Framework for Climate Change Impact Assessment (source: Kay and Waterman, 1993, p. 214)

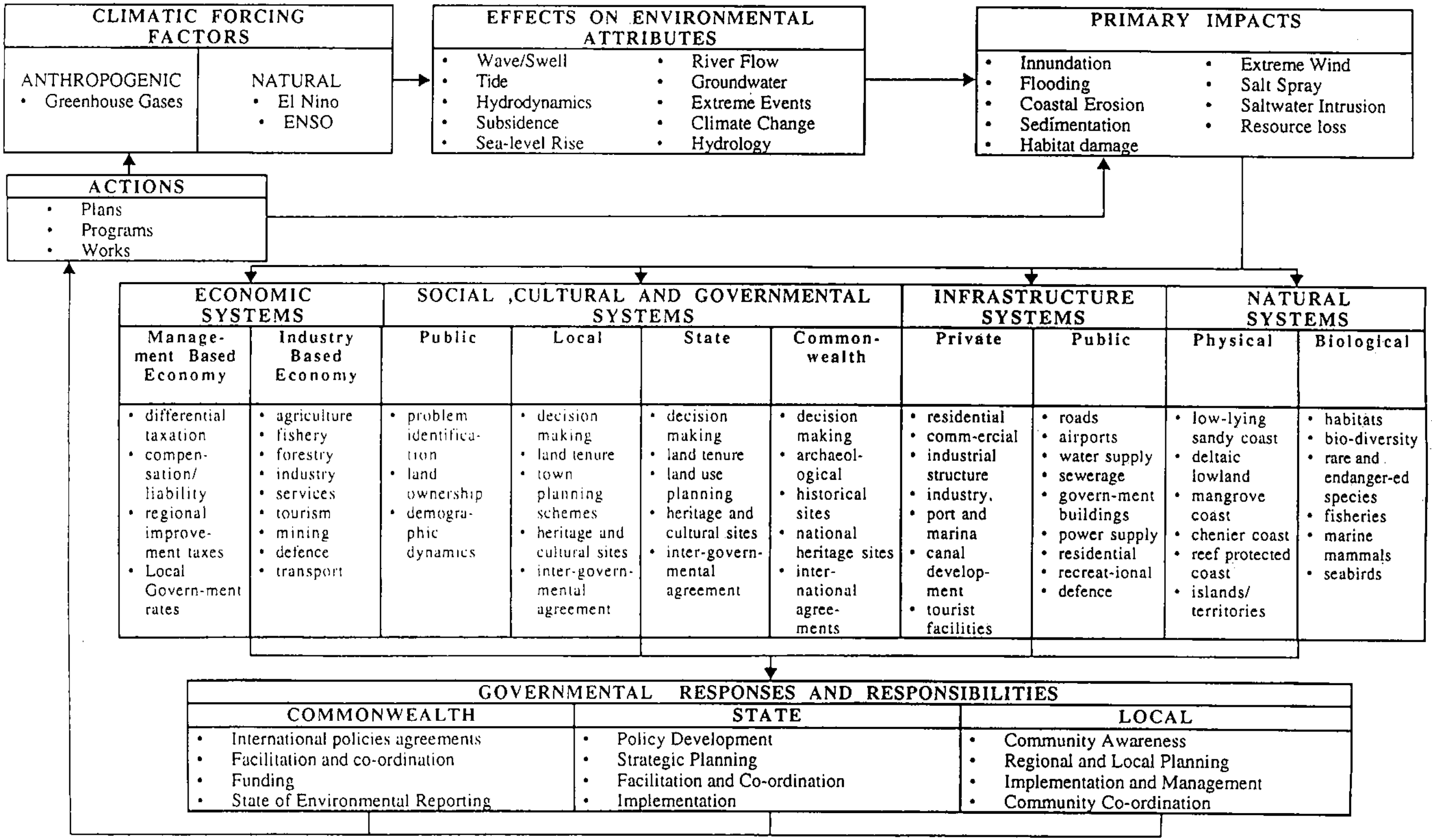


Table 2.2: Factors to be considered in the Revised Vulnerability Assessment (source: Adapted from Kay and Waterman (1993), pp. 247-248)

1 NATURAL SYSTEMS			
Inventory	***Data type***	***Source***	***Timetable***
1.1 climate variables	1.1.1 Pressure systems - intense low pressures, storm recurrence 1.1.2 Wind direction & strength 1.1.3 Seasonal/annual temperature 1.1.4 Seasonal/annual precipitation 1.1.5 Seasonal/annual evaporation	Bureau of Meteorology; Atlas of South Australia, Earth Sciences, Flinders Uni " " " "	Initial collation, general data " " " "
1.2 Oceanographic characteristics	1.2.1 Upper Spencer Gulf bathymetry 1.2.2 Wave data (runup) 1.2.3 Storm surge 1.2.4 tide data 1.2.5 Currents and water circulation 1.2.6 Salinity profiles	DHUD GIS; navigation charts; Dept of Transport To be calculated To be calculated National Tidal Facility, Eng. consultants Oceanography, Flinders Uni NTF, Flinders Uni	Initial collation; check intervals More data needed More data needed Initial collation; general & specific data " "
1.3 Physical setting (terrestrial)	1.3.1 Topography 1.3.2 Geology and groundwater 1.3.3 Geomorphology; landforms 1.3.4 Soils and drainage patterns 1.3.5 Flood hazard zones	DHUD GIS; Dept of Lands topo series (5m contours?), Twidale, Adelaide Uni DHUD GIS; DME geologic and hydrogeology maps DHUD GIS; South Australia Atlas DHUD GIS; CSIRO Lange Dames & Campbell (Eng) DENR GIS	May have to gather <1m contour data Initial collation; general data " " Initial collation; general & specific data
1.4 shoreline conditions (onshore and offshore)	1.4.1 Sediment budgets 1.4.2 On/offshore, longshore drift 1.4.3 Erosional or accretionary areas 1.4.4 Beach gradients	To be ascertained To be ascertained Aerial p/g, fieldwork Fieldwork	Priority for Vulnerability Assessment " " "
1.5 Ecological considerations (terrestrial, shoreline and marine)	1.5.1 Vegetation cover and habitats 1.5.2 Conservation areas, National Parks, and proposed reserves 1.5.3 Rare or endangered species 1.5.4 Ecological conditions 1.5.5 Natural Resources	DHUD GIS; aerial p/g, fieldwork DHUD GIS DHUD GIS Aerial p/g; fieldwork DHUD GIS; fieldwork	Collation & site profiles needed Initial collation; general data " Collation & site profiles needed "

2 SOCIAL, ECONOMIC AND CULTURAL SYSTEMS			
Inventory	***Data type***	***Source***	***Timetable***
2.1 Social structure	2.1.1 Demographic characteristics: size, density, migration, health	DHUD GIS; Bureau of Statistics	Initial collation; general & specific data
	2.1.2 Workforce structure & employment	SA Atlas, Bureau of Statistics	"
	2.1.3 Community networks	To be ascertained - Local Councils	Priority for hazard response (VA)
2.2 Economic activities	2.2.1 Regional economy; GDP	Centre for Economic Studies, AU	Initial collation; general & specific data
	2.2.2 Resources: agricultural, fisheries, mineral, industrial,	DHUD GIS; Depts. of Ag, Fisheries, M&E, NP&WS, M&H (ports); ETSA	General and specific data collation; priority of Vulnerability Assessment
	2.2.3 Land use and productivity	DHUD GIS	"
	2.2.4 Land tenure	Depts of Land, Planning	Initial collation; general & specific data
	2.2.5 Real Estate (residential, commercial)	Real Estate Companies	
	2.2.6 Commercial/small business Activities	Local Councils	
	2.2.7 Tourism/recreational areas & facilities	Dept of Tourism	"
	2.2.8 Proposed developments	Dept of Planning	" (Strategic plan)
2.3 Socio-economic infrastructure	2.3.1 Public utilities and infrastructure; coastal amenities	ETSA, E&WS, Local Councils (waste disposal)	General and specific data collation
	2.3.2 Transport networks	Dept of Roads, National Rail, M&H, Airports (Aviation Industry)	"
	2.3.3 Private infrastructure (e.g., businesses, hospitals, marinas)	Local Councils	"
	2.3.4 Public assess areas, National parks, proposed reserves	DHUD GIS	"
	2.3.5 Linkages to systems within and outside	Local Councils; to be assessed	
2.4 Cultural and heritage issues	2.4.1 Aboriginal land rights	Dept State Aboriginal Affairs	"
	2.4.2 Aboriginal heritage	Dept State Aboriginal Affairs; DHUD GIS	"
	2.4.3 European heritage/ National Trust		"

3 GOVERNMENTAL SYSTEMS

Inventory	*Data type*	*Source*	*Timetable*
3.1 Commonwealth responsibilities	3.1.1 Legislative framework	Commonwealth Government Depts	General information
	3.1.2 Policy frameworks	"	"
	3.1.3 Cultural/heritage considerations	"	Initial collation; general & specific data
	3.1.4 International obligations	"	"
	3.1.5 Spheres of Government & community interaction	To be assessed	Important for Vulnerability Assessment implementation
	3.1.6 Community awareness and education	To be addressed	"
3.2 State responsibilities	3.2.1 Legislative frameworks	State Government Depts	General information
	3.2.2 Regulatory frameworks	"	"
	3.2.3 Planning and engineering responses	"	Priority for Vulnerability Assessment
	3.2.4 Spheres of Government & community interaction	To be assessed	Important in Vulnerability Assessment implementation
	3.2.5 Community awareness and education	To be addressed	"
3.3 Local responsibilities	3.3.1 Statutory framework	Local Councils	General information
	3.3.2 Planning implications	"	"
	3.3.3 By-laws/regulations	"	"
	3.3.4 Management programs (ICM/TCM, ICZM)	"	Vulnerability Assessment as a part of ICZM
	3.3.5 Mitigation measures	Consultant reports, and to be determined	Priority for Vulnerability Assessment
	3.3.6 Spheres of Government & community interaction	To be assessed	Important in Vulnerability Assessment implementation
	3.3.7 Community awareness and education	To be addressed	"
3.4 Community networks	3.4.1 Community groups; e.g., Landcare, Greening Australia	Through local councils, surveys,	General information
	3.4.2 Community involvement programs	"	Priority for Vulnerability Assessment
	3.4.3 Spheres of Government & community interaction	To be assessed	Important in Vulnerability Assessment implementation
	3.4.4 Community awareness and education	To be addressed	"

Flood studies- Port Pirie and Port Augusta

The flood studies undertaken for Port Pirie and Port Augusta provided information on area at risk from inundation. These maps were produced at a scale of 1:2 500 with 0.5 metre contours showing spot heights, building outlines and other features. The studies included an allowance of 0.3 metre predicted sea-level rise to the year 2050 and damage costs for projected areas of inundation were estimated. Full details of the studies and their respective methodologies are outlined in Chapter 4, Sections 2 and 3.

Levelling/Biota - Port Pirie

To assess the potential effect of sea-level rise on vegetation communities a 3 kilometre transect was levelled across the salt marshes at Port Pirie. The transect extended from the flood protection levee on the outskirts of Port Pirie to the mangrove edge. Two sea-level rise scenarios of 18 cms to 2030 and 44 cms to 2070 were used to adjust the existing profile to demonstrate changes in the plant communities. The results were loss of supratidal communities that were unable to retreat. The full details of the study and results are included in Appendix 2.

Existing Contour Information

Topographical Cadastral overprint maps at a scale of 1:50 000 provided the most detailed information available for all of the Northern Spencer Gulf. More detailed information was available for the selected study areas of Port Pirie, Port Augusta and False Bay. The Department of Environment and Natural Resources (Resource Information Group) had Topographic maps of Port Pirie and False Bay available at a scale of 1: 10 000 and a contour interval of five metres. For Port Pirie and Port Augusta finer scale topographic maps at 1: 2 500 were available with contours of two metres. Ten maps were available for Port Augusta and two for Port Pirie.

Terrain Modelling

To obtain more detailed contour information, the Resource Information Group of the Department of Environment and Natural Resources were contacted to obtain a quote for producing a Digital Terrain Model of the Port Pirie area with 0.3 metre contours. For an area of approximately 5759 hectares the cost was $16 650 which was considered to be too expensive as it was only one of four studies areas. However, the exercise did highlight the high cost of obtaining the detail of information necessary to accurately delineate the impact zone. Chapter 4, Section 2 includes a full breakdown of the costs involved.

Contouring - False Bay

While it was not feasible to obtain detailed contour information for the whole of the Gulf the opportunity did arise for aerial photography and mapping of the western section of False Bay. The resulting information was transferred to a GIS system and maps of the area highlighting areas that would be inundated with a 0.5 metre sea-level rise produced. Full details of the costs and maps are given in Chapter 4, Section 1.

Surveying of Shacks

There are a number of shack sites in the Northern Spencer Gulf which have been surveyed by the recent Shack Site Freeholding Committee. Shacks at Blanche Harbour which were not included in the report were surveyed in 1985 to determine those which would be at risk from flooding. Results of these surveys are included in Chapter 4, Section 4 and Chapter 5.

Coastal Geomorphological Interpretation

Through the interpretation of 1:15 000 aerial photography the coastal geomorphology of the Northern Spencer Gulf has been mapped, digitised and loaded on to a GIS system at Mines and Energy S.A. Details of the method and results are given in Chapter 3.

Archival Sources of Information
Survey of Yatala Harbour to Point Paterson

All survey work carried out by holders of a mineral exploration license must be given to the Mines and Energy SA. It was discovered that some detailed survey work of the eastern coast of the Northern Spencer Gulf was held in Envelope 1330. This work was done by Delhi Australia Petroleum Limited, Vam Ltd - Hardman Chemicals Pty. Ltd., in 1970 under the title S.M. L., No 375 - Point Paterson and Pt. Pirie. They surveyed elevation transects on 11 sheets with spot elevations accurate to 0.1 inch relative to mean sea level Pt. Adelaide. The grid interval was 200 feet. From photogrammetry work contours were plotted in one foot intervals. The survey was done from a landward elevation of 20 -30 feet and terminating in the mangrove fringe at a height of about four feet.

It is possible that such information could be digitised and processed in a Geographic Information Systems format. As discussed above survey work undertaken now at that level of detail would be prohibitively expensive except where valuable industrial, residential or infrastructure was at risk. This highlights the value of research into existing data for coastal vulnerability assessment.

Chapter 3 summarises the physical, biological and socio-economic conditions for the Northern Spencer Gulf and the general vulnerability of the area. Chapter 4 gives greater detail of the four study sites and the coastal hazards particular to them.

Field Trips and Community Contact

To gain a greater understanding of physical characteristics of the Northern Spencer Gulf three field trips were taken during the study. These trips also involved consultation with community groups, in particular, the Spencer Gulf Environmental Alliance to gain local knowledge of areas considered vulnerable. The chairperson of the group, Doug Reilly, an environmental consultant has been working at the Environmental Research Station, Chinaman Creek, for many years and was able to outline many of coastal issues in the area and commented on the initial drafts of Chapter 4. Visits were also made to the City Councils of Port Pirie, Port Augusta and Whyalla to determine what coastal management policies were in place and any future plans for development in the respective cities. The council have continued to provide information for the project as required. The third field trip was primarily an exercise in ground truthing for the mapping that had been done in False Bay. It also was an opportunity to visit the BHP site at Whyalla to determine vulnerable areas and potential hazards for False Bay. BHP allowed access to private reports but did not allow this information to be reproduced for this project.

STAGE 2: ANALYSIS OF THE VULNERABLE AND RESILIENT COMPONENTS OF THE SYSTEMS WITHIN THE ZONE.

Analysis of vulnerability includes some notion of the susceptibility to stress, shock and damage cause by Climate Change. However, susceptibility is conditioned by the resilience of the natural coastal system, that is, its ability to adapt which is influenced by past, current and future population and settlement patterns and rates of socio-economic change. Therefore, at this stage an attempt is made to incorporate the socio-economic and cultural systems into the analysis to enable an interacting systems approach to be taken. The aim is to distinguish impact reduction responses into measures for 'vulnerability reduction' and 'resilience enhancement'.

- The mapping of the coastal features of the Gulf was undertaken in an effort to produce vulnerability profiles based on coastal types.

- The vegetation transect undertaken in Port Pirie was used to determine the ability of the vegetation to adapt to sea-level rise. By demonstrating the elevation of the various groups of vegetation it is then possible to assess, changes in vegetation due to sea-level rise and likely losses due to impediments for retreat.

- The identification of shacks that are likely to be affected by potential sea-level rise is an example of a policy response that enhances the resilience of the area. However, as mentioned in Chapter 5 the South Australian Government has adopted a shack freeholding policy which forgoes the retreat option and which will decrease the resilience of coastal environments to the impacts of climate change.

- Within the analysis of the defined study areas and the entire Gulf (Chapters 3 and 4) consideration has been given to the socio-economic setting, land use and proposed developments as part of the vulnerability assessment.

STAGE 3: ANALYSIS OF THE LINKAGES BETWEEN THE IMPACT ZONE AND CONNECTED AREAS.

Here the analysis is focused on the linkages within the system and between connected systems. Kay and Waterman make no attempt to define the extent of the connected systems. As the study being undertaken includes four defined areas and the characteristics of the entire Northern Spencer Gulf it is considered that these linkages are inherent within the study. Chapter 3 provides on overview of the physical and socio-economic characteristics for the entire region within which the four studies areas are set as described in Chapter 4.

STAGE 4: FORMULATION OF MANAGEMENT STRATEGIES WITHIN THE IMPACT ZONE AND CONNECTED AREAS.

Stage 4 considers the interaction of the systems and range of policy options which will be determined by State and Local government policies and plans. Policies at the Commonwealth level may also be relevant. These policies would be determined by strategic economic and social needs and therefore it is envisaged that coastal management plans would be embedded within a regional or local strategic planning framework (Kay and Waterman 1993).

Initially, the Northern Spencer Gulf was chosen as the study area so that the assessment could be incorporated into the Regional Development Plan for the area. However, this strategy has now taken on a much larger focus including most of the north and west of South Australia and the co-ordinating body, the Department of Premier and Cabinet does not consider including the issue of coastal vulnerability into their current strategy. However, the strategic plan will be reviewed on an annual basis, and information gained from the coastal study may be included at a later date. As the coastal zone is a dynamic one it is essential that planning reflects this rather than static management plans that are replaced on an intermittent basis.

State government policies and plans have been outlined in Chapter 5 along with Commonwealth responsibilities for the study area. It has also been noted in Chapter 5 that there is conflict between some government policies with regard to the coastal zone which have considerable implications for coastal management. If the coastal vulnerability assessment of the Northern Spencer Gulf is to work towards integrated coastal zone management there needs to be greater co-ordination of government departments. Three national reports on the coastal zone "The Injured Coastline" produced in 1991, the Resource Assessment Commission Final Report, 1993 and "Living on the Coast" (1995) recommend the integration of government departments to provide co-ordination of coastal management throughout Australia within a national coastal zone management strategy. However, a recent review of coastal management arrangements in South Australia, as mentioned in Chapter 5 indicated that the level of awareness and concern needed to be raised within Government Agencies, especially at senior and policy levels.

CHAPTER 3 - CONNECTED AREA ANALYSIS AND ASSESSMENT: STAGES 1,2 & 3

Information was collected where possible for all the relevant factors as outlined by Kay and Waterman (1993) and adapted in Table 2.2. From the data and other techniques for delineation of the impact zone, some general observations on the vulnerability of the Northern Spencer Gulf have been made. This has then led to more detailed studies of the four specific sites as outlined in Chapter 4.

3.1 CLIMATE

The climate and hydrology of the Northern Spencer Gulf is typically semi-arid. The average rainfall for the region is between 200-400 mm per annum increasing to 600 mm in some parts of the southern Flinders ranges. Evaporation rates range from 1900 and 2600 mm a year. The western side of the Gulf has an annual average rainfall of 270 mm which occurs irregularly, and an evaporation rate of 2400 mm/year. When surface runoff does occur it is usually as a flash flood into wide, flat ephemeral rivers and creeks with wide floodplains. Average annual rainfall on the eastern side of the Gulf is 345 mm with evaporation rates of 2200 mm/year. Drainage systems along this eastern side are better defined and generally stem from the Flinders Ranges (Mines and Energy, 1994, p.42).

Most of the rainfall is received in the winter months with an average July temperature of 12°C. In January the average temperature is 25°C at Port Augusta with an average daily maximum of 32°C. There are prevailing southerly sea breezes in summer months whilst during the winter months the prevailing winds are light northerlies (Gostin et al, 1984, p.116). The wind speeds are generally highest during the day and in the warmest months and lowest at night and in the coldest months. The annual average wind speed at Whyalla is 3.2m/s (Mines and Energy, 1994, p.44).

Meteorological records from Whyalla show mean sea level (MSL) barometric pressure is highest in June (1023 h Pa at 9 am) when the anticyclone belt moves to its northern extremity around latitudes of 30°S. Minimum value occur in January (1014 hPa at 9 am) which correspond to the anticyclone belt shifting to the south of its range at latitudes around 40°S (Mines and Energy, 1994, p.43).

3.2 GEOLOGY

The study area includes three major geological provinces. These are the Gawler Craton, the Stuart Shelf to the west and the Adelaide Geosyncline to the east. The Gawler Craton is exposed west of Whyalla and near point Lowly and comprises Early to Mid Proterozoic rocks (greater that 1500 million year old.) The Stuart Shelf is the geological province, located between Whyalla and Port Augusta that extends to the north. It comprises the Adelaide Geosyncline and Cambrian formations which overlie the Gawler Craton. The Adelaide Geosyncline includes the succession of rocks (approximately 850 to 540 million years old) which form the Flinders Ranges, east of Port Augusta and Port Pirie. (Mines and Energy, 1994, p37). Figure 3.1 demonstrates the known mineral occurrences and mines of the Northern Spencer Gulf study area.

From the known seismicity of the area it is thought tectonic uplift, lowered sea level by 2.5m to the present level about 1700 years ago. After this relative sea level fall, wide intertidal and supratidal areas evolved on the surfaces of the seagrass banks, and the present mangrove and samphire colonisation commenced about 1400 years BP (Belperio et al, 1984, p.297). These extensive seagrass banks which resulted from this process are thought to be of national/international significance.

The western shoreline is less sheltered, and during the Holocene higher wave energy, generated by south easterly winds built up the shingle or cobblestone beach ridges which are now a feature of the shoreline in Fitzgerald Bay and north of Blanche Harbour. The same processes contributed to the present narrower shoreline and deeper channel on the western side of the Gulf in contrast to the wide intertidal flats described for the eastern coast (Harbison and Wiltshire, 1993, p.5).

3.2.1 GROUNDWATER

Groundwater data are limited for this region. The eastern side of the Gulf forms part of the large underground Pirie-Torrens basin which covers 1 000 km^2 and spans the area from Port Broughton to the northern part of Lake Torrens. Water quality increases towards the south and near Port Pirie a confined aquifer has been formed which is utilised to irrigate crops. Unconfined aquifers also occur towards the flanks of the Flinders Ranges in fractured rock and alluvium with quality ranging from potable to suitable only for stock.

Groundwater on the western side of the Gulf is only available in small quantities and is saline. There are some cliff-foot springs near the coast and the dune areas are also expected to contain minor amounts of low salinity groundwater. However, groundwater sources are extremely limited in extent and sustainable yield (Mines and Energy, 1994, p.25).

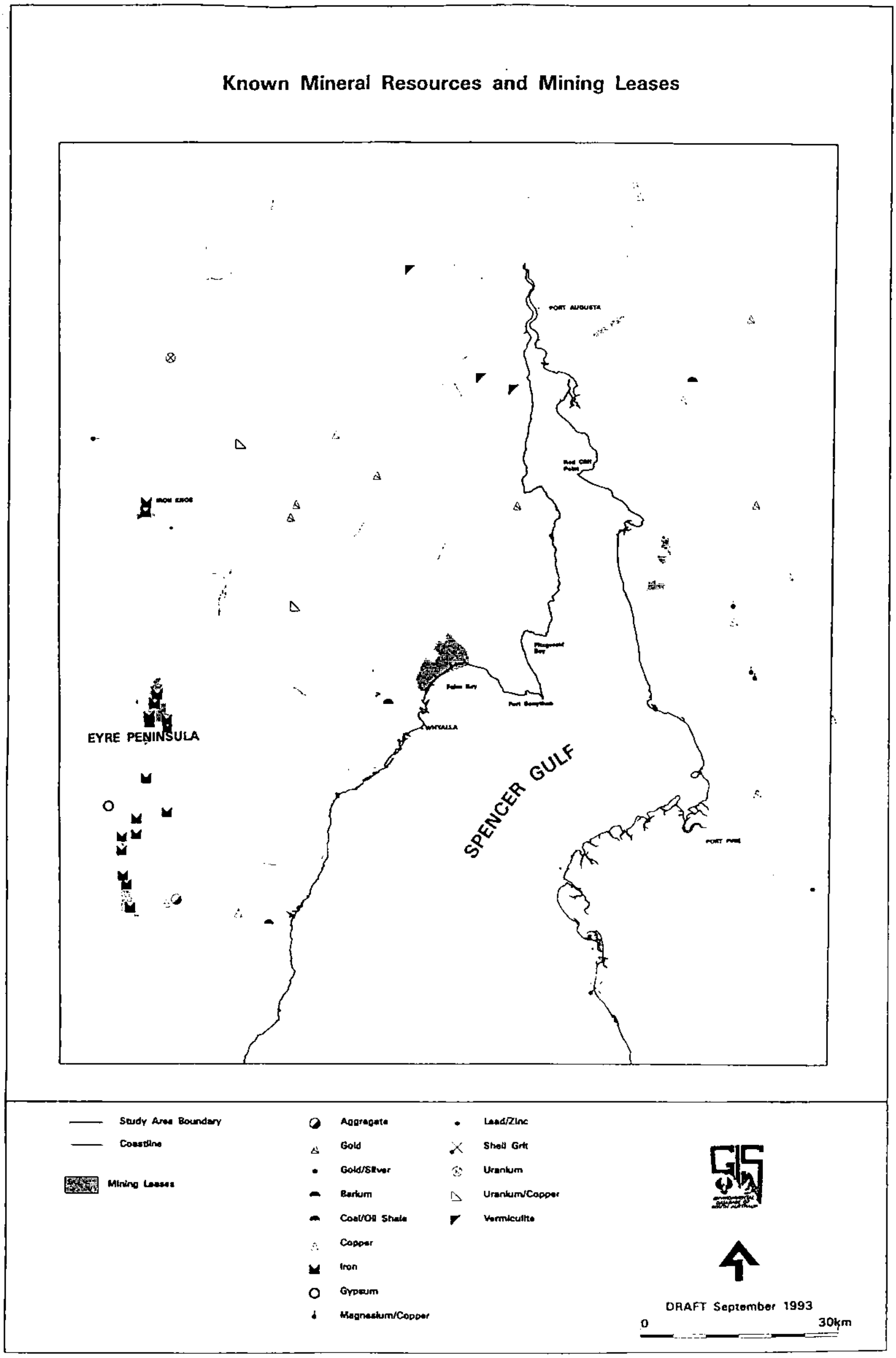


Figure 3.1: Known Mineral Resources and Mining Leases (source: Goodwins et al. 1993)

Flooding studies (including groundwater assessment) have been undertaken for Port Pirie and Port Augusta. The standing water levels were reported to be between 0.5 and 6 metres in Port Augusta and 0.5 and 1 metre in places for Port Pirie. The direction of local groundwater flow is towards the coast so that in the Port Augusta area the Gulf acts as a groundwater divide. High groundwater salinity levels suggests that groundwater discharge is taking place in this area. It is thought that in time the groundwater levels in the coastal zone will rise by an amount approximately equal to that experienced by the mean sea level. This is expected to result in increasing soil salinisation resulting from the evapotranspiration process which may increase the difficulty of maintaining some species of plants (Lange Dames and Campbell Australia, 1991 a & b, Appendix 1).

3.3 OCEANOGRAPHY

3.3.1 OVERVIEW

The Northern Spencer Gulf is considered to be an inverse estuary, with a net northward or landward flow, in contrast to a classical estuary. Nunes Vaz et al. (1989a) have defined an inverse estuary as "one in which seawater is measurably concentrated by the removal of freshwater".

The Gulf also has an eccentric tidal regime with strong and null tides. Even though tidal currents play a major role in Gulf's water circulation, thermohaline, wind and wave driven currents are also important. Sea level has been recorded at Port Pirie for the past 70 years. The gulf is subject to non-astronomic tidal variations with oscillation influenced by its natural period. Tides frequently exceed predicted vaules and the combination of storm surge with other factors have lifted the high tide by as much as 1.7 m above the predicted value. More commonly, major storms will raise tides to 1.0 to 1.5 m above predicted heights.

According to Gostin et al. (1984), the eastern side of the Northern Spencer Gulf has the most extensive intertidal areas, with depths of no more than 10 m, whereas a relatively deep channel, 10-20 m, is present along the western side. Intertidal and supratidal environments constitute around 33% of the area, varying during high or storm tides. Depths between low tide and 5 m represent 16% of the area, while 18% are between 5 to 10 m and 15% are deeper areas of 15 to 25 m. Isolated depressions occur near Black Point, Lowly Point, and south of Whyalla. Figure 3.2 illustrates the bathymetry and coastal sediments of the Gulf.

The Northern Spencer Gulf floor has regions with an irregular topography that have been created by seagrass meadows separated by scour hollows, while in other areas the floor has been completely scoured. When compared to the northern part of the Gulf, the southern part is

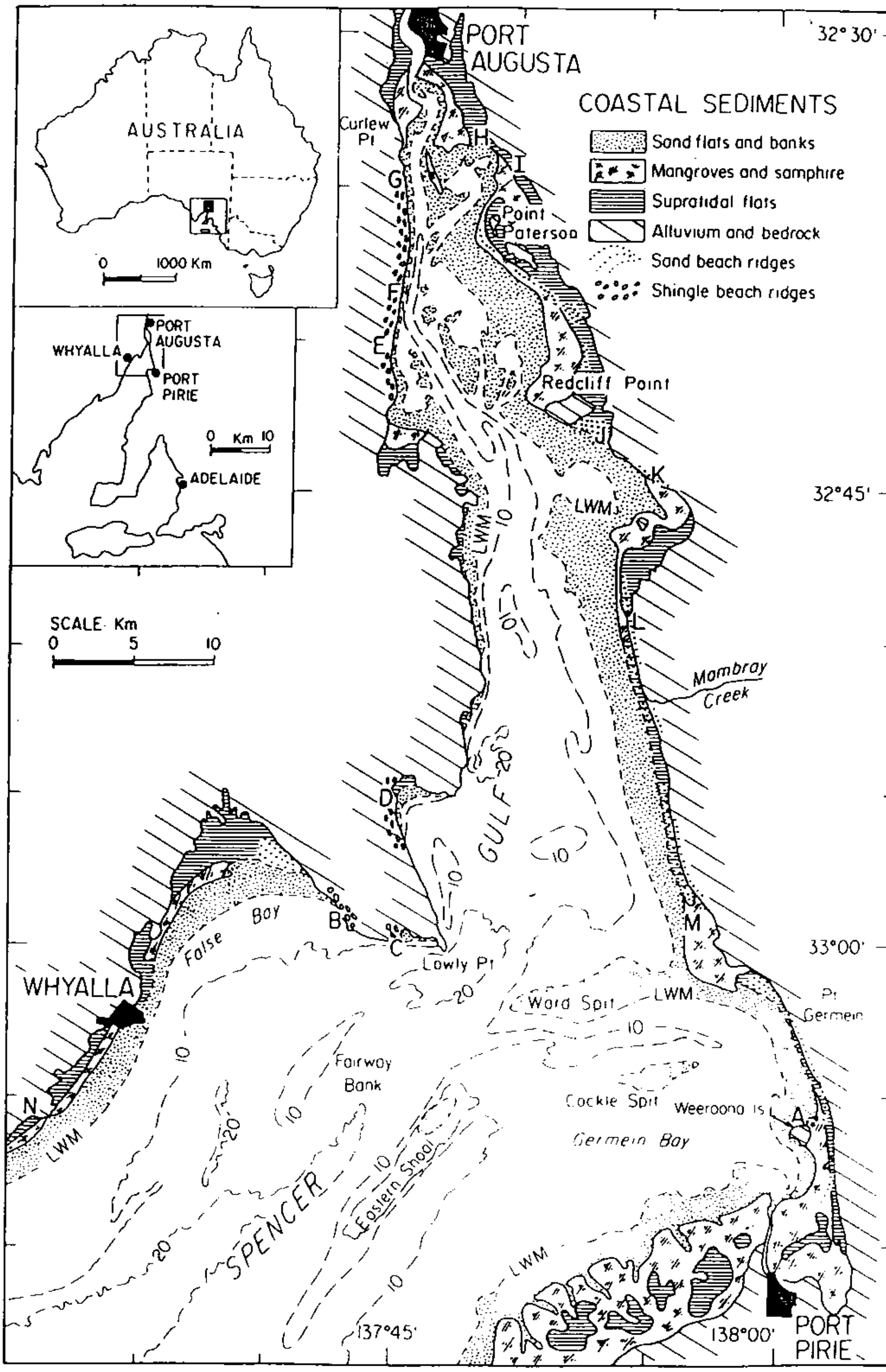


Figure 3.2: Coastal Sediments and Bathymetry, the Northern Spencer Gulf. The landward limit of the supratidal zone approximates the 6600 yrs B.P. shoreline. Isobaths are in metres. (source: Hails et al, 1984, p.375)

characteristically featureless, with a few isolated narrow zones of sand megaripples. The northern area has many linear belts and broad areas of megaripples below 10 m water depth.

The megaripples occur as linear belts, usually between 200 and 500 m wide, elongated parallel to the local channel margins. They vary in size along the belts. The small megaripples have wavelengths in the 2-6 m range and heights around less than 0.5 m. The large megaripples which are less common, have wavelengths of 8-10 m, and a few at 13, 18 and 20 m, with heights around 0.5 and 1.3 m (Gostin et al., 1984).

3.3.2 SALINITY AND TEMPERATURE

The high rate of evaporation, which exceeds precipitation due to the regional arid climate, removes freshwater from the Gulf. Evaporation from the water surface has been estimated at a rate of 1 cm per day during summer and 0.2 cm per day in winter (Gostin et al., 1984). Therefore the Northern Spencer Gulf has a negative salinity gradient, with very high salinity at the head of the Gulf decreasing towards the open boundary

The absence of significant sources of terrestrial runoff or groundwater also contributes to the high salinity in the Northern Spencer Gulf. Nunes and Lennon (1986) pointed out that a hypersaline character is found at the head of the Northern Spencer Gulf in late summer, when salinity reaches 48 ppt. In late winter, salinity falls to around 43 ppt. Annual salinity ranges from 40 to 45 ppt at Point Lowly and 44 to 49 ppt at Port Augusta (Gostin et al., 1984).

Variation in temperature is further evidence of the Gulf's response to seasonal influences. Temperatures vary considerably from season to season. According to Burne and Colwell (1982), summer surface water temperatures in the Northern Spencer Gulf reach 26°C, while in winter temperatures vary from around 12°C to 15°C. Shallow waters can reach up to 40°C at high tide. Temperature increases about 2°C from Point Lowly to Port Augusta.

Surface heat exchange and local meteorology are responsible for the substantial variations in seasonal water temperatures. With the exception of the shallowest regions, depth-related observed gradients are generally small and temperature is uniform in the horizontal distributions. Tides and wind are responsible for maintaining uniform conditions in the water column since stratification has been noticed during their absence (Nunes and Lennon, 1986).

3.3.3 TIDES

The Northern Spencer Gulf has an unusual tidal regime. At Port Augusta the tide is mostly semidiurnal with a large inequality (Easton, 1978). The ratio of the solar astronomical tide in equilibrium to the lunar astronomical tide is usually 0.47, whereas observed values for the Northern Spencer Gulf are 1.1. As a consequence, there is not a usual lag of 50 minutes per day in time of tide height and a "dodge tide" phenomenon occurs during the Spring-Neap cycle (Noye, 1984).

Tides and tidal turbulence are strong at spring tides. Spring tides have a great tidal range and occur every fortnight when the moon is full or new. These tides range over 3.0 m compared to the mean tidal range of approximately 1.5 m (Burne and Colwell, 1982). Noye (1984) affirmed that values of a maximum spring range of tide of 4.32 m were registered at Port Augusta, 3.44 m at Port Pirie, and 3.06 m at Whyalla.

Neap tides, in contrast to spring tides, have a small range and occur every fortnight near the times of the first and last quarter moons. During neap tides, also known locally as "dodge tides", the tidal range is 0 m and all tidal movements cease for a period of two to three days (Lennon et al., 1987). According to Bye (1981), a stratified flow regime in the Northern Spencer Gulf may exist during the neap tides. Therefore, tide currents play an important role in the uniformity of the Gulf's waters.

Tidal excursion which is the distance over which a tidal current can transport material, varies from one site to the other in the Gulf. According to Steedman & Associates (1983) it exceeds 7 km at Port Augusta for a tidal current of 0.5 m s^{-1}, while at Redcliff it is about 14 km .

3.3.4 CURRENTS, WATER CIRCULATION AND SEA LEVEL OSCILLATIONS

Noye (1984) noted five major types of current important for water circulation in the Northern Spencer Gulf: tidal currents, wind driven currents, thermohaline currents, water movement associated with long period sea level oscillations and drift owing to wind waves in very shallow water. However, Bye (1981) argues that tidal currents are the dominant currents in the Northern Spencer Gulf.

Tidal Currents

Tidal current velocities vary within a range of 0.5 m s^{-1} to 1.5 m s^{-1}, reaching their maximum speeds when the tide level coincides with the mean sea level. These currents generate turbulent mixing in the water column, dissolving substances until they become almost uniformly distributed (Hails and Gostin, 1978).

The irregular bottom topography of the Northern Spencer Gulf contributes to the non linear tidal circulation. Modelling of the Northern Spencer Gulf which is outlined in Appendix 1 demonstrates this feature in Figure 1. Tidal circulation generally has a north-south movement, reversing direction at the end of each tide period (see Figures 1.2 - 1.3 in Appendix 1).

However there are tidal circulation around the banks and shoals in the Gulf. A high resolution tidal model for the Gulf, as shown in Figures 2.2 - 2.7, demonstrates the gyre which forms behind Point Lowly. Waters at this point indicate convergence of surface currents due to the presence of foam and debris, usually associated with a front. A front may form when there is a strong tidal residual circulation around a headland. The modelling demonstrates the complexity of the tidal currents in the Northern Spencer Gulf and the difficulty in predicting the effects of sea-level rise in terms of changing bathymetry and circulation.

Other gyres have been reported in the Northern Spencer Gulf. Noye (1984) affirmed that north of Point Lowly currents directed southerly in the eastern channels and northerly in western channels were in the order of 0.25 m/s. According to Green (1984), residual currents present in the Northern Spencer Gulf are organised in cells of circulation driven by the tides. Those cells are formed due to a series of points or headlands that exist especially in the eastern shore of the Gulf, above Yatala Harbour (32^{o} 46'S), and in the western shore, below Blanche Harbour (32^{o} 43'S).

Wind Driven Currents

According to Noye (1984) wind driven circulation depends on the direction, duration and strength of the wind, and also on the phase of the tide. During spring tides, when tidal currents are strong, wind-driven circulation is smaller than at neap tides, when the tide is null.

Bullock (1975), applying a model, concluded that the surface current is predominantly northward in direction in the presence of a 14 m/s south west wind, whereas it is directed southwards during wind absence. He found the same results for the bottom current. The model also predicted an increase of 0.37m at the surface elevation at the end of the Northern Spencer Gulf, where the water tends to be piled up. Moreover, Harbison and Wiltshire (1993) affirmed that north west wind induces a poorly defined inflow on the western side of the Gulf, and a strong outflow near the eastern shoreline.

Thermohaline Currents

Thermohaline currents, also called density currents, are defined by Noye (1984) as "the result of the horizontal pressure gradients produced by lateral differences in density due to varying temperatures and salinity". According to Bullock (1975), the typical thermohaline induced velocity in the Northern Spencer Gulf is of the order of 0.1 m/s, which is the same order of magnitude as the wind driven circulation with a 14 m/s south east wind.

During summer, when temperature is high, due to high salinity conditions the density gradient is low. In winter, cooler waters at the head of the Gulf form a denser water mass that sinks and drains along the sea bed in the Spencer Gulf (Lennon, pers. communication, 1995). The water flux from the Northern Spencer Gulf to the Southern Spencer Gulf takes place relatively steadily throughout the year, whereas water exchange between Southern Spencer Gulf and the shelf is more intense during winter due to the larger density gradients.

Nunes and Lennon (1986) suggested that the southern basin in the Spencer Gulf acts as a reservoir for the high-density outflow from the northern Gulf during the year, flushing the load to the shelf during winter. The salty water accumulated in the Northern Spencer Gulf due to the evaporation is therefore removed from the Gulf mainly by the spring-neap tidal cycle. However, during neap tides, when the tide is null, the effects of the wind-driven and thermohaline currents dominate.

Other Circulations And Sea Level Oscillations

Wave driven currents affecting the Northern Spencer Gulf are caused by locally generated wind waves that may reach up to 2 m high during storms. Longshore currents which are one form of wave driven currents, are formed by the dissipation of energy when waves break approaching a coastline. During storms longshore currents may reach velocities of 1.0 m/s confined to within 1 km of the coast (Noye, 1984).

Some oscillations also occur in the Northern Spencer Gulf as a response to long period waves propagating west to east across the Great Australian Bight passing the entrance to the Spencer Gulf. These oscillations in the sea level vary with periods between 4 to 10 days and 20 to 30 days (Steedman & Associates, 1983). According to Noye (1984) these waves should propagate into the Gulf reaching Port Pirie some six hours later with less amplitude.

Meteorological conditions also affect sea level in the Northern Spencer Gulf. Noye (1984) pointed out that during the 12 months, from November 1976 to October 1977, there were 17 positive storms surges which raised the tide height more than 1 m at Port Pirie. Another example of tidal increase occurred at Redcliff in 1981 with a high tide of 5.2 m (recorded at the Port Augusta tide guage) which was some 2.0 m above the predicted level (Gostin et al., 1984). On the other hand, 7 negative storm surges occurred during the same period reducing the predicted tide height by more than 0.5 m.

3.4. ECOLOGICAL /BIOLOGICAL CHARACTERISTICS

The area is of significant biogeographical importance as it includes an interface between temperate and semi-arid biomes with the Gulf and ranges acting as natural barriers to species migration, some of which are at the limits of their distribution (Mines and Energy, 1994, p.38) . Figure 3.3 simplifies the region into major landscape units.

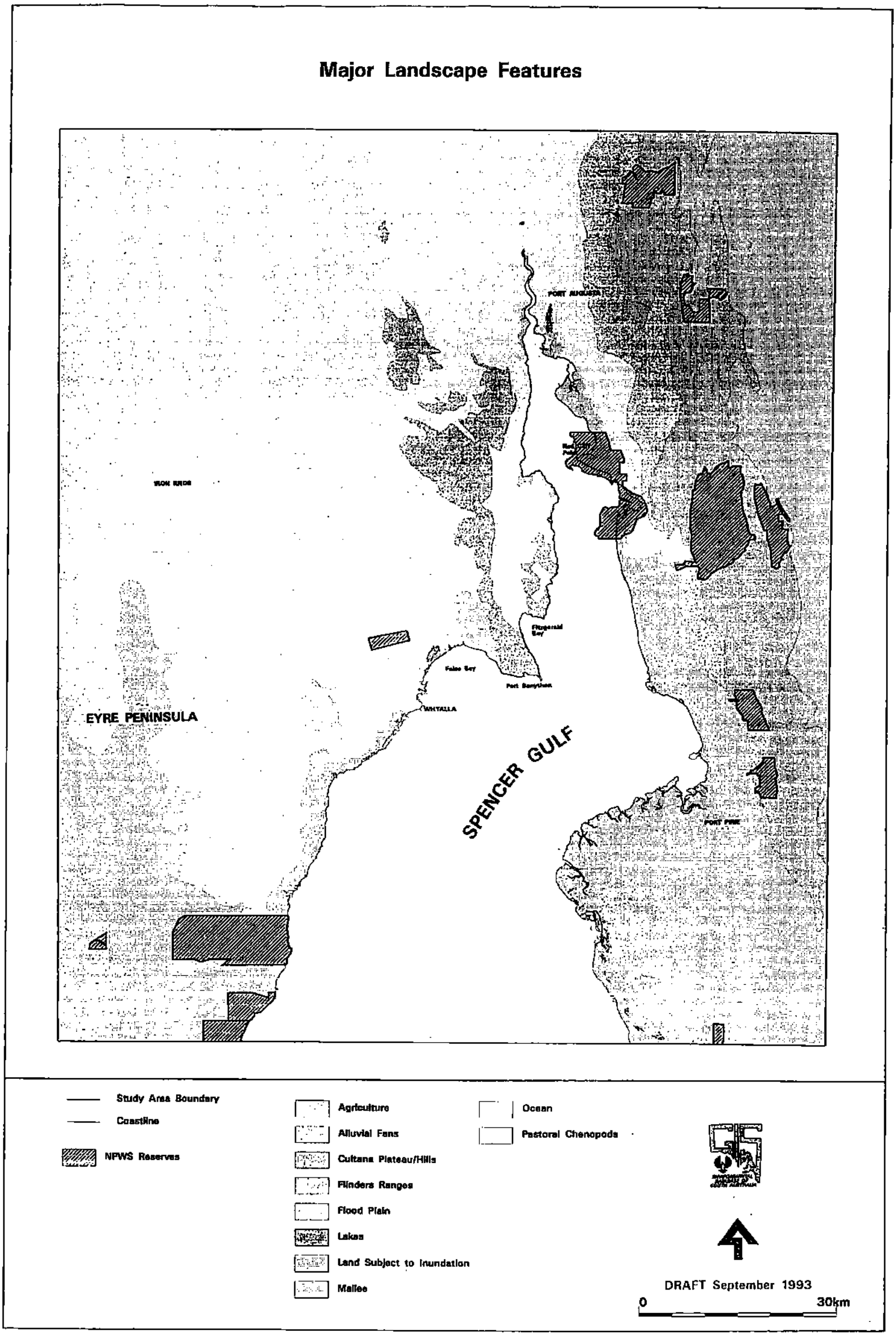


Figure 3.3: Major Landscape Features (source: GIS Environmental Database of South Australia, Department of Housing and Urban Development, 1993)

3.4.1 COASTAL VEGETATION

The marine ecology of the Northern Spencer Gulf has evolved in response to a number of unique conditions. These include relatively high salinities (from 40 ppt in winter up to 49 ppt in summer), wide temperature ranges, low levels of natural nutrient input with little terrestrial run-off and the relatively low wave energy which prevails in much of the system. There is a gradual and continuing tectonic uplift and an accumulation of reworked biogenic carbonate sediments, stabilised by seagrass beds at the Gulf margins. As a result the region supports a sub tropical marine ecosystem, containing numerous relict species with tropical affinities.

On the sheltered eastern shore of the Gulf the principal habitats are defined by beach ridges, wide intertidal flats and tidal creeks that are frequently colonised by seagrasses, mangrove and samphire communities. The shallow subtidal zone (less than 10 metres) is colonised by extensive seagrass meadows. On the west coast there are narrow deep channels with fine silt bottoms, that are dominated by benthic communities. Here there is also a rocky intertidal zone and shallow reef communities that fall away steeply into deep water (Harbison and Wiltshire, 1993, p.16).

Subtidal Zone

The shallow subtidal zone of the Northern Spencer Gulf is dominated by stands of the seagrasses Posidonia *australia* and *P. sinuosa,* with subordinate growth of *Heterozostera tasmanica, Amphibolis antarctica* and *Halophila ovalis.* The growth of the *Posidonia* species is particularly vigorous, with an estimated annual leaf blade production in excess of 9 kg/sq. m in shallow water (Shepherd, 1983 in Gostin et al, 1984 p127). *P. australis* may grow within the intertidal zone to almost sea level but predominantly from between spring low water level to about 4m depth. *P. sinuosa* dominates between 8 m and 10 m depth. The seagrass stands occupy broad shallow platforms, particularly along the eastern margin of the Gulf, as well as on and around discrete offshore banks. The seagrasses support a rich and diverse epibiota including a complex community of epiphytic algae that colonises the leaves and stems. The high turnover rate of seagrass leaves results in the transport of significant quantities of leaf litter, and its skeletal and encrusting epiphytes into the intertidal zone (West and Larku, 1979 in Gostin et al, 1984, p.128).

Intertidal and Supratidal Zone

The mangrove and samphire communities of the Northern Spencer Gulf are the most extensive in South Australia. They are located along the east coast where Holocene sediments have accumulated at Port Pirie, Port Germein, Yatala Harbour and Chinaman's Creek, as well as around the head of the Gulf at Port Augusta. They are less abundant on the west coast where there is less accumulation of Holocene sediments.

Tidal sandflats and banks cover the largest area of the intertidal zone. On coasts of low wave activity, the tidal flats merge with mangrove or samphire environments but on shores exposed to moderate wave action, small shelly beaches and beach berms form (Burne and Colwell, 1982 in Gostin et al, 1984, p.131). In the intertidal zone samphire - algal and mangrove -algal associations occur and cover 9% of the Northern Gulf. Bare or *Zostera* covered intertidal sandflats cover a further 17% (Gostin et al, 1984, p.128). *Avicennia marina* stands form a low woodland forest from mean sea level to spring high-tide level. While progressively higher vegetated zones are a *Halosarcia-Sclerostegia* (samphire) association, a *Maireana Halosarcia* (samphire) association, *Halosarcia spp.* and an *Atriplex* (saltbush) association (Chinnock, 1980 in Gostin et al, 1984, p.129).

The supratidal zone is dominated by extensive samphire communities of *Halosarcia spp.* up to 7 km wide and cover about 7% of the total area. These communities often join the *Avicennia marina* communities in the intertidal mudflats and tidal creeks. Ephemeral saline lakes fed by groundwater seepage are commonly found along the landward margin of the supratidal flats (Gostin et al, 1984, p. 131).

The seagrass, mangrove/samphire and tidal flats provide essential nursery habitats for fish and crustaceans. The samphire flats which back the mangrove communities provide a filtering mechanism for nutrients and provide an important buffer for protection of mangroves and the intertidal systems. The seagrass communities play a central role as primary sources of organic matter, as they fix carbon as organic matter which contributes to the detritus based food chain. Preservation of these communities is critical for the stability of coastal and marine ecosystems particularly in view of the fact that the Northern Spencer Gulf supports a commercial fishery industry.

Associated Fauna

Mangrove and samphire communities support a great diversity and abundance of fauna, including micro-organisms, isopods, amphipods, polychaetes and molluscs which in turn support a great diversity and abundance of fish and crustacean species (Johnson et al 1979 in Harbison and Wiltshire, 1993). The near-shore rocky reefs along the west coast of the Northern Spencer Gulf also support an abundant and diverse community of flora and fauna. The reef fauna is dominated by sponges, cnidarians, molluscs and echinoderms. There is also a variety of reef fish.

3.4.2 TERRESTRIAL VEGETATION

In general the agricultural areas lie to the south of Mambray creek on the eastern side of the Gulf and to the south of Whyalla on the western side. To the north of these areas the land use is primarily pastoral with sheep grazing on the native vegetation. Current vegetation patterns have thus been subject to varying degrees of disturbance since European settlement in the area. This has ranged from broadscale clearance of vegetation where it has been replaced by the cultivation of crops, to increased grazing pressure, addition of fertilisers, erosion, modified fire frequencies, logging and invasion by introduced species (Mines and Energy, 1994, p.38).

As a result of this vegetation clearance the agricultural plains now have less than 2% of native vegetation remaining thus any remnants in these associations are considered to be of high conservation significance. The remaining native vegetation consists of *Eucalyptus socialis, E. gracilis* low woodland and *E. poroasa - E. odorata* woodland, often with highly modified understoreys (Goodwins et. al, 1993).

The vegetation on the western side of the Northern Spencer Gulf is primarily a chenopod shrubland, Saltbush (*Atriplex vesicaria)* or Bluebushes (*Maireana sedifolia/M. pyramidata)* with a variable overstorey which is sometimes Western Myall (*Acacia papyrocarpa)* or False Sandalwood (*Myoporum platycarpum).* This type of vegetation is poorly represented in the South Australian National Parks System. As this is the most south-east distribution of Western Myall and Saltbush/Bluebush association it is considered to be of high conservation value (Goodwins et. al, 1993).

3.4.3 RESERVE SYSTEMS

On the steeper foothills and ranges in the southern Flinders Ranges remnant woodland vegetation occurs and is will preserved in a number of reserves. If planned extension of these reserves eventuate then 4% of the region will be included in the South Australian National Parks system.

The Northern Spencer Gulf has nine reserves, seven of which are located on the Eastern side of the Gulf. The Cultana Army Reserve which has restricted public access can also be considered as a defacto reserve.

There are three aquatic reserves, Blanche Harbour-Douglas Bank, Yatala Harbour and Whyalla-Cowleds Landing. Winninowie Conservation Park, on the eastern side of the Gulf extends down to the low water mark. Although theses areas provide some degree of site or habitat based conservation in the Northern Spencer Gulf they provide little ecosystem protection (Mines and Energy, 1994, p.38).

3.4.4 RARE AND ENDANGERED SPECIES

Many species are likely to be at the limits of their distribution and are of particular ecological interest. The study area covers a small part of each of three herbarium regions, the Northern Lofty, Flinders Ranges and Eyre Peninsula and so there is no status of taxa available solely for the Northern Spencer Gulf Area.

Due to excessive clearance for agricultural purposes on the eastern side of Gulf, the remaining native vegetation maintains high conservation significance as its rarity value increases. The fragmentation of vegetation has also resulted in the isolation of many native animal species. This in turn has increased the vulnerability of populations to local extinction through natural disasters, particularly fire and disease. In the Northern Spencer Gulf, the SA Museum has records of 26 terrestrial mammals 3 of which are extinct, 3 are rated as rare or vulnerable and 2 are of unknown status. However, due to the lack of recent studies in the area the current local situation is unknown (Goodwins et al., 1993). Coastal reserves have been targeted as potential wildlife corridor reserves and rehabilitation of disturbed coastal habitats are highlighted as part of the proposed Biological Conservation Strategy for the area.

3.4.5 NATURAL RESOURCES

Apart from the mineral resources upon which industry depends the Northern Spencer Gulf is also important for the number of commercial fish species that are exploited. Over 40 species of fish have been recorded and more probably occur. The most important species in economic terms are the western king prawn *Penaeus latisulcatus,* garfish *Hyporhamphus melanochir,* King George whiting *Sillaginodes punctatus,* snapper *Chrysophys auratus,* western sand (or silver) whiting *Sillago schomburgkii,* tommy ruff *Arripis georgianus,* snook *Australuzza novaehollandiae,* calamari *Sepioteuthis australia* and Australian salmon *Arripis trutter esper* (SEA, 1981a, in Harbison and Wiltshire, 1993, p.20).

The Northern Spencer Gulf (south of Lowly Point) represents 75% of the State's total prawn harvest and approximately 45% of the State's scale fish catch and more than 45% of the State's blue crab catch. Although only 1% of the catch is caught north of Lowly Point the shallow water seagrass and mangrove environments of the Northern Spencer Gulf act as a nursery and breeding habitat (Mines and Energy, 1994, p.46).

3.5 SOCIO-ECONOMIC STRUCTURE

3.5.1 LANDUSE AND TENURE

The Northern Spencer Gulf region displays complex land use patterns due to the interface between urban, industrial and rural land uses. Residential areas are centred on the three main towns of Whyalla, Port Augusta and Port Pirie. There a number of smaller towns in the region mostly located on the eastern side of the Flinders Ranges. Commercial and industrial activity is also primarily based around the three main centres. Land Tenure is identified in Figure 3.4 which portrays a combination of tenure and management. The map is based on identifying crown lease areas, pastoral (42 year lease), government operated land and South Australian National Parks and Wildlife Service reserves.

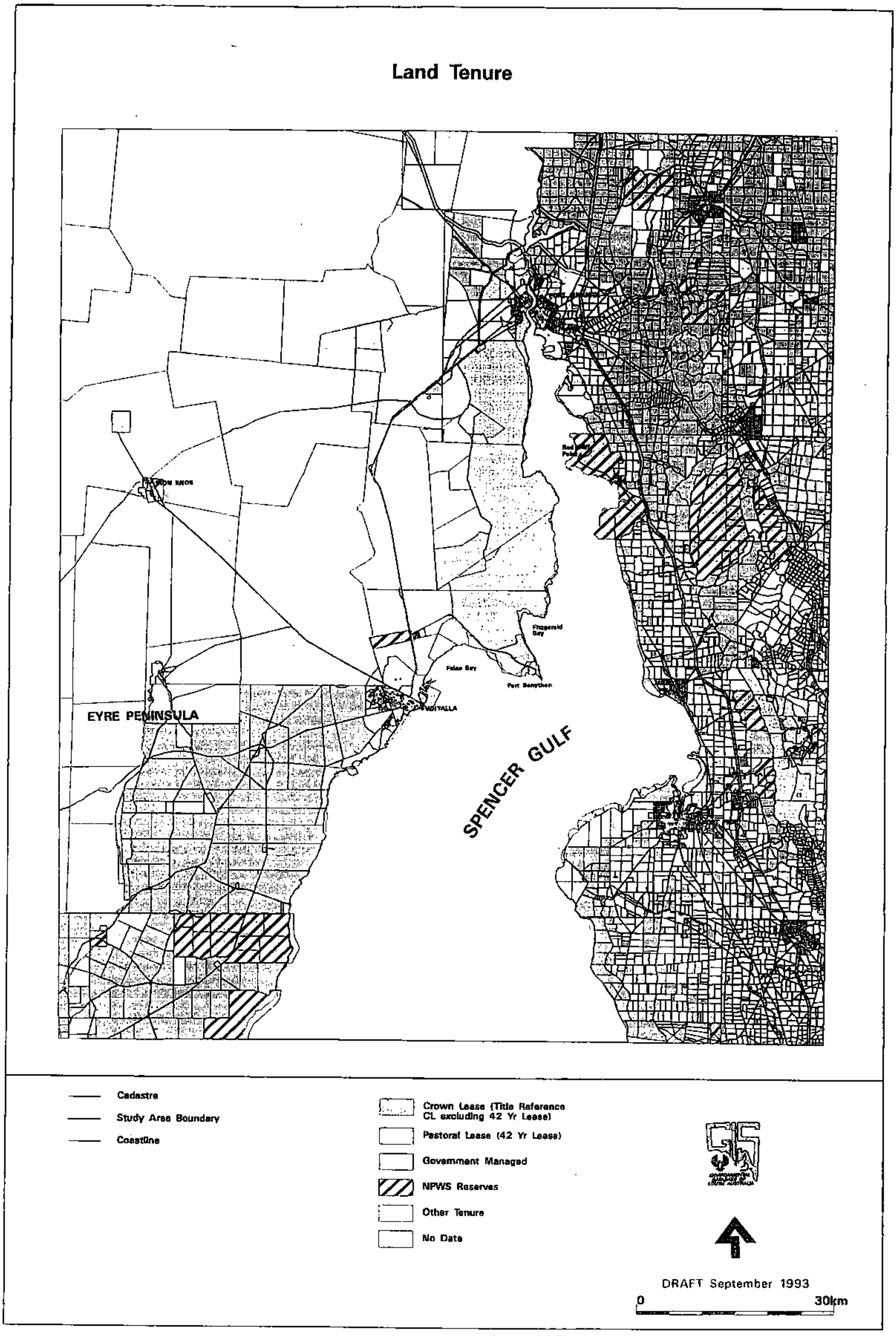


Figure 3.4: Land Tenure (source: GIS Environmental Database of South Australia, Department of Housing and Urban Development, 1993)

3.5.2 ECONOMIC AND SOCIAL PROFILE OF URBAN CENTRES

The cities in the Northern Spencer Gulf of Port Pirie, Port Augusta and Whyalla share some common characteristics. The economy of each city is based on mineral resources and processing. They have all experienced population decline since the mid-eighties, have higher than the state average unemployment (estimated at 13.4% - 15.8% in 1991 census) and sole parent families. They have lower than average education levels for the state but a higher proportion of people with basic and skilled vocational qualifications. Trades persons and labourers are the largest occupational categories reflecting the industrial nature of the cities. Overseas exports by ship from Port Pirie, Whyalla and Port Bonython account for 34.5% of all such exports in South Australia (Mines and Energy, 1994, p.24).

The infrastructure of three cities is thought to be adequate with good road and rail services. There is also community infrastructure in terms of hospitals and education facilities which could support much larger populations. Therefore, it is unlikely there will be any further demand to extend these services given the declining population in the area.

Port Pirie

Port Pirie is situated on the eastern side of the Spencer Gulf with a population of over 14,000 people with approximately 2,000 further residents in the region. It is the site of the world's largest lead smelter, Pasminco-BHAS, which treats lead, silver and zinc ores from Broken Hill. Current employment at the smelter is about 900 persons. Other major industries include medium to heavy engineering, industrial clothing manufacturing, soft drink bottling, a bakery and dairy processing. The major commodities shipped through the port are ores, concentrates and non-ferrous metals as well as wheat and barely which is grown in the surrounding districts (Mines and Energy, 1994, p.22).

Port Augusta

Port Augusta is located at the head of the Gulf and is a transport cross roads for rail and road links with a populations of 15,000. It services the northern part of the state for both agricultural producers and mining areas such as Roxby Downs, Coober Pedy and the Moomba Gas Field. Economic activity has been based on two government owned employers Australian National and the Electricity Trust of South Australia (ETSA). Both have recently reduced their workforce numbers. The newer Northern Power Station which utilises brown coal from Leigh Creek has supplied one-third of South Australia's power since 1985. Australia National accounted for 34.6% of employment in Port Augusta in 1974 but by 1991 this had been reduced to approximately 9.5%. Tourism is the other major industry in the city as it is the gateway to the Flinders Ranges and to the northern outback. Port Augusta has 9.1% of its population being of Aboriginal or

Torrens Strait Island descent and this is considerably higher than the State average of 1.2%. Therefore, there is the potential for aboriginal cultural tourism in this area (Mines and Energy, 1994, p.21).

Whyalla

Whyalla is situated on the west coast of the Gulf and is the largest of the three cities with a population of 25,000. The BHP steelworks utilises the large deposits of iron ore which are found inland in the Middleback ranges. Over half a million tonnes of iron ore and a similar amount of iron and steel were shipped from Whyalla in 1991-1992. However, BHP has reduced its workforce from a peak of 6,000 employees in 1965 to a target of 2,000 in 1995. Recent new industries in the area include the Santos fractionation plant at nearby Port Bonython, processing liquid hydrocarbon from the Moomba gas fields and an algae extraction plant producing beta carotene (Mines and Energy, 1994, pp. 20-21).

3.5.3 CULTURAL AND HERITAGE ISSUES

While individual Aboriginal heritage sites have not been identified for the Northern Spencer Gulf it should be noted that the whole region contains some significance to the Aboriginal people. The Environmental Sensitivity Map displays areas that have been identified.

The South Australian Heritage Branch has delineated three regions that are partly included in the Northern Spencer Gulf. These are the Upper North, Flinders Ranges, and Eyre Peninsula. However, only the Eyre Peninsula has been surveyed with forty-four European sites listed.

The National Register lists 21 sites that have either historical, cultural, archaeological, scientific or biological significance in a national context. Most are contained within the existing reserve system with the exceptions being;

Corunna Range Geological Area
Moonabie Range Geological Formation
Lincoln Park Historic Reserve which is of aboriginal heritage significance
Whyalla-Iron Knob-Iron Baron Western Myall Habitat

Also, in the study area there are approximately 50 significant geological sites. Some of these may also be recorded on the State or National Estate registers. The more notable areas are the Corunna Range north west of Whyalla and Redcliff point which lies on the east coast and is now part of the Winninowie Conservation Park (Mines and Energy, 1994, p.41).

The geology along the western shoreline of the Gulf is also noteworthy as significant coastal dunes, shingle beach and shell ridges exist there.

3.6 TECHNIQUES FOR ASSESSMENT OF GENERAL VULNERABILITY

3.6.1 EXISTING CONTOURS

While the 1:50 000 Topographical Cadastral overprint maps were the most detailed information available for all of the Northern Spencer Gulf, more detailed information was available for the four selected study areas of Port Pirie, Port Augusta and False Bay. The Department of Environment and Natural Resources (Resource Information Group) had Topographic maps of Port Pirie and False Bay available at a scale of 1: 10 000 and a contour interval of five metres. Two maps were required to cover the Port Pirie area and three for False Bay at a cost of $7.10 per sheet. These were subsequently purchased.

For Port Pirie and Port Augusta finer scale topographic maps at 1: 2 500 were available with contours of two metres. Ten maps were available for Port Augusta and two for Port Pirie, again at a cost of $7.10 each and these were also purchased.

3.6.2 COASTAL GEOMORPHOLOGICAL INTERPRETATION

Another technique for assessing coastal vulnerability is by reference to the coastal geomorphology. This was used for the Victorian Coastal Vulnerability Study which used a generalised coastal classification together with notations of levels of impact for different coastal types. In addition, the Victorian study used Bruun rule calculations as a basis for estimates of foreshore erosion for sea-level rise scenarios of plus 0.3m and 0.5m. While this may be useful for natural coastlines where there are no obstructions to recession, the calculations do not allow for longshore variations in erosion. As noted by Gordon in New South Wales, the effects of littoral drift as a coastal erosion hazard may in some places may be more important than any sea-level rise effects.

In South Australia, a pilot hazard mapping study has been conducted by the Coastal Management Section of the Department of Environment and Natural Resources. The aim of this is to identify coastal morphology and hazard zones. A preliminary map sheet (see Figure 3.5) has been prepared for Streaky Bay on the Eyre Peninsula (outside the study area). This approach identifies broad sediment/hazard areas as Holocene marine sediments, storm surge hazard zone and inland runoff zone. In addition various beach types (eg dissipative or reflective) and dune/beach stability categories (accretion/erosion) categories are identified.

The Northern Spencer Gulf study attempted to use a pragmatic approach to using existing data sets rather than undertake a major hazard identification study. First, the AGSO coastal classification system was investigated in liaison with Dr Bob Burne, for its adaptability to the identification of hazard zones. However, the satellite imagery used was

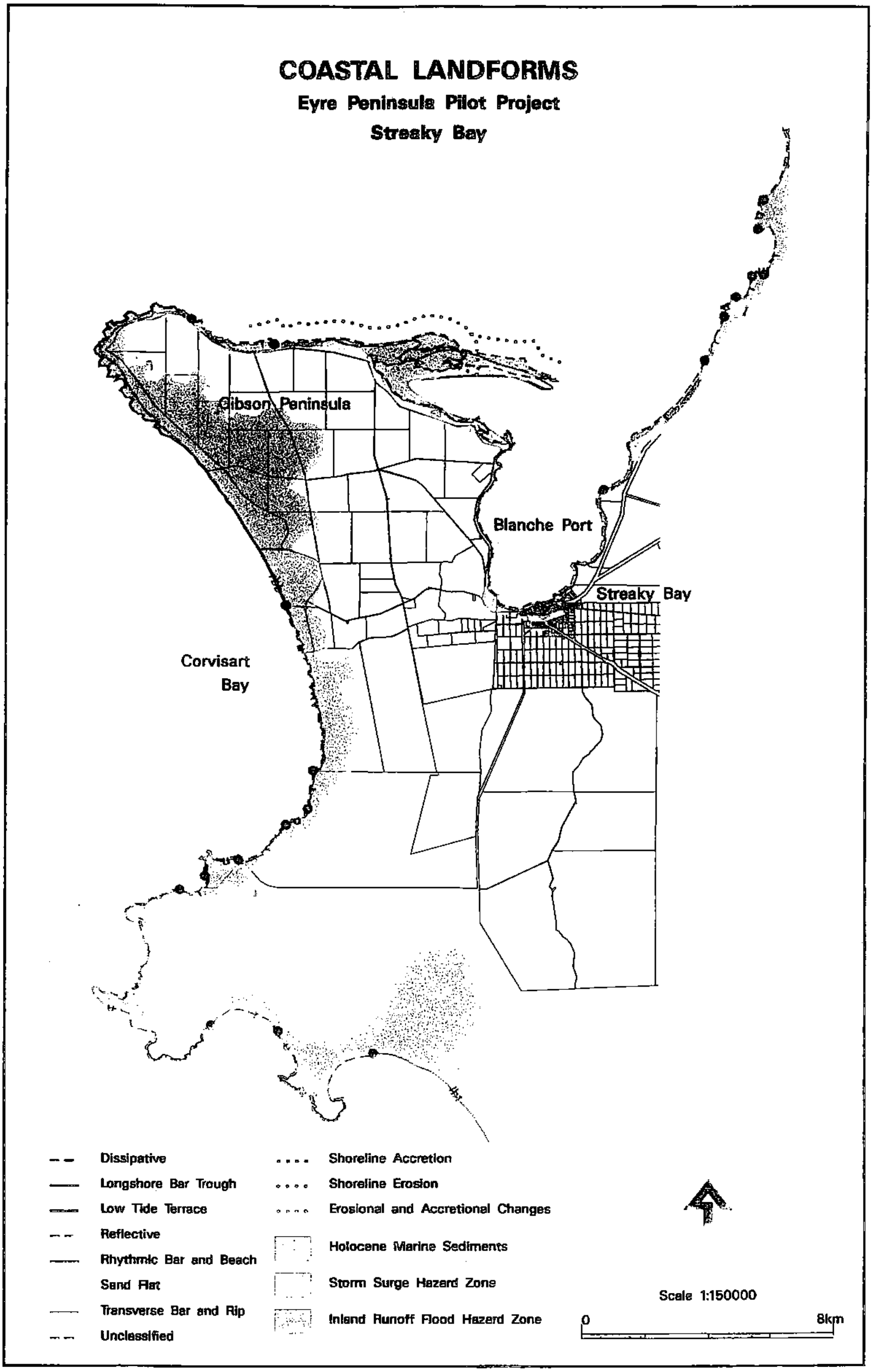


Figure 3.5: Coastal Landforms, Eyre Peninsula Pilot Project, Streaky Bay (source: Coastal Management Section, Department of Environment and Natural Resources, 1995)

found to be fairly coarse in the accurate delineation of various coastal units. In the future it may be possible for the AGSO classification to produce some broad hazard related geological categories. The advantage of this would be for local councils and State governments to use an existing digital GIS data base which could then have various units tagged according to their coastal hazard classification.

The Northern Spencer Gulf study attempted to produce more detailed coastal maps in conjunction with the State Geological Survey. The whole of the study area was mapped at a scale of 1:15,000 according to detailed Quaternary coastal geology. The purpose of this was to identify detailed geological units which were then digitally recorded on a GIS system and could then be used for coastal hazard classification purposes. The Holocene coastal geomorphology is an important indicator of coastal processes and often defines specific levels around the coast. For example the intertidal mangrove facies and the higher samphire/algal marsh facies have clearly defined boundaries which correspond to relative tidal flooding and hence to flood hazard.

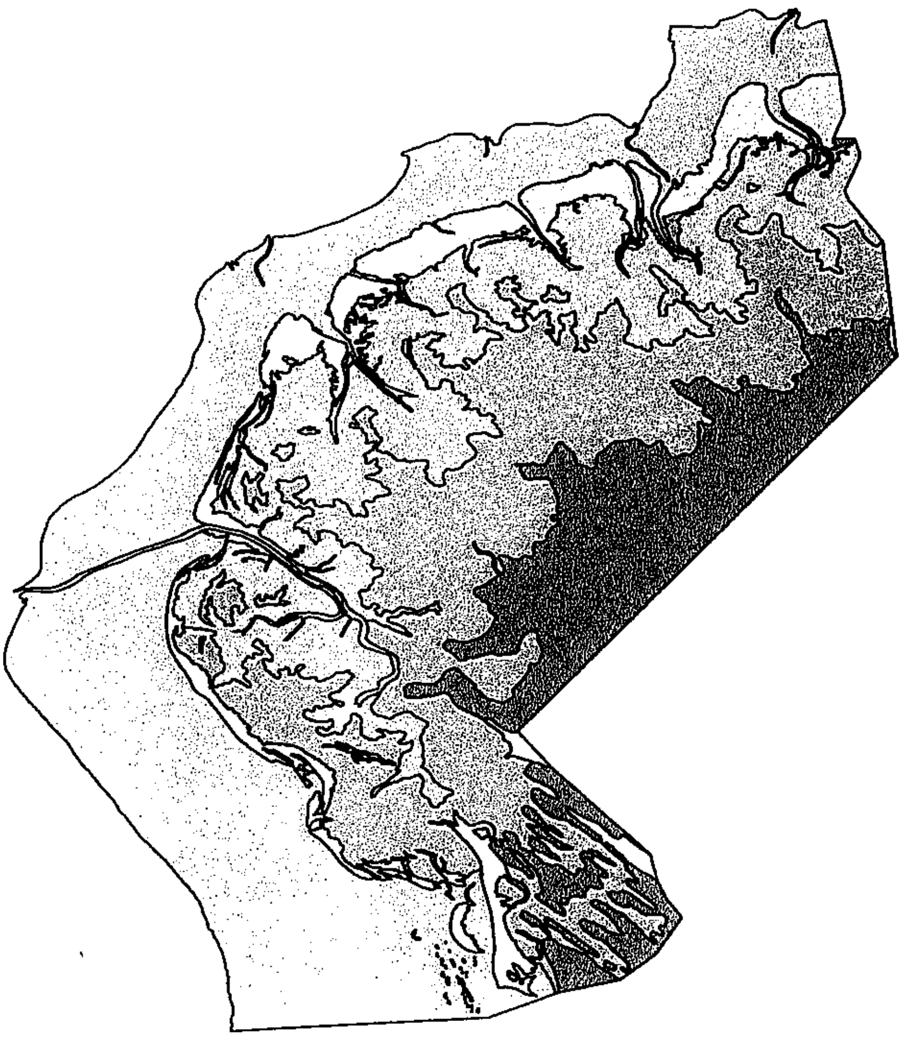
The mapping study identified the following units near the Port Pirie case study site:

- supratidal and extratidal clay and gypsum dunes and lunettes (RL >3.00m, except in saline depressions where it can be lower)
- supratidal flats. Gypseous clay (RL 3.00-3.5m)
- stranded beach ridges and coastal dunes, Shellgrit, shelly sand and fine sand (RL >3.00m)
- samphire-algal marsh. Carbonate and terrigenous muds (RL 2.6/2.8-3.00m)
- mangrove woodland. Organic, terrigenous mud (RL 1.4-2.8m)
- bare or zostera - colonised low intertidal sand or mud flat. Mixed shell and quartz muddy sand (RL 0-1.4m)
- Pleistocene and older units (not related to current coastal processes)

The mapping has been completed and is currently being entered onto a GIS data base. One section just to the south of Port Pirie has been prepared as an example of the level of detail (see Figure 3.6). Given the time constraints of the coastal vulnerability project, it is intended that this work is an ongoing study which will be completed in conjunction with the local councils and the Coastal Management Section. The next phase is to tag each of the detailed geological units with an appropriate hazard classification. This will then allow a rapid broad hazard assessment using the GIS data. Following preliminary identification of these units, it will then be possible to focus any hazard identification. It is planned to trial the use of these maps as a complementary system to the geomorphological mapping program being piloted by the Coastal Management Section. The only available hazard map (Figure 3.5) produced by the Coastal Management Section has limited differentiation between Holocene sediment types (mostly dunes), which reduces its usefulness for identifying different hazard levels. However, the Coastal Management

Northern Spencer Gulf

Port Davis



Coastal Geology
Qha (Holocene Alluvium)
Semaphore Sand (Coastal Dunes and Beach Ridges)
St. Kilda Formation (Gypsum Dunes and Lunettes)
St. Kilda Formation (Supratidal Flat)
St. Kilda Formation (Samphire-Algal Marsh)
St. Kilda Formation (Mangrove Woodland)
St. Kilda Formation (Tidal Sandflat)
St. Kilda Formation (Mixed Mangrove-Samphire)
Moornaba Sand (Aeolian Dune Sand)

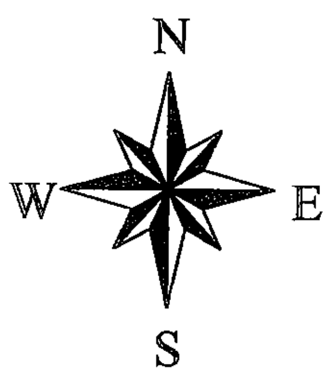


Figure 3.6 (a): Coastal Geomorphology / Geology - Port Pirie Area (source: Mines and Energy, S.A., 1995)

Example ArcView2 Screen Print

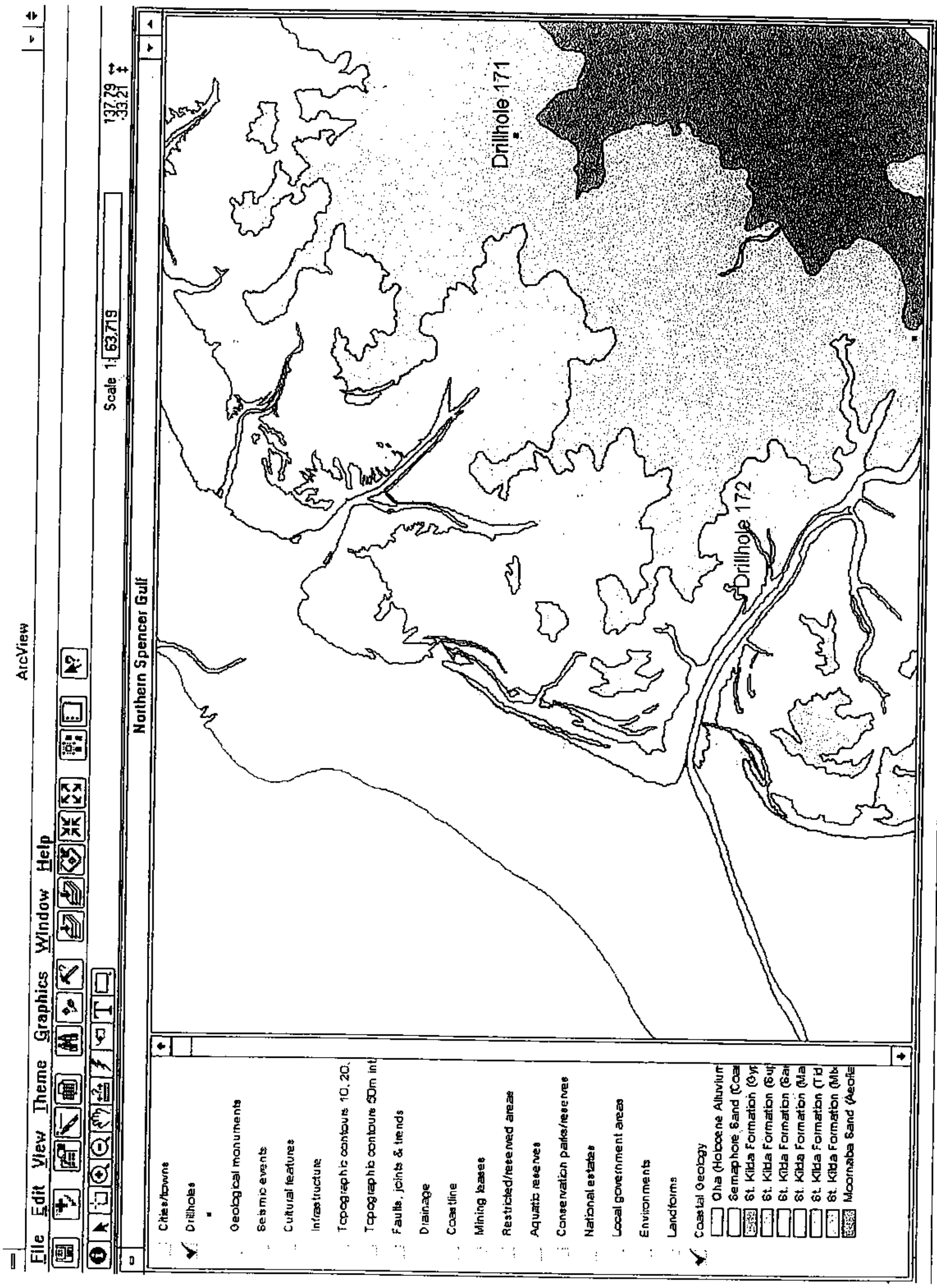


Figure 3.6 (b): GIS example of Coastal Geomorphology / Geology - Port Pirie Area (source: Mines and Energy, S.A., 1995)

Section has conducted detailed mapping of Holocene sediments elsewhere, although no maps have yet been produced for those areas.

The detailed mapping carried out for the current project from 1:15,000 aerial photography reveals a clear delineation in tidal flooding levels between the bare or Zostera flats (RL 0.1.4m) to the mangrove zone (RL 1.4-2.8m). There is some overlap between the mangrove and the samphire zone (RL 2.6/2.8-3.00m) and then the infrequently flooded saltpans or bare supratidal flats (RL 3.00-3.5m). The GIS maps will give important information on the location of mangrove and samphire zones and the potential restrictions on their landward migration. This will be of importance in areas of high conservation significance. The delineation of the bare or supratidal flats is important, as this has high flood potential and is particularly vulnerable to future sea-level rise. This area has been encroached upon in the development of Port Pirie and has consequently resulted in a flood hazard problem. Even the higher elevation storm ridges and sand deposits are obviously subject to flooding and erosion. It is important to note that their morphology is the result of modern or earlier Holocene processes. Whilst there is likely to be a wide range in the return interval of the events which formed the ridges, they represent the lower frequency hazard zone after the supratidal flats.

The above broad description indicates the usefulness of applying existing detailed geological data to a broad zoning for coastal hazard identification, where there is a low gradient coast with significant intertidal and supratidal deposits. The geological mapping, however, does not provide data on the nature of terrestrial flood potential which is included in the Coastal Hazard Map produced by the Coastal Management Section. In addition, the Coastal Hazard Maps attempt to give an indication of beach type, although this will mostly be reflected in the geological descriptions.

3.6.3 NEOTECTONICS

While estimates of present sea-level rise are based on the averaging of data from tide gauges worldwide, the secular sea level trend measured by individual tide gauges varies widely around the globe (±10 mm/yr) (Belperio, 1993). This is due to variable rates of land subsidence and uplift operating at a range of spatial and temporal scales. Tectonic response of the land and isostatic response of the continental margins, plus human activities such as groundwater or hydrocarbon extraction, land reclamation, artificial coastal structures, dredging and pumping of sediment can all affect local sea level change. It has therefore been suggested that local secular tide gauge data which are dominated by these effects have resulted in an over-estimation of global sea-level rise by 2 to 3 times (Harvey and Belperio, 1994).

Records of sea-level in Australia, from the period 1897 to present, have been monitored and analysed by the National Tidal Facility (NTF) at Flinders University in South Australia. These demonstrate the spatial inconsistency in secular sea level rise related to the above factors. Analysis of these figures gives an Australian average of 1.51 ± 0.18 mm/year at the 95% confidence level which is in agreement with global analyses of 1.0-2.0 mm/year (Mitchell 1991 and Gornitz 1933 in Harvey and Belperio, 1994). From reconstruction of palaeo-sea level histories the complexity of underlying factors that control relative sea-level have been demonstrated.

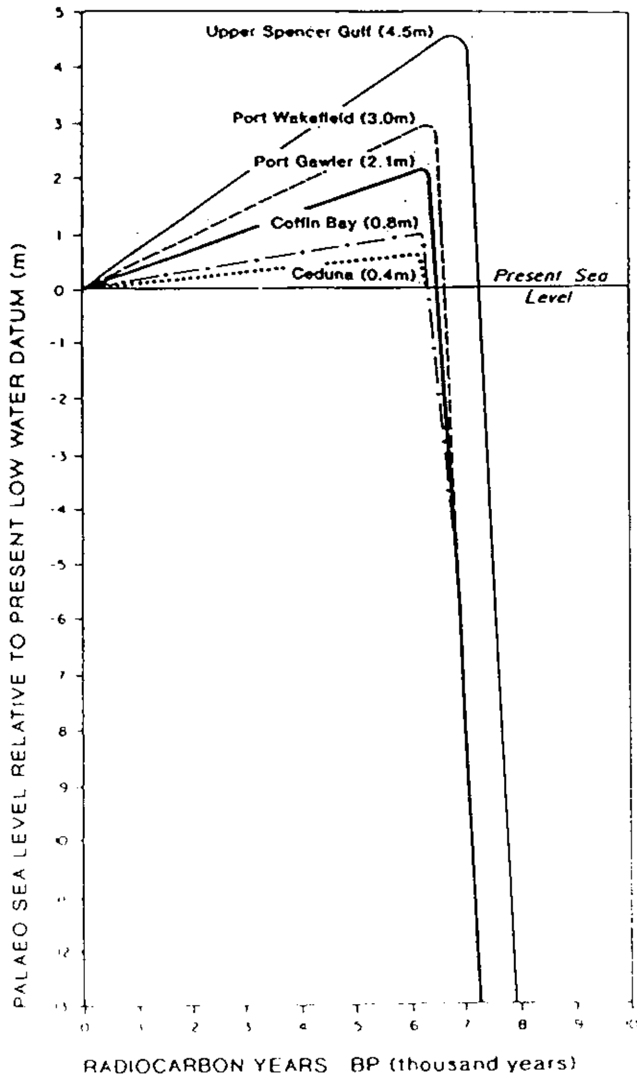


Figure 3.7: Palaeo sea levels relative to present sea levels at various sites in South Australia. (source: Harvey and Belperio, 1994, p.48.)

The present sea level was reached in South Australia around 6000 to 7000 years BP. However, the area is still affected by subtle, ongoing isostatic adjustment of the shelf and coast. This is manifested as an apparent high stand of the 6000 yr BP shoreline as shown in Figure 3.7 (Harvey and Belperio, 1994). This height of the high stand varies around the coast and increases up the two Gulfs with increasing distance from the continental margin. Sea-level change dominated by this regression is estimated at 4.5m for the Upper Spencer Gulf which has caused slow but obvious coastal regression (Harvey and Belperio, 1994).

Superimposed on isostatic warping are the longer term tectonic movements as illustrated in Figure 3.8. Preliminary corrections have been made for South Australian tide gauge sites. Data in the Northern Spencer Gulf are only available for Pt. Pirie. Here records have been collected for 51 years and show a trend of -0.20 mm /year which gives a preliminary adjusted trend of 0.3 mm/ year (Mitchell, 1993, per comm. for Harvey and Belperio, 1994). Thus, in the Gulfs of South Australia, any rise of sea level will be mitigated by ongoing isostatic upwarping of up to 0.8 mm/yr.

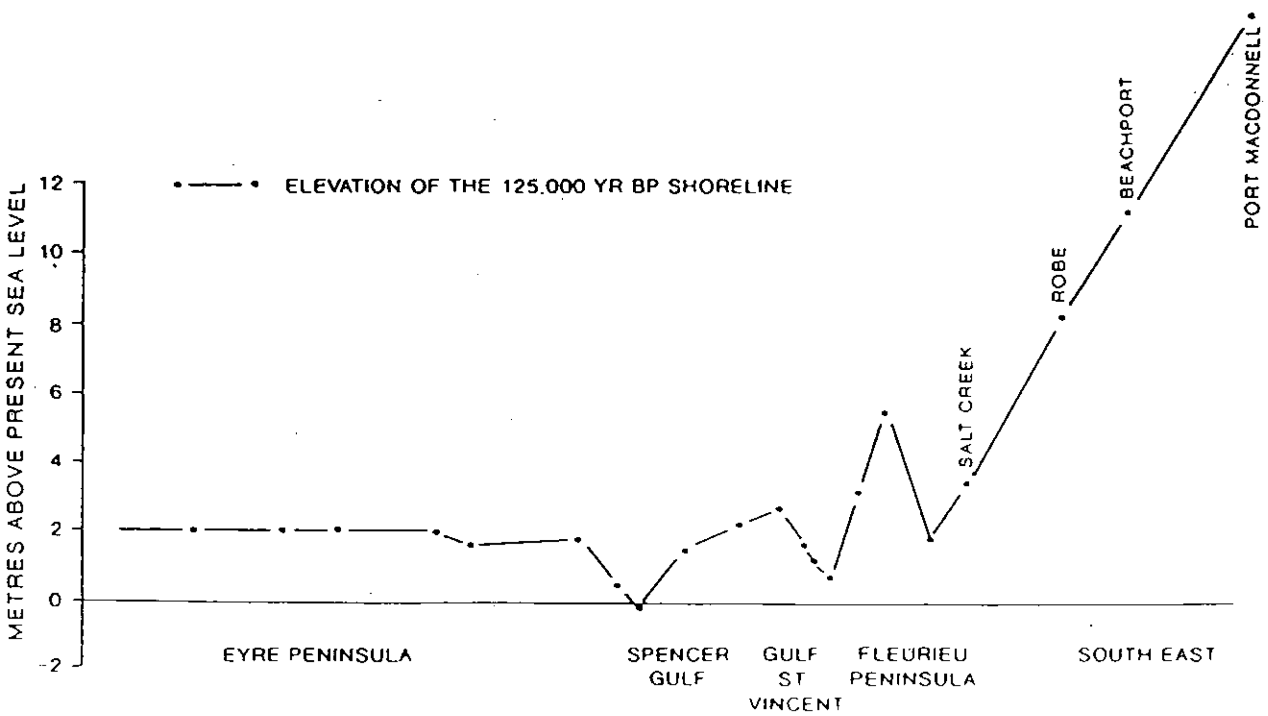


Figure 3.8: Changing elevation of the last interglacial shoreline (125 000 yr BP) in South Australia. (source: Harvey and Belperio, 1994, p.49.)

3.6.4 SURVEYING OF SHACKS

The Shack Site Freeholding Committee was formed in March 1994 to undertake a review of all shack sites located on Crown land on the coast, the River Murray and Glenelg River. The Committee's final report "Freeholding of Shack Sites on Crown Land" was published in November 1994. According to this report, the objectives of the Committee were to "recommend appropriate methods of freeholding shack sites" and "to define and implement solutions to problems rather than obstruct the process of freeholding" (Shack Site Freeholding Committee, 1994, p.9).

The report has been prepared in two parts. "Volume 1 provides the detailed information on the review, including the background to the detailed information on the criteria and issues that arose during the review. Volume 2 of the report provides Summary Reports on each of the shack areas" (Shack Site Freeholding Committee, 1994, p.9).

Among the information provided by the individual Summary Reports on each shack area it is the compliance with coastal hazard criteria in State Planning policy (except that the requirement for a 50 m setback was not applied). Tide and wave inundation together with susceptibility to shore erosion are the specific information provided in order to indicate the likely impact of flooding and erosion. Specific sites surveyed in the Northern Spencer Gulf were False Bay, Point Lowly West, Point Lowly North, Fitzgerald Bay South, Backy Bay/Fitzgerald Bay, Douglas Point South, Douglas Point North, Chinaman Creek and Weerona Island. Results of the surveys are described on section 3.7.4.

3.7 GENERAL VULNERABILITY

Given the complexity of circulation in the Gulf it is not possible to predict the changes that will occur with potential sea-level rise. For example, features such as Ward and Cockle Spit which deflect currents (see Appendix 1) may become completely inundated and thus tidal currents and circulation will be altered. Changes in the pattern of circulation could affect prawn larvae dispersion, trajectory of oil spills, salinity and temperature of the Gulf waters. A decrease in average recurrence interval for extreme events will affects areas of population concentration such as Port Pirie, Port Augusta and Blanche Harbour which are already subjected to flooding problems.

Other undeveloped but important mangrove and samphire areas will also need to adapt to changes in water levels. Also, the amplification of the tidal range towards the north of the Gulf, combined with the prevailing south and south-west winds will accentuate these effects. Further, changes in sediment distribution resulting from higher sea-levels could have implications for the ecologically important seagrass areas in the Gulf. The vulnerability of the area to the coastal hazards of oil pollution, changes in water temperature and ballast water are addressed below.

3.7.1 OIL POLLUTION

Oil spills can contribute sublethal levels of petroleum substances to the marine environment. This can have a number of adverse effects, including tainting of seafood, and the potential to cause detrimental histopathological changes to organisms (SOMER, 1995b, p.51).

A moderate but relatively destructive oil spill occurred off Port Bonython on Sunday, August 30, 1992. A collision of the tanker ERA and the tug Turmoil resulted in the rupture of the ERA'S starboard fuel tank and the spillage of 296 tonnes of marine fuel oil over a period of approximately 2 hours and 20 minutes. Three hundred birds were oiled, mostly cormorants (only five survived) and 100 hectares of mangroves were affected on the eastern side of the Spencer Gulf., to the south of Port Pirie (Zann and Sutton, 1995, p.48). The dispersal was not consistent with model predictions used by Santos but correlated better with models developed by Noye, Bills and Lewis at the University of Adelaide (See Appendix 1).

The slick made landfall on the following Tuesday evening as predicted by the Noye et al (1994) model while the SANTOS prediction was for it make landfall at Port Germein on Sunday evening and thus the landfall personnel were sent to that location. This highlights the risks of oil pollution in the area and the lack of information regarding oil slick trajectory.

From a study undertaken in November 1992 for the Environment Protection Council it appeared that oil had impacted on both sediments and mangroves along a 12 km stretch of the coastline during conditions of high tides and high on shore winds. Note that this was almost 12 weeks after the spill so the report attempts to infer the original degree of oiling. Oiling was largely limited to trunks and foliage on the outer mangrove fringe but heavily impacted the inner fringe areas, some 50 metres from the coastline. These areas formed a relatively thin band of oil, some 20 to 30 m in depth, running parallel to the shoreline (Wardrop et al, 1993, p. 4-1).

Of the 2000 hectares of mangrove swamp in the area it was considered that 3.9 ha of mangroves were heavily oiled. Moderately oiled areas covered an estimated 5.5 ha of swamp while lightly oiled areas covered about 70 hectares and are characterised by clean sediments and light to moderate oiling of mangroves. Also, there were thick depositions of oil on extensive seagrass mats. In some cases these were underlain by relatively non-viscous (i.e. fresh) oil. It was not possible to quantify the amount of oil in them, or the amount of residue which remains within them, or underlying them. However, the authors noted "that they constitute the main reservoir of residual oil within the swamp" (Wardrop et al, 1993, p4-3). At the head of Sixth Creek oil had penetrated tidal channels and extensive staining and tarry residues were evident on the samphire areas above these. Oil was restricted to the surface of the sediments with little penetrating below 2 cm depth.

Monitoring of other potential effects of the oil spill on birds, juvenile prawns, mangroves, with photo points of samphires and mangroves, benthic sampling for traces of hydrocarbons and seagrasses and associated fauna is still being undertaken to determine the likely effects and best methods of response given the risk of future spills in the Spencer Gulf. Interim results from these studies as of September 1993 show that the oil coverage of sediments and mangroves had remained largely unchanged except for a reduction in the amount of oil-soaked seagrass debris. While there had been a decrease of hydrocarbons in the surface sediments there was an increase in the size of the lightly oiled sediments suggesting a redistribution of oil. Defoliation of mangrove trees in the oiled areas increased relative to the initial survey but leaf damage had decreased on the moderately and lightly oiled trees.

One of the initial problems and hence the time lag in monitoring is that there is no monitoring included in the National Plan for oil spills and there was no single agency responsible for ensuring relevant monitoring was done. That is there was no contingency plan and no chain of command. Therefore, recommendations from the various reports include that those responsible for the oil spill should also be responsible for the costs of monitoring the effects on marine ecosystems and this should be included in the National Plan. Also, the new Environmental Protection Agency should be the appropriate body to co-ordinate monitoring and should maintain an emergency fund so a prompt response can be made.

3.7.2 Increase in Water Temperature

One of the impacts of climate change will be an increase in air temperature. In the relatively shallow waters of the South Australian Gulfs there is a pattern of water temperature fluctuations which respond rapidly to changes in the air temperature. From studies done in the Northern Spencer Gulf it has been shown that in the large shallow embayment (such as False Bay) water temperatures fluctuated through about half the range of air temperatures in the region (Ainslie R., 1988).

Although it is difficult to predict the full consequences of this it is extremely likely that biological change will occur. Increases in water temperature of 2-3°C can result in changes in the characteristics of the benthic communities, changes in dominate species, species number, numbers of individuals and changes to the fitness of individuals or populations to survive. This may be particularly relevant in the Northern Spencer Gulf where many communities are living at the upper limits of their temperature tolerance.

One investigation which compared the productivity's of seagrasses (*Posidonia sinuosa*) in similar depths of water but with differing water temperatures showed that the productivity of seagrasses in the warmer water was reduced in the summer months. Water temperatures in the shallow embayment of the Northern Spencer Gulf exceed 28°C which is the highest published temperature for the seagrasses of this genus any where in the world (Ainslie, R. 1988). The adverse effects of temperature on seagrasses has also been documented where regions have been artificially warmed by thermal discharge.

The Betatene plant at False Bay also identified the predicted increase in temperature as being of major concern as temperature is a critical factor in the survival of the organisms *Dunaliella salina* , from which the beta-carotene is extracted.

3.7.3 BALLAST WATER

The introduction of exotic pests and diseases via ship's ballast water is a potentially serious problem in Australia's marine environment. Around 55 species are known to have been introduced into Australia, largely via ship's ballast waters and on ship's hulls (Zann, 1995, p.64). Ships which presently use the SANTOS jetty discharge ballast water (which is likely to contain high concentrations of hydrocarbons) into an onshore treatment system and the final effluent is discharged into the Gulf at approximately 15 metres depth (A. G. Consulting Group, 1989b). While this treatment appears to be successful there remains the hazard of accidental discharge of ballast water before treatment has been undertaken.

Predicted warmer water temperatures and the decreased temperature differential between lower and higher latitudes will probably increase the chances of survival of animals and diseases transported in ballast water. This may result in an increased likelihood of the establishment of feral populations, particularly species with subtropical affinities in the Northern Spencer Gulf (Johnson et al, 1988).

3.7.4 SHACKS

According to the final report of the Shack Site Freeholding Committee, "it was evident the adoption of the current Coast Protection Board policy (see Chapter 5) for coastal erosion and flooding would permit the freeholding of only a small number of shack sites" (Shack Site Freeholding Committee, 1994). The Committee therefore, requested a review of all shack areas by the Coastal Management Section that disregarded the recommended 50 metre setback.

Cabinet endorsed the option of freeholding the shacks, even tough they would not conform with the flooding and erosion policy, with the requirement that before a freehold title will be issued "the lessee of any shack site must sign a legally binding agreement that indemnifies the Crown and Local Government against any future claim resulting from erosion or flooding". Also, "neither the State Government nor the Local Council should have responsibility for the funding of any required protection works now or in the future" (Shack Site Freeholding Committee, 1994, p.23).

Volume 2, part A, of the summary report address Spencer Gulf as region 3 of the study. The shacks surveyed on the Northern Spencer Gulf and the results with regard to the compliance with coastal hazard criteria of tide and wave inundation and the susceptibility to shore erosion (less the 50 m setback) are described below:

False Bay-1 shack site:
One shack and no report has been prepared.

False Bay-12 shack sites:
Three shacks just comply with tide and wave inundation while none comply with susceptibility to shore erosion.

Point Lowly West-30 shack sites:
All of the shacks comply with tide and wave inundation. Seven shacks in the group do not comply with susceptibility to shore erosion.

Point Lowly North-14 shack sites:
Seven shacks do not comply with both inundation and erosion criteria.

Point Lowly North B-11 shack sites:
All of the shacks comply.

Fitzgerald Bay South-8 shack sites:
None of the shacks comply.

Fitzgerald Bay South b-11 shack sites:
Eight shacks do not comply with tide and wave inundation and seven do not comply with susceptibility to shore erosion.

Back Bay/Fitzgerald Bay-6 shack sites:
All shacks comply.

Back Bay/Fitzgerald Bay1 B 2 shack sites:
Two shacks do not comply with tide and wave inundation and five do not comply with susceptibility to shore erosion.

Douglas Point South-11 shack sites:
Two shacks do not comply with tide and wave inundation and eight do not comply with susceptibility to shore erosion.

Douglas Point South B-1 shack site:
It does not comply with both criteria.

Douglas Point North-4 shack sites:
All shacks comply with tide and wave inundation and two do not comply with susceptibility to shore erosion.

Douglas Point North B-36 shack sites:
Two shacks do not comply with tide and wave inundation and most comply with susceptibility to shore erosion.

Blanche Harbour was not assessed as part of the review.

Chinaman Creek-4 shack sites:

None of the shacks comply.

Weeroona Island-19 shack sites:
Half would comply with tide and wave inundation and none would comply if existing protection were not taken into account. See Photo 1.

Photograph 1: Shack development in the coastal zone, Weerona Island.

3.8 SELECTION OF SPECIFIC STUDIES SITES

To enable a more detailed vulnerability assessment to be conducted, four case study areas within the Northern Spencer Gulf have been selected based on a number of coastal management issues found in each of the locations.

Port Pirie and the surrounding environs have been selected as the area is subject to coastal flooding. On the north western margin of Port Pirie, several levee banks have been constructed to protect the township from flooding and further protective works are now being undertaken. Similarly, Port Augusta located at the head of the Gulf also has a tidal flooding risk. While at present there is the potential for water to just enter the city centre with a 1 in 100 year peak tide level of 2.85 metres AHD (Coastal Management Section), a projected greenhouse sea-level rise of 0.3 metres by 2050 for a 1 in 100 year tide level would inundate around half of the city centre (Lange Dames & Campbell Aust. Pty. Ltd., 1991a).

Blanche Harbour was selected to assess the vulnerability of the linear shack development in the area. A management plan for the area has been approved that will allow freeholding of the shacks. However, this is in conflict with the Coastal Areas Plan Amendment Report and thus will create inconsistencies for development within the coastal zone of South Australia.

False Bay was selected as it is an important conservation area surrounding by industrial development, with BHP to the west, Port Bonython gas refraction plant to the east and salt water retention ponds to the north. False Bay has been identified as an important prawn nursery area.

Each of the study areas is exposed to different physical factors just as prevailing winds and wave climate. They are also subject to varying coastal hazards such as flooding, pollution, industrial and urban development. These factors have been outlined in the table below.

Table 3.1: General physical description of the four selected study areas. (source: Adapted from Coastal Management Section)

SITE	1:50 ARI (m AHD)	1:100 ARI (m AHD)	WAVE SET-UP ALLOWANCE (m)	WAVE RUNUP ALLOWANCE (estimated average value-m)	PHYSICAL FEATURES
FALSE BAY	-	2.75	0.15	0.5	an open bay, on the west side of the gulf, facing south and under the impacts of prevailing south winds
THE CITY OF PORT PIRIE	2.64	2.85	0.2 (combined)		situated on the sheltered banks of the Port Pirie River, on the east side of the gulf, on a flat area subject to flooding and surrounded by tidal creeks with extensive mangroves and samphires habitats
THE CITY OF PORT AUGUSTA	2.90	3.15	0.2 (combined)		located at the head of the gulf, where tides are the highest of the area due to the gulf's funnelling effect, lying on flat ground formerly occupied by mangroves and samphire habitats, and highly subject to inundation
BLANCHE HARBOUR	-	3.05	0.3 (combined)		a 20 km sandy beach coastline, situated south west of Port Augusta, developed by 280 shacks just adjacent to an aquatic reserve

CHAPTER 4: SELECTED STUDY SITES ANALYSIS AND ASSESSMENT: STAGES 1 & 2

The four study areas, False Bay, Port Pirie, Port Augusta and Blanche Harbour have been investigated in terms of their bio-physical and socio-economic characteristics. Various techniques have been employed to determine the vulnerability of the impact zone. As a result an assessment has been made of the general coastal hazards and areas that would be vulnerable from potential climate change impacts.

4.1 FALSE BAY

INTRODUCTION

False Bay was chosen as one of the specific study sites in the Northern Spencer Gulf (Figure 1.3) due to its conservation value and economic characteristics. The shape of the bay combined with the prevailing currents have created an area of relatively sheltered water which then acts as a nursery ground for many of the commercial (and other) marine fauna in the area. However, these same characteristics also make it vulnerable to pollution emanating from BHP Whyalla which is located to the west of the bay. It is also just east of the Port Bonython gas refraction plant so it is vulnerable to the hazards of oil spills and discharged ballast water. Embankments to the north of the bay are used for the ponding of salt water and limit the inland retreat of vegetation in the face of sea level rise and also impede the flow of freshwater to the mangroves. The area is important from the perspective of Aboriginal Heritage as the song cycles of several tribes pass through this area.

4.1.1 PHYSICAL CHARACTERISTICS

False Bay is an area of coastline which extends some 11 kilometres from Black Point in the east to within 2 kilometres of Whyalla in the west. The bay is south facing and hence open to the prevailing southerly winds. The associated beach is 9 kilometres long and at low tide it is up to 2 kilometres wide as shown in Figure 4.1. It is the most expansive sandy beach in the Whyalla region. It features an extensive low lying coastal area underlain by shallow sediments of the St Kilda Formation. The beach substrate varies from sand to cobble, becoming more rocky towards the rock platform and boulder overlay at Black Point. Extending to the west the upper intertidal zone is characterised by cobble and sand substrate. At the high tide mark, mud sediments associated with the mangroves and seagrass litter are evident. Fine sand dominates the middle and lower intertidal zone. Mangroves are present in the western intertidal area that is protected by the BHP effluent ponds. A small, low and generally sparse

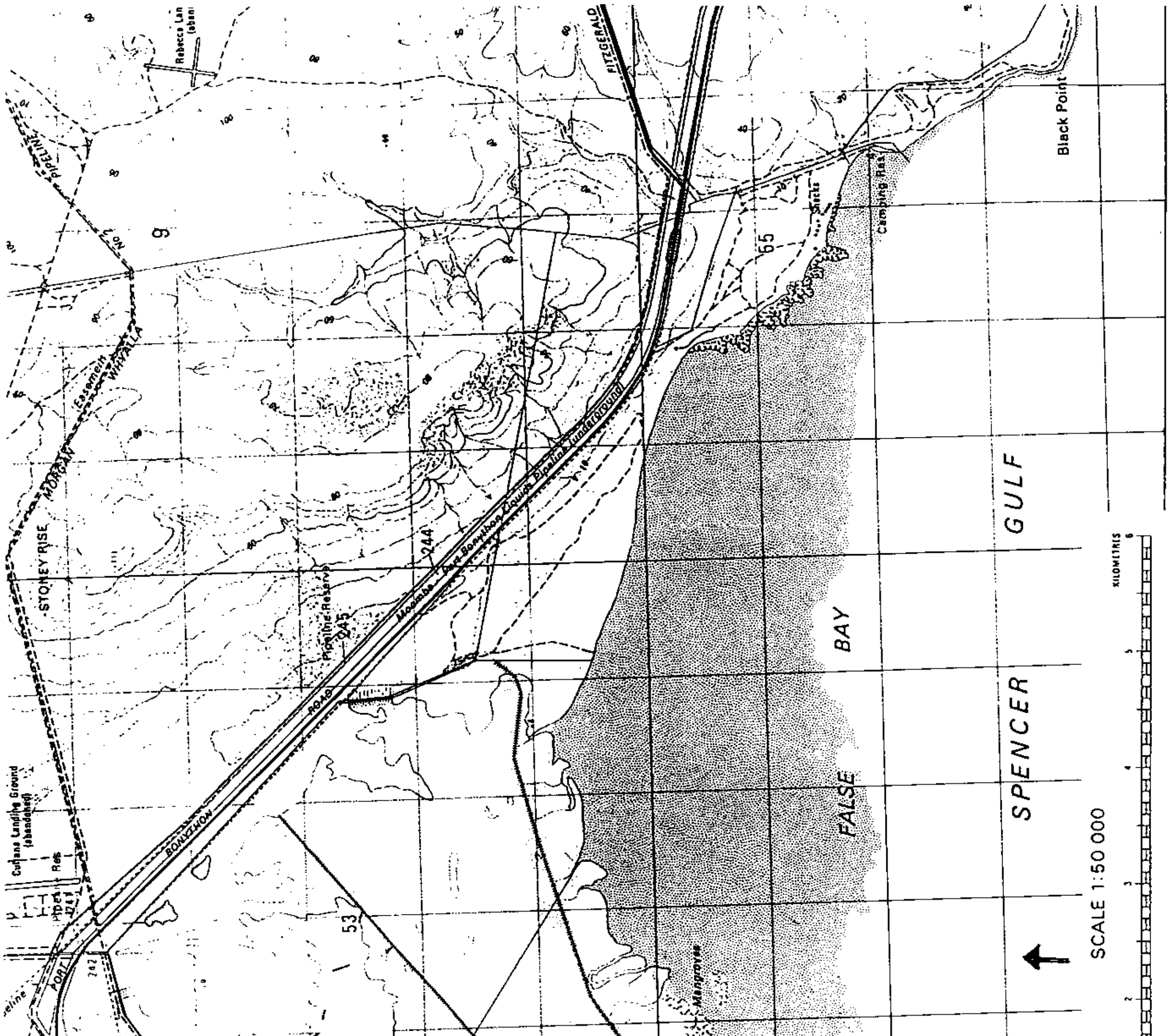


Figure 4.1: False Bay

stand of mangroves occupies the soft sandy sediments adjacent to the saltworks. There is another dense patch of mangroves present opposite the Beta Carotene plant extending from the levee bank to the intertidal zone.

4.1.2 CLIMATE

Whyalla has an average annual rainfall of 270 mm and an annual evaporation rate of 2400 mm/year. There are prevailing southerly sea breezes in summer and light northerlies in winter (Gostin et al, 1984). The annual average wind speed at Whyalla is 3.2 m/s (Mines and Energy S.A., 1994).

Tides

The National Tidal Facility estimates a maximum height for a storm event of 2.69 metres. Figures for False Bay give a 100 year average recurrence interval of extreme tides predictions of 2.75 m AHD and wave allowances are estimated at 0.65 m. (Coastal Management Section). In addition an allowance must be made for sea level rise. Given the predicted sea-level rise of 18 cms to 2030 and 44 cms to 2070 used in this report an extra allowance of this amount would need to be added to the above figures when considering the location of any new industry in the area.

There is a maximum spring tidal range of 3.06 metres at Whyalla (Noye, 1984).

Wave Climate

The wave climate in the Northern Spencer Gulf consists of short period seas. The wave climate off Stony Point is dominated by wind-generated sea waves. Studies have shown that it is impossible for ocean swell to penetrate Spencer Gulf as far as Stony Point. The direction of the most persistent and strongest winds is south to south-west and the longest fetches also occur from this direction. Storm surges in the Northern Spencer Gulf are associated with the more severe southerly storms. Storm debris occurs on the foreshore about 1 metre above normal wave run-up levels.

Littoral Drift

There is a net northerly movement parallel to the coast which is estimated to be 2,500 cubic metres per annum at Whyalla (Assessment Report, Whyalla Boat Harbour). This northerly direction of littoral drift has resulted in the accumulation of a wide sand bank at the top of False Bay (rates unkown) which extends out into the bay for more than 2 kilometres. It is therefore expected that suspended material from the BHP steelworks at Whyalla will be carried by the same wave and wind action and accumulate on the False Bay shoreline.

4.1.3 GEOLOGY

The surface geology is shown in Figure 4.2. The Tent Hill Formation quartzite form the most prominent landform, the Rebecca Plateau. It is divided into several members. The Corraberra Member's shales are poorly exposed as they lie beneath the resistant surface of the youngest Simmens Member. The Tent Hill Formation occurs as outcrops in the low cliffs west and north of Lowly Point. Hence, this area will be less likely to suffer from erosion as a result of sea-level rise. The Tregolana Shale underlies the Quaternary cover of the Tregolana Plain. A period of formation of siliceous duricrust and laterization in the early Tertiary period resulting in the Tertiary mantle are largely responsible for the general topography of the region. More recently, various thin sedimentary units of Quaternary age have been deposited which include:

- Coastal sediments of the St Kilda Formation
- beach sands and coastal dunes
- alluvium of drainage lines and the Tregolana Plain
- seif dunes and associated sand accumulations
- near coastal sediments such as emergent beach gravels and offshore bars.

(A G Consulting Group, 1989b, pp 59-60).

Groundwater

Groundwater is only available in small quantities and is saline. It is thought that it follows the flow of the ephemeral surface waters towards the coast from a water divide along the Rebecca Plateau from north-west to south west. Discharge is believed to occur to the wetlands and nearshore zone of False Bay. No springs have been recorded in the area (A G Consulting Group, 1989b, p.160).

The area is outside the Pirie Torrens sedimentary basin as the western boundary is the Precambrian bedrock of the Tent Hill Formation. Available catchments for groundwater recharge are small and it is suggested that recharge of the underground aquifer does not occur annually but only after extreme rainfall events.

Although groundwater in the area is not a potential resource of the region the fact that it discharges to False Bay makes is part of the water balance of the region and hence an environmental resource.

Surface Drainage

There are no permanent streams in the region. Flow is intermittent in response to seasonal rain. Most streams drain into the sea, except those within the Tregolana Plain where drainage is interior. The drainage of the

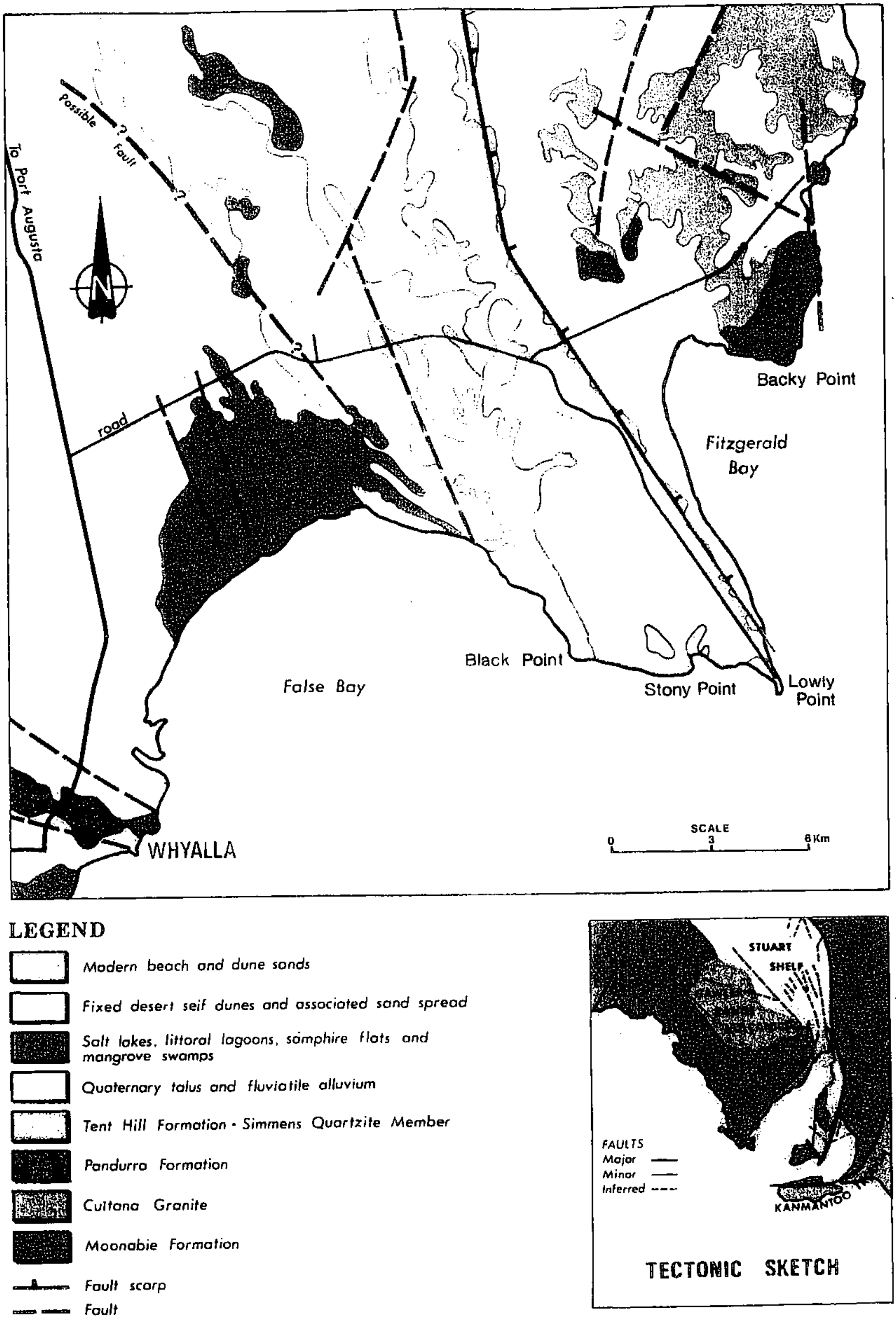


Figure 4.2: Surface Geology, False Bay (source: A G Consulting Group Pty Ltd, 1989)

Tregolana Plain is centripetal with the streams converging on two small salinas, though in the west some of the streams die before reaching either the sea or the salinas (Social and Ecological Assessment (SEA), 1981a, p124).

4.1.4 VEGETATION

False Bay lies on the Tregolana Environmental Association which is 54,000 ha of undulating plain with occasional low dunes, salt pans and tidal flats, chenopod and samphire shrublands and mangrove flats. There are stands of mangrove swamps as shown on Figure 4.1 at False Bay but these are not comparable with the stands on the eastern side of the Gulf.

On the northern region of the sand flats Samphires (*Halosarcia sp.),* Saltbush (*Atriplex cinera, A. paludosa* and *A. vesicaria), Maireana* sp., *Rhagodia spinescens,* Iceplant (*Mesembryanthemum crystallinum)* and Pigface (*Disphyma crassifolium sp. clavellatum)* are present, particularly in the elevated areas but are sparse and dry over the southern sections. Further south, *Halosarcia sp.* again becomes dense, in association with *Sarcocornia,* and *Threlkeldia diffusa. Maireana oppositifolia, wilsonia humilis* and *Frankenia pauciflora* become more common in the southern section towards the low, narrow fore dune. *Sarcocornia* dominates sediment close to the mangroves in the west (A G Consulting Group, 1989b, p.91).

A low shrubland of Tea Tree (*Melaleuca lanceolata)* and Acacias (*A. oswaldii, A. ligulata* and *A. papyrocarpa)* extend over low sand ridges in a southeast-northeast direction in the east of the bay. There is a varied but sparse understorey which includes Sea Rocker (*D. revoluta),* Coastal Daisy Bush (*Olearia axillaris), Leucopogon parviflorus* and *Myoporum* sp. with saltbush and samphire species towards the sea. *E. socialis* , a tall shrubland, can also be found in the east of the bay. This area is identified by the Whyalla Council as the False Bay woodland and is of conservation significance. On the western flats, the Western Myall (*Acacia papyrocarpa)* forms a low woodland formation with an understorey of Bladder Saltbush (*Atriplex vesicaria)* and Bluebush (*Maireana pyramidata)* (A G Consulting Group, 1989b, p.92).

4.1.5 MARINE FAUNA

Figure 4.3 illustrates the marine biological features of the region. Seagrasses are the most important component of the system in providing shelter and a primary source of productivity within the food chain. The dense leaf canopy reduces the current velocity near the sea floor providing a sheltered environment. Fertilised eggs and larvae drift northward into the shallow, nutrient rich seagrass and mangrove habitats of the Upper Gulf, such as False Bay and remain there for up to two years.

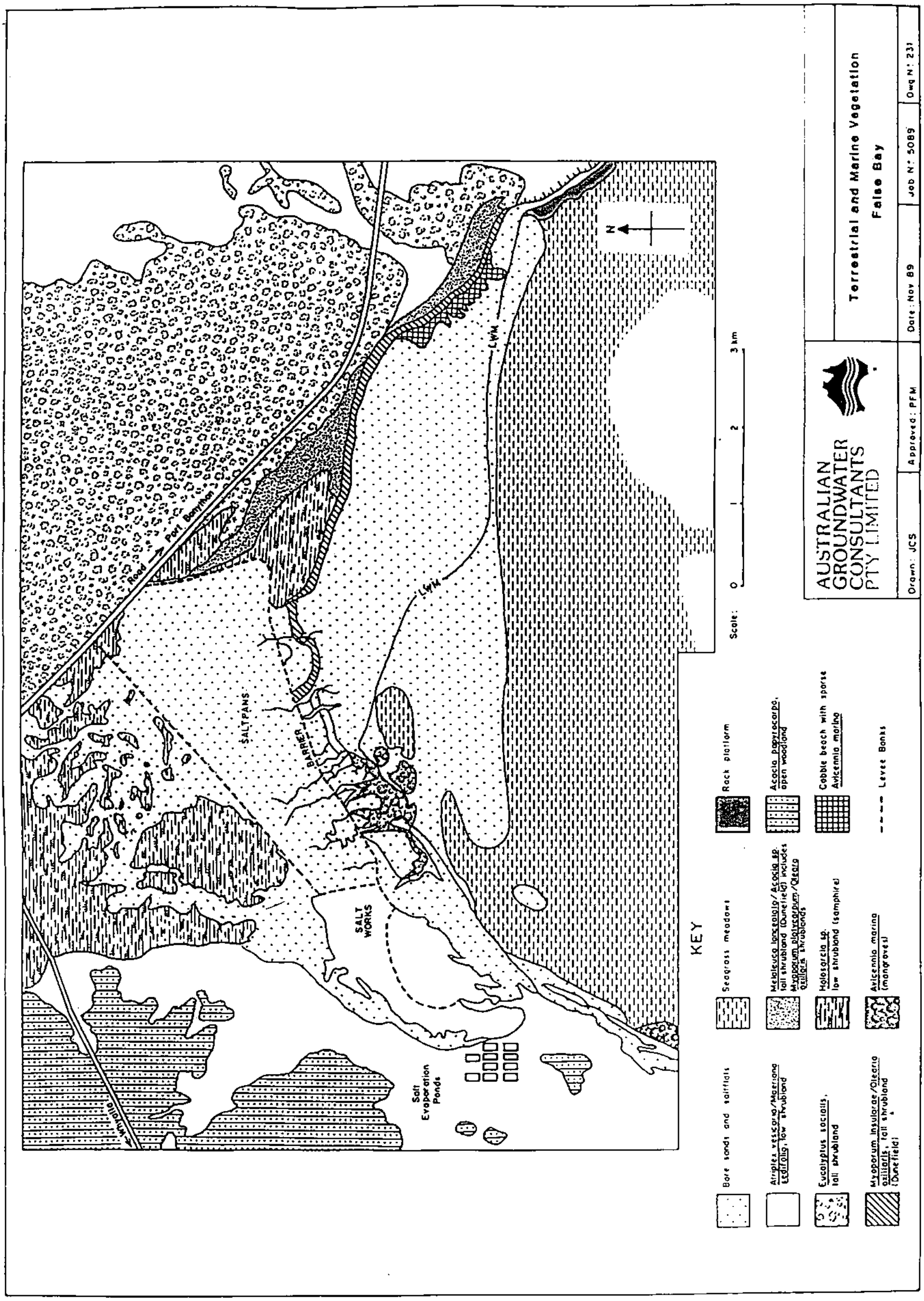


Figure 4.3: Marine Biological Features, False Bay (source: AG Consulting Group, 1989b, p. 90).

Garfish (*Hyporhamphus melanochir*) graze on the algal epiphytes and copepod crustaceans that are found on the surface of the seagrass leaves. They also lay their eggs within the *Heterzostera tasmanica* seagrass beds. Calamari (*Sepioteuthis australia*) also attach their eggs to the Zostera seagrasses. While the juvenile King George Whiting (*Sillaginodes punctatus*) feed on the polychaetes and crustaceans which are part of the infauna of the seagrasses. Beyond the depth of 10 m filter feeding benthic organisms, including the razor shell *Pinna bicolor*, hammer oyster *Malleus meridianus*, sponges, ascidians and cnidarians are found. The main component of their food is probably the suspended organic matter originating from the sea grass meadows.

The shallow waters of False Bay are a known nursery area for the Western King Prawn (*Penaeus latisulcatus*). Spawning occurs in the summer months (November to March) in the open waters of the Gulf with major grounds between Fairway Bank and Eastern Shoal. When the eggs are hatched, they pass through several larval stages in the open sea. These prawn reach the shallow waters as small post-larvae and may remain there for 9-12 months (SEA, 1981a, p.182).

Mathematical models have been used to simulate the dispersal of prawn larvae in the Spencer Gulf. Noye et al (1992) have produced a model that takes account of larvae position within the water column as they are known to be photonegative. The influence of tidal currents on larvae dispersion is then examined by considering their effect on larvae hatched at the peak spawning times of 15 December 1988 and 15 February 1989. Wind effect is taken into account looking first at the typical general south to south-east wind which occurs in summer when spawning occurs and secondly at the situation if NNE along the axis of the Gulf is imposed on the tides. In the northern region, Yarraville Shoals is the main breeding grounds and the model predicts that after 21 days that 60% of coastal settlement will occur on the north west coast while 40% will occur on the north east coast. This confirms the importance of these nursery areas.

When it is considered that the prawn fishery in the Spencer Gulf is worth up to $20 million p.a., with catches over the ten years 1981-1991 averaging 1.6 -2.3 thousand tonnes conservation of such environments is of considerable importance to the South Australian economy (Dames and Moore, 1991, p.92).

4.1.6 LAND USE

False Bay is used little for recreational purposes except in the far eastern sector. The main reason for this is lack of general access to the area. However, there are several shacks in the east on the dune area adjoining the bay.

BHP hold the mining lease for the western section of False Bay. Part of this area is leased to Pacific Salt which operate a salt extraction industry. A beta-carotene plant, Betatene, was established in 1985 to the east of the salt works and utilises waste water from BHP. A levee bank, approximately three metres high is used to contain the salt water and beta carotene ponds and extends approximately 9 kilometres along the intertidal area of False Bay.

The area to the north-east of False Bay has been zoned for industrial development and a Whyalla Investment Park has been investigated for environmental and other constraints. At present SANTOS operate a port and terminal facility for hydrocarbons extracted from the Cooper Basin at Port Bonython which is located to the east of False Bay. However, this has increased the vulnerability of False Bay due to ballast water discharges and oil pollution. These issues are addressed below.

A titanium dioxide plant has been proposed for the area north of False Bay, with an Environmental Impact Statement completed for the development (Dames and Moore, 1991). However, there are no plans to proceed with the development at present. As the site is 10-23 metres above sea level any predicted sea level rise is not expected to put the proposal at any risk.

The Fitzgerald/False Bay Management Plan produced by the Department of Lands with the City of Whyalla (1988), has identified the False Bay woodland area in the eastern section of False Bay as an important conservation area. As such no development will be allowed in the False Bay woodland. Camping is prohibited and vehicle access to sensitive environments is being restricted. The plan also suggests promoting the significance of the area to ensure greater public compliance with the management objectives.

To the north-east of False Bay and extending along the western shore is the Cultana Army Reserve as illustrated in Figure 3.4.

4.1.7 HERITAGE

Aboriginal

The area to the east and west and including False Bay is of Aboriginal cultural heritage significance. False Bay is within the traditional area of the Pangkala people. The area from Lowly Point to Whyalla (which includes False Bay) is part of the aboriginal Dreamtime journey of the Moon, the Seven Sisters (Pleiades) and the Rainbow Serpent. The Adnjamathanha people from the Flinders Ranges also have an interest in the area as it is also relevant to their song cycle which was an integral part of their initiation ceremonies which ceased in 1947-48. The Wiljera song cycle of the Kokatha people from the Port Augusta region also passes through this area (SEA, 1981b, p.251).

Figures 4.4 and 4.5 show the path of the Pangkala Mythical Journeys and the Adnjamathanha song cycle(SEA, 1981b, p249 & 250,).

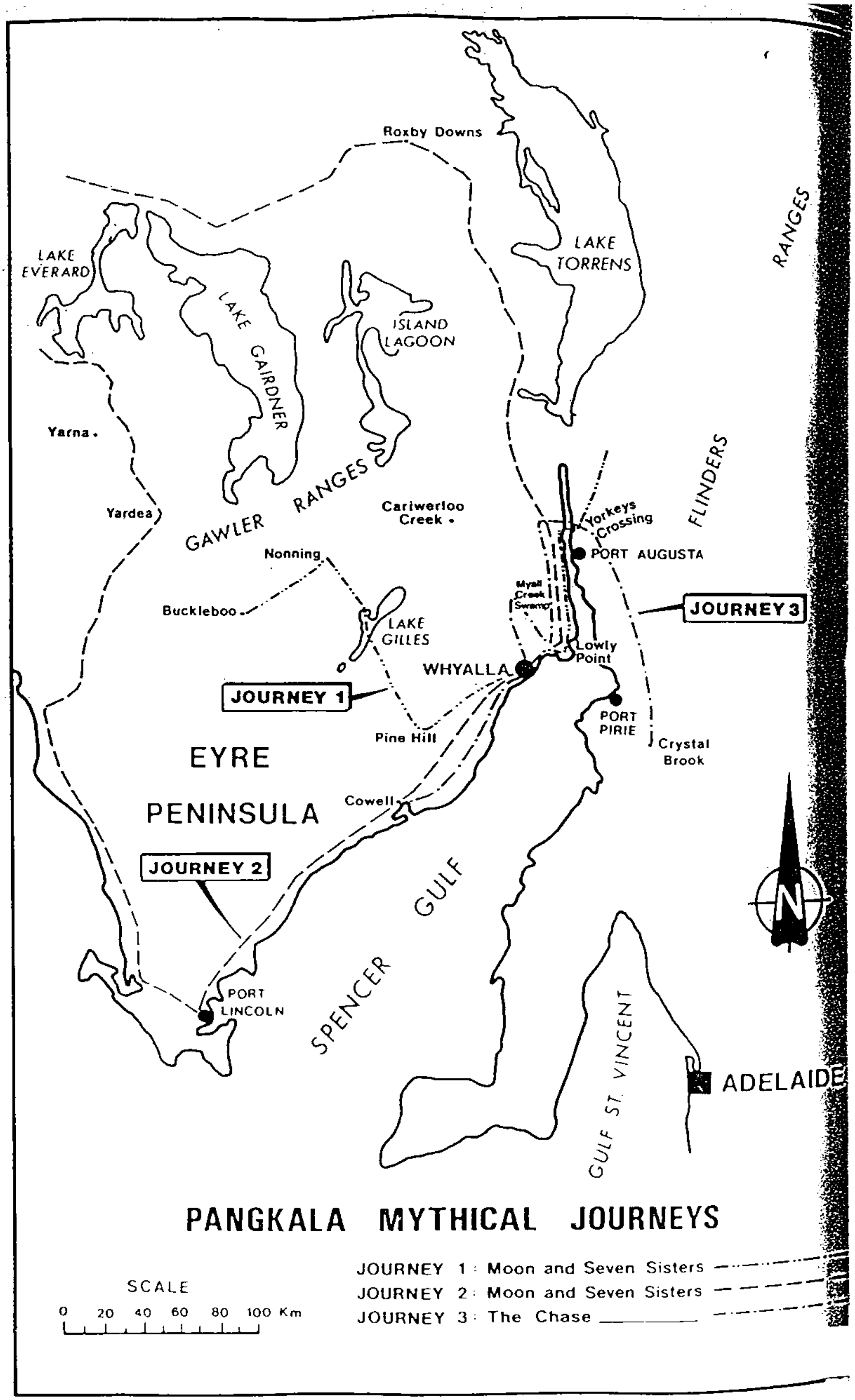


Figure 4.4: Pangkala Mythical Journeys. (source: SEA, 1981b, p. 249).

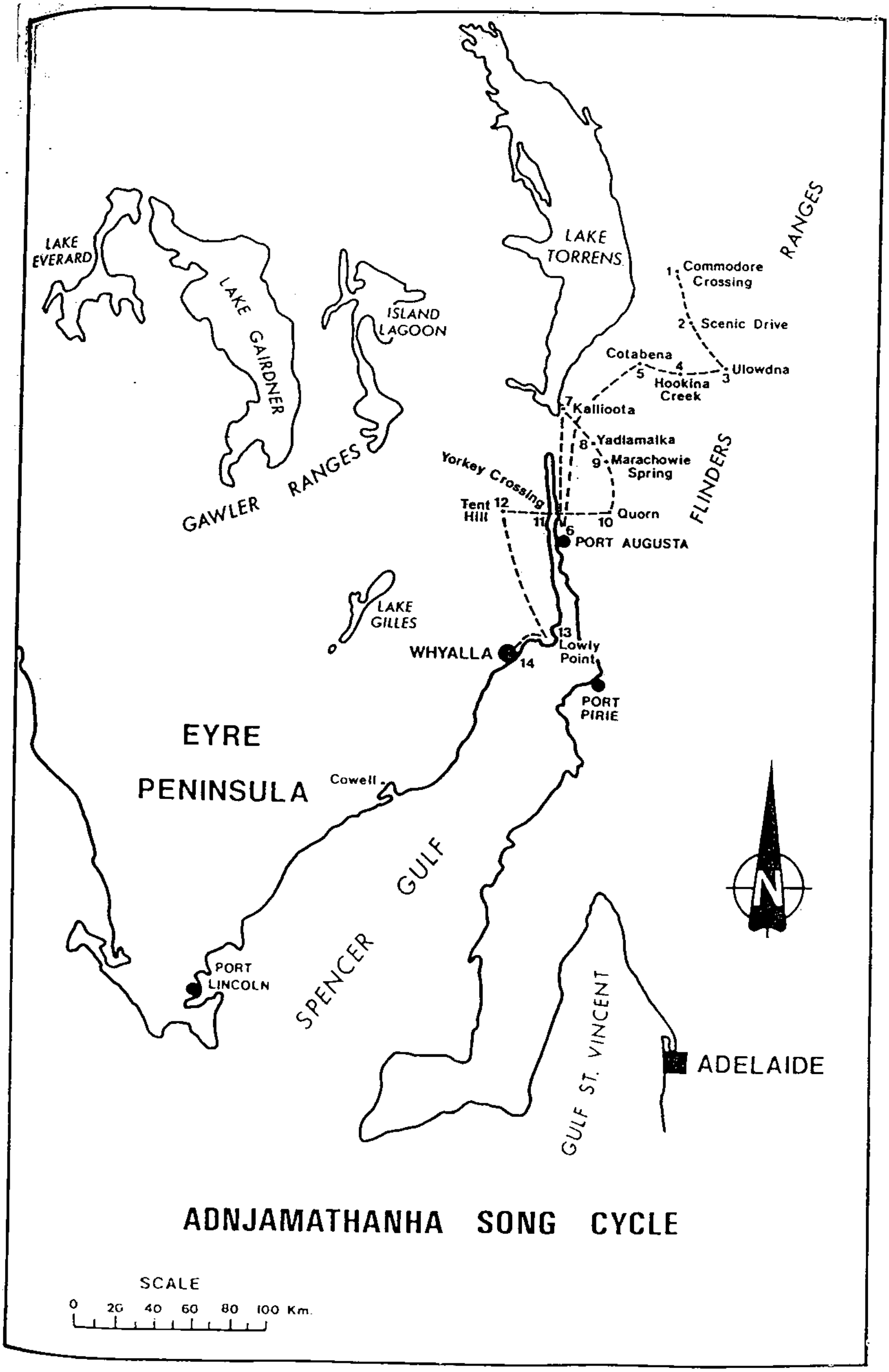


Figure 4.5: Adnjamathanha Song Cycle. (source: SEA, 1981b, p. 250).

European

The closest site of significant European heritage is the lighthouse at Lowly Point built in 1883 and two cottages built for the lighthouse keepers in 1887. It is thought the complex is a well-preserved example of the functions and livelihood of nineteenth century Australian lighthouses and lighthouse keepers. The lighthouse itself retains its old light machinery in working order. The lighthouse is listed as part of the National Estate and is also on the Classified List of the National Trust (SEAa, 1981, p. 253). The lighthouse was purchased by the Whyalla City council in April, 1995 and will be recommissioned as a tourist attraction.

4.1.8 DELINEATION OF THE IMPACT ZONE

While it was not feasible to obtain detailed contour information for the whole of the Northern Spencer Gulf the opportunity did arise for aerial photography and subsequent mapping for part of the study area in False Bay. BHP undertakes regular aerial photography for stock assessment and they agreed to undertake this work for the western section of False Bay where there were existing ground controls. The purpose of the exercise was to determine how useful the information would be in assessing the vulnerability of this area.

Work carried out by BHP Engineering and the associated costs were as follows:

Targeting of existing ground control	\$1,100
Aerial Photography. Colour photography at scale 1:8 000	\$1,200

Two runs total 13 frames, including supply of one set of prints

Mapping	\$3,200

Mapping of specified area defined by a 40m grid of spot heights and breaklines. Spot heights accurate to 0.1m to 0.15m. Contours generated at 0.5m interval. Data supplied on 2 A0 sheets at scale 1:5000 and in DXF digital format.

Copies of photographs were supplied prior to the commencement of mapping to allow the required area to be specifically defined. The photographs were subsequently used for groundtruthing on a further field trip to False Bay, especially for the location of mangroves and the interruption of natural tidal flows due to the levee banks of the salt works and beta-carotene plant.

The maps confirmed that the embankments would impede the retreat of mangroves and samphire vegetation. It was noted in areas with the typical coastal vegetation the elevation was higher than the areas of mangroves where tidal inundation occurs.

The digital information was transferred to an Arc-info system and a map (Figure 4.6) produced that outlines the 0.5 and 1 metre contours. The 100 year average return interval tidal height for False Bay is 2.75 metres and therefore the area between the 0 metre and the 3 metre contour has been shaded. To illustrate the effect of a 50 cms sea level rise, the area between the 3 metre and the 3.5 metre contour has also been highlighted in Figure 4.7. Due to the effect of the existing embankment the only area that would be inundated in the latter case is the western section of the bay in front of the salt works. However, in such a situation the mangrove areas would be subject to higher water levels which may cause death from drowning as there is no possible landward retreat option. The other complexities of sea-level rise would also effect False Bay such as a change in the tidal regime and the effect of increased storms to which the Bay is particularly vulnerable given that it is faces the prevailing southerly storm direction.

While detailed information has been obtained using this methodology due to the expense it would not be recommended for general CVA but only is cases where particularly sensitive environments are to be assessed.

4.1.9 HAZARDS

Flooding and Sea Level Rise

The construction of the levee banks for the salt works and beta-carotene ponds provide protection for these industries against sea level rise. However, they have interrupted the tidal flow in the intertidal channels in the areas which are colonised by mangroves. They have also halted the free flow of terrestrial runoff to the area which has implications for the salinity and supply of nutrients to the mangroves (Harbison, 1980, p.48). These levees do increase the vulnerability of the mangroves to sea level rise as they limit the landward migration of the species.

Pollution

The general northerly direction of littoral drift on the western side of the Gulf which results in prawn and fish larvae being deposited in False Bay has also been identified as a factor in the degree of metal enrichment of the sediments of False Bay from the point source (BHP) at Whyalla (A G Consulting Group, 1989b, p119). Very high concentrations of metals have been recorded in the marine and estuarine sediments near Whyalla.

BHP at Whyalla discharges the largest volume of chemically contaminated effluent into South Australian waters. Figure 4.8 demonstrates the general distribution of metal enriched sediments in the Northern Spencer Gulf (A G Consulting Group, 1989b, p117). The pollutants of greatest concern are zinc, iron from the blast furnace and nutrients (900kg/day of ammonia nitrogen and albunimoid nitrogen) from the coke ovens (Harbison and Wiltshire, 1993). Waste water containing metal sediments

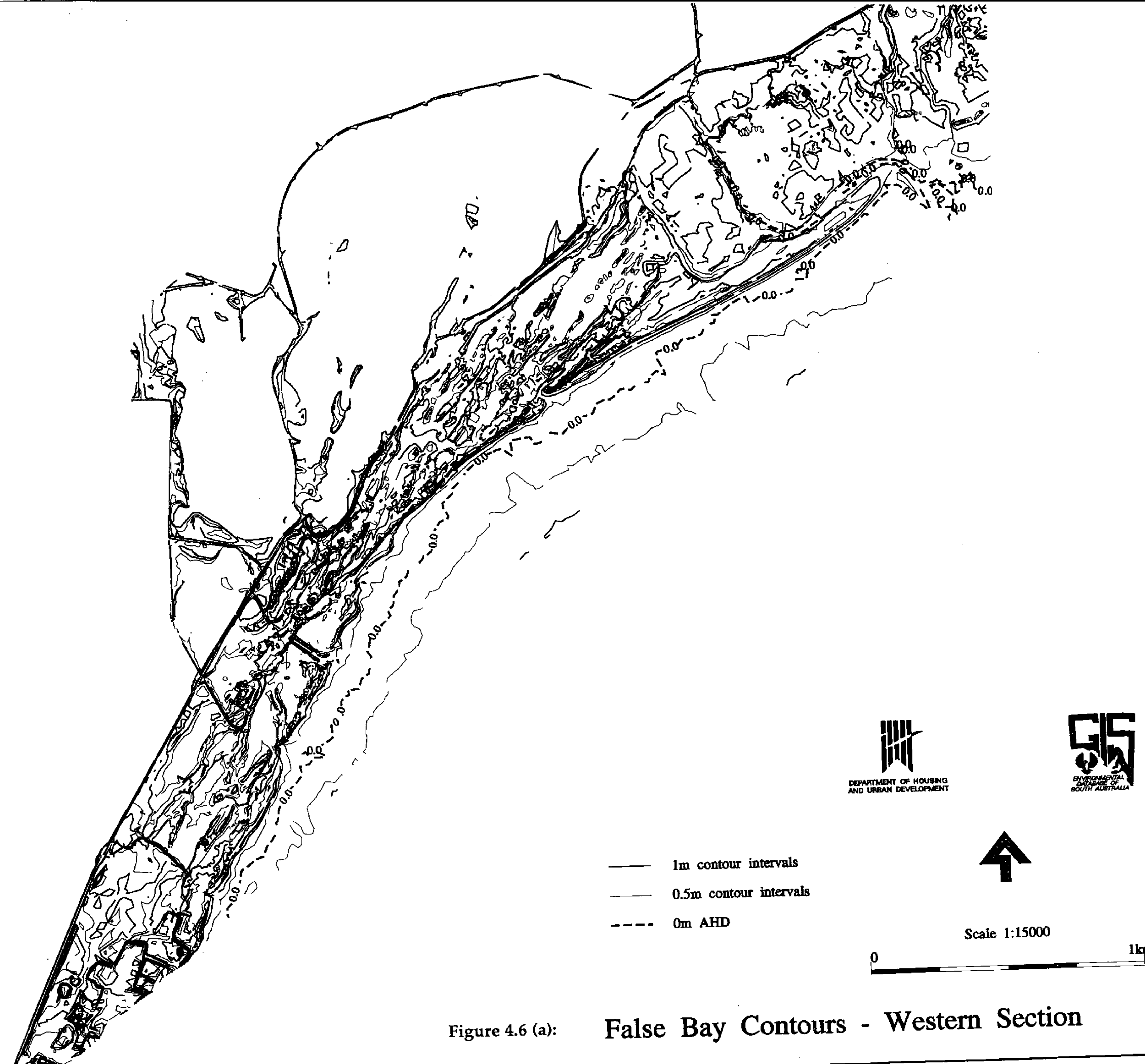


Figure 4.6 (a): False Bay Contours - Western Section

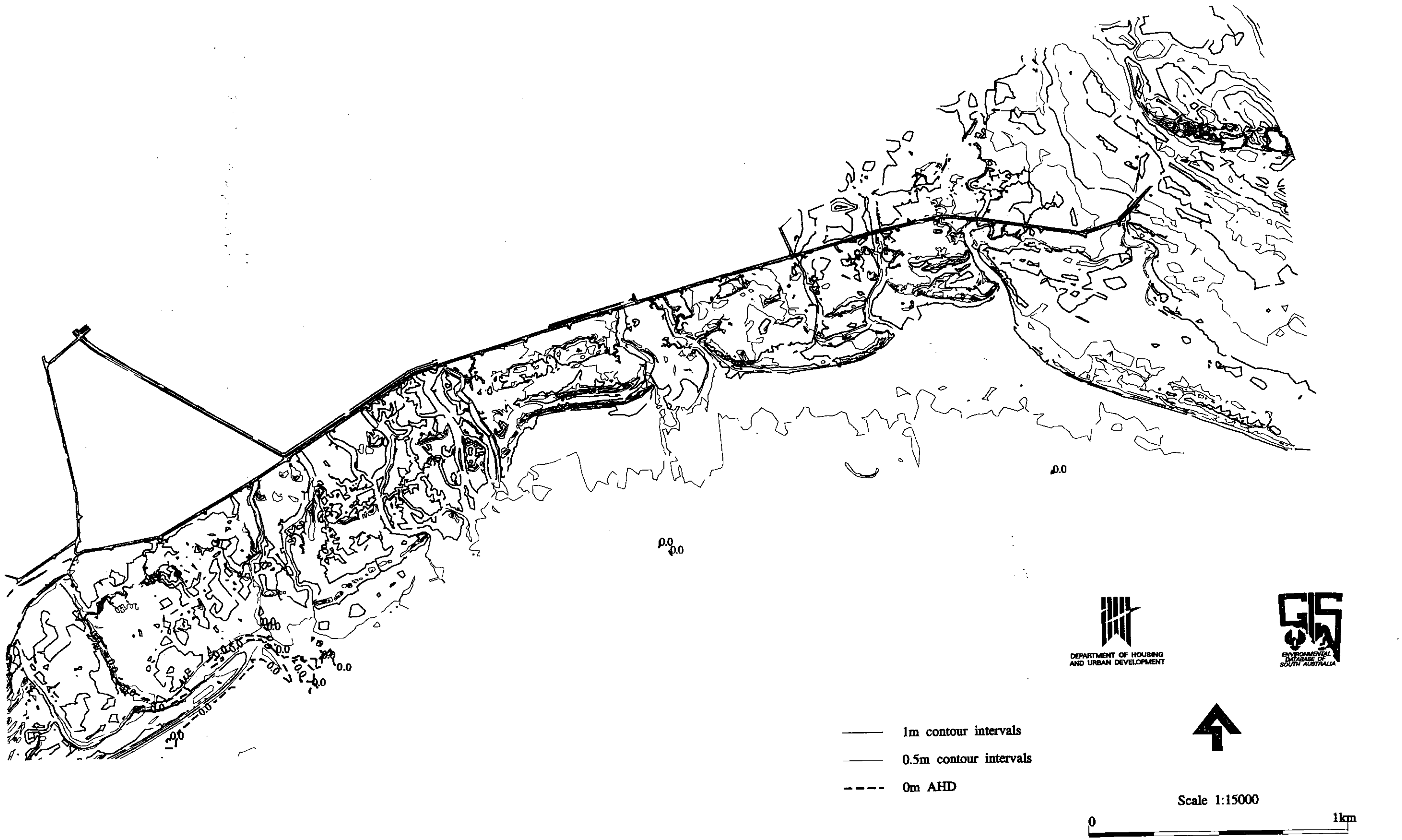


Figure 4.6 (b): **False Bay Contours - Eastern Section**

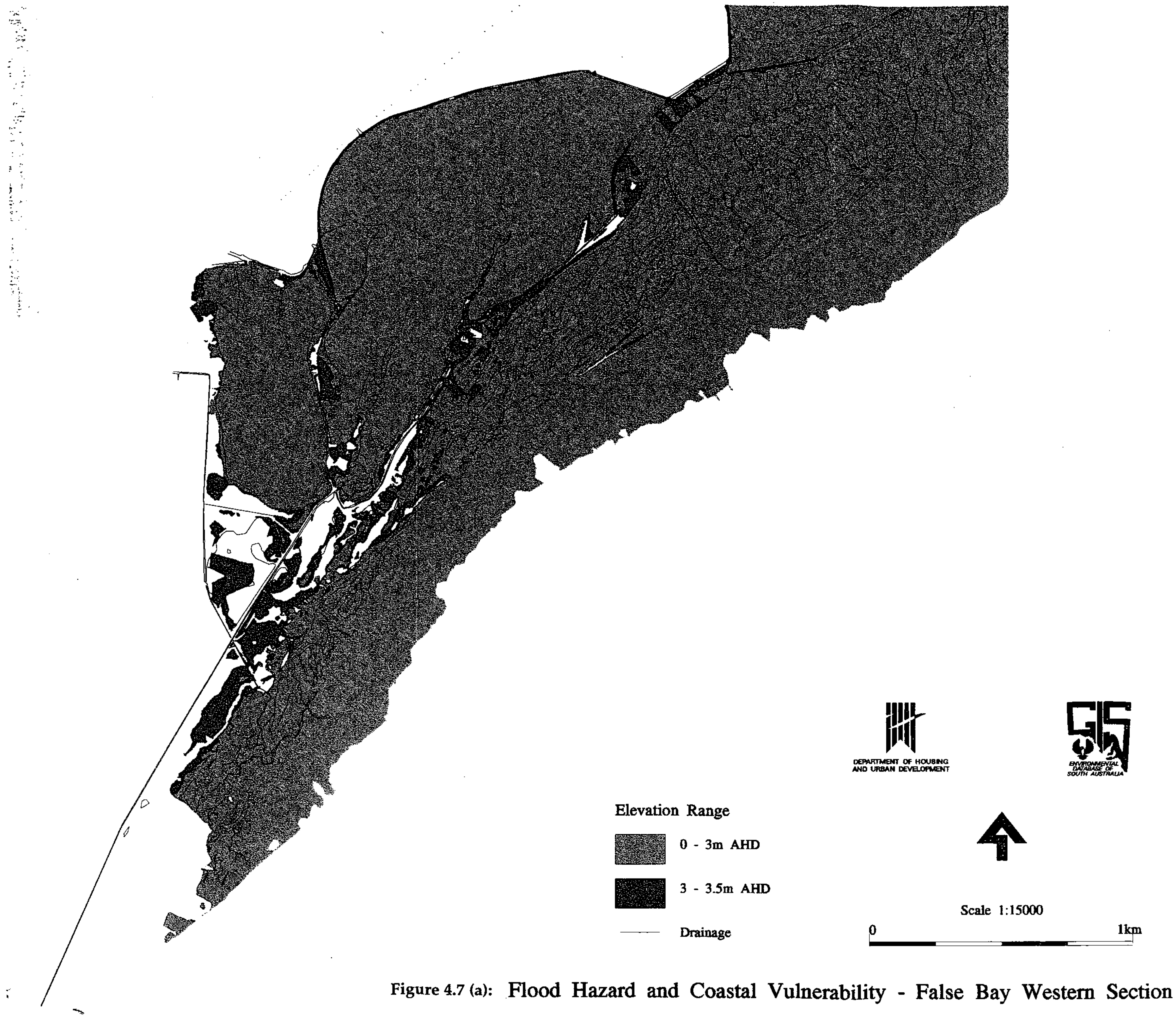


Figure 4.7 (a): Flood Hazard and Coastal Vulnerability - False Bay Western Section

Figure 4.7 (b): Flood Hazard and Coastal Vulnerability - False Bay Eastern Section

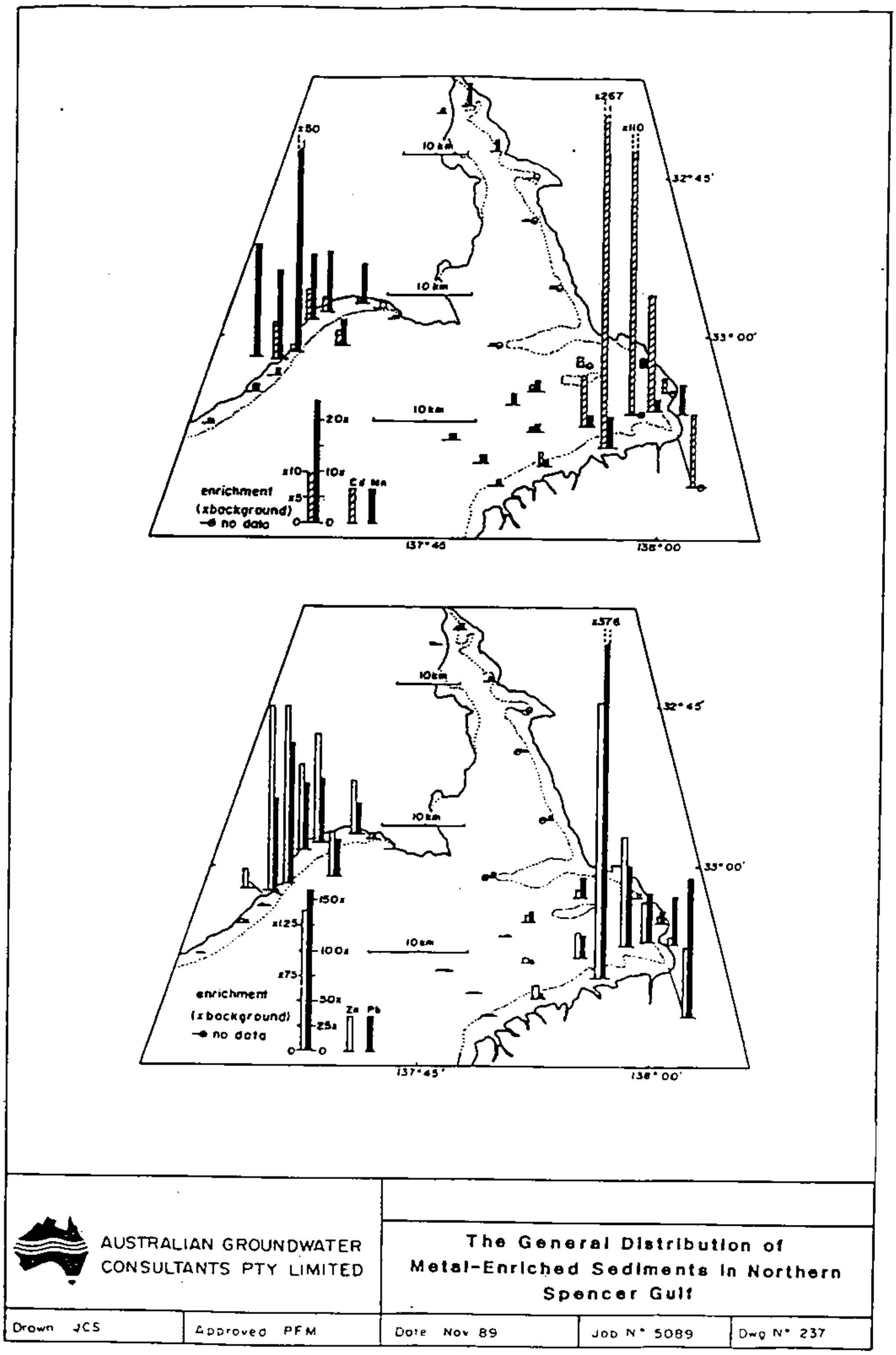


Figure 4.8: The General Distribution of Metal Enriched Sediments in the Northern Spencer Gulf. (source: A.G. Consulting Group Pty. Ltd. 1989 b)

from the blast furnace go through a series of settling and aeration ponds before being discharged to an area of natural tidal wetlands. Nutrient waste water from the coke ovens is also discharged into this area after being channelled through the coke oven ponds. It is known that high levels of nutrients increase epiphytic growth on seagrass leaves and attenuates the light reaching the leaves which can contribute to loss of seagrass. Approximately 500-1000 ha of seagrass has been totally lost in False Bay, and another 500-1000 hectares has been significantly degraded (Harbison and Wiltshire, 1993). Given the importance of the habitat provided by the seagrass meadows at False Bay, this discharge is a potential hazard. Loss of seagrass may also lead to increased erosion in the area as the benefit of the vegetation in baffling wave action would be reduced. It is suggested by Harbison and Wiltshire (1993) that the high turbidity levels that now exist at False Bay are a result of seagrass dieback and sediment destabilisation. This may place additional stress on the remaining seagrasses.

The mangrove swamp provides optimum conditions for the accumulation of metals. However, if climatic and tidal conditions favour the release of these metals (which would occur when there is low salinity, high temperature and low pH after summer rains) the marine organisms could be endangered by the toxic metals becoming available from the sediments (Harbison, 1980, p.113). There is little known about the effects of the heavy metals discharged from BHP on the fauna of False Bay. However, high concentrations of particulate metal has been found in seston traps which would suggest that filter feeders would accumulate a high concentration of these metals (Harbison and Wiltshire, 1993).

It is not thought that the impoundment ponds would be vulnerable from higher sea-levels as an outer protective wall which extends 3.5 kilometres into False Bay, and is 10 metres high and 10 meters wide has been built from slag which would protect the area from any storm surges. This wall does help to provide a sheltered environment for mangrove colonisation at the BHP site. However, further study would need to be undertaken to determine its effects on the distribution of sediments as it interrupts the natural northerly littoral drift.

Also, the Pacific Salt works (located behind the saltflats on the western side of the Bay) discharges bitterns into the western section of False Bay. The wastewater contains elevated levels of a number of salts including barium sulphate, magnesium hydroxide and calcium carbonate. Magnesium salts are toxic to mangroves at quite low concentrations. Also, elevated calcium carbonate levels cause shell thickening in molluscs (A G Consulting Group, 1989b, p.164).

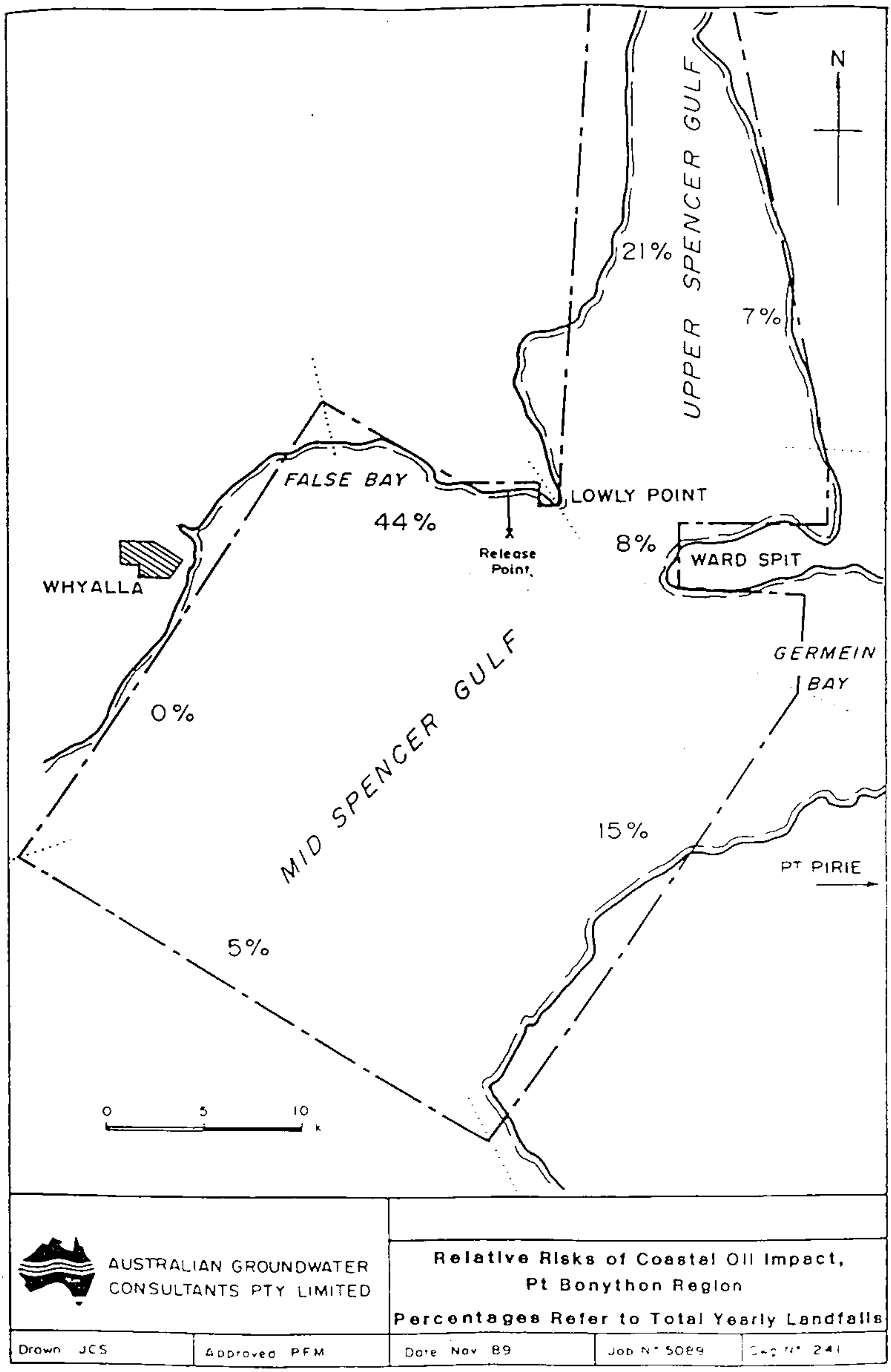


Figure 4.9: Relative Risks of Coastal Oil Impact, Pt Bonython Region. Percentages Refer to Total Yearly Landfalls. (source: A G Consulting Group Pty. Ltd., 1989 b, p. 143)

Oil Pollution

As noted in Chapter 3, there has already been one oil spill in the vicinity of False Bay and the potential still exists for further accidents of this nature. While, False Bay was not directly impacted in the incident its location between two port facilities (BHP, Whyalla and Port Bonython) increases its vulnerability. Figure 4.9 demonstrates the relative risks of coastal oil impact of the Pt Bonython region for an oil spill as identified by SANTOS. The dispersion of oil depends on the timing of an accident in relation to prevailing winds, currents and tides and hence it is possible False Bay (and other areas of the Northern Spencer Gulf) could be affected if another spill was to occur.

Increase in Water Temperature

Due to the wide intertidal area at False Bay with its shallow gradient (refer Figures 4.6 and 4.7) an increase in water temperature could affect the growth of seagrasses and hence their attenuate marine fauna. The Betatene plant at False Bay also identified the predicted increase in temperature as being of major concern as temperature is a critical factor in the survival of the organisms *Dunaliella salina,* from which the beta-carotene is extracted.

4.2 PORT PIRIE

4.2.1 BACKGROUND

Port Pirie was chosen as one of the specific study sites in the Northern Spencer Gulf not only because it is one of the major cities in the Gulf, but it is also the site of the world's largest lead smelter and has suffered from coastal flooding during recent storm events.

Port Pirie is on the eastern shore of the Northern Spencer Gulf, 220 km north of Adelaide. It has a population of more than 16,000 people including the surrounding districts. It is the regional centre of the Mid-North farming district that stretches south to Port Broughton, east to Peterborough, and north to Melrose. The city was developed during the 1880's with the establishment of a smelter to process the lead-silver-zinc ore mined at Broken Hill.

Port Pirie's main industry is the Pasminco Metals-BHAS smelter which produces lead, zinc, silver, copper, sulphuric acid and gold. It exports more than 80% of its annual lead production of 226,000 tonnes, 81% of its silver production of 208 tonnes, and some of its zinc production of 42,500 tonnes. Other major industries include medium to heavy engineering, industrial clothing manufacturing, and meat and dairy processing (Mines and Energy S.A., 1994).

The city's surrounding district is a significative producer of cereals, sheep and cattle, and there is a thriving market gardening area that supplies both the Mid North region and Adelaide. In 1991-92 Port Pirie's harbour shipped more than half a million tonnes of wheat and barley, and half a million tonnes of ores, concentrates and non-ferrous metals.

4.2.2 PHYSICAL CHARACTERISTICS

Port Pirie is located on the banks of the Port Pirie River, a tidal estuary running into the Northern Spencer Gulf. (See Figure 4.10) Much of the city is located on a flat supratidal zone with large areas below recorded high tide levels. The site has a high groundwater table. The coast is dominated by extensive tidal creeks, mudflats and mangroves and are backed by large areas of samphires and saltbush.

Figure 4.10 demonstrates that the north east region of the coast is a shallow area dominated by mangroves and samphires with associated intertidal and subtidal seagrass meadows. The north west region is also shallow and dominated by mangroves, extensive samphire and wide mudflats with some associated seagrass communities. West and south west of the city (where the tidal estuary of Port Davis and the promontory of Point Jarrold are located) the coastline and creeks are dominated by mangroves, samphires and saltbush flats extending landward. The southern region, south of Point Jarrold, is distinguished from the other regions for its sandy coast with wide intertidal sands and an open bay.

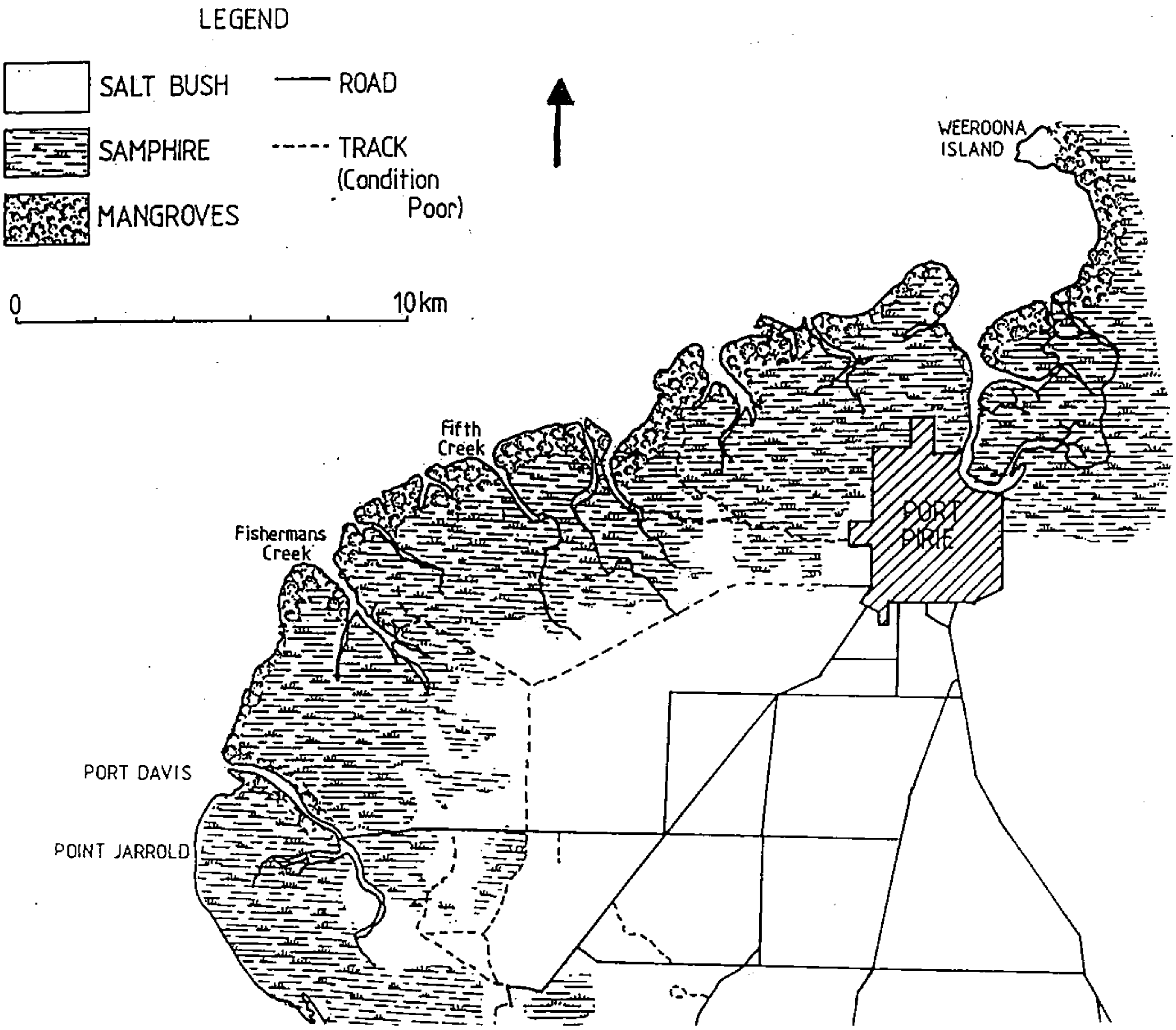


Figure 4.10: Port Pirie. (source: A.G. Consulting Group, 1989a).

It is clear from topographic maps that the city was built on an area adjacent to land subject to inundation. Levees were built on the north and north west parts of the city and embankments in the Solomontown were recently constructed, and this work is continuing, in order to protect the city from tidal flooding . Port Pirie has experienced various tidal inundations with the 1934 the most disastrous. On December 1979 a storm produced up to 125 mm of rain in six hours and flooding was experienced in the city centre. It was estimated that the cost of damage was $1 million. In 1994 the city experienced another rain produced flood.

Port Pirie is located in zone 1 according to the SA Earthquake Code (AS 2121-1979). Although it is within about 200 km of areas where several seismic events of moderate intensity have occurred, the seismic risk at Port Pirie is not considered high (Mines and Energy S.A., 1994).

Climate

Port Pirie's climate is warm and dry with a mean average maximum temperature of 24.1°C and a mean minimum of 12.7°C. Monthly average maxima range from 31.6°C in January and February down to 16.2°C in July. Monthly average minima range from 7.7°C in July to 18°C in February. The average annual rainfall is 345 mm and the town has an average of 76 wet days per year.

Tides

The S. A. Port Corporation (formerly the Department of Marine & Harbors) has recorded the extremes tides at Port Pirie since 1919. Recorded extremes are shown on the table below.

Table 4.1: Extreme tides recorded for Port Pirie and their approximate recurrence interval (values obtained from DENR).

YEAR	SEA LEVEL (m AHD)	APPROX. RECURRENCE
1934	2.78	1:100
1953	2.64	1:50
1981	2.64	1:50
1987	2.42	1:10

4.2.3 GEOLOGY

Port Pirie is located on the Adelaide Geosyncline province which includes the succession of rocks (about 850 to 540 million years old) that formed the Flinders Ranges (Mines and Energy, 1994). The lower lying areas to the north and west of Port Pirie comprise the St Kilda formation. The basement rocks are of Proterozoic age (AGC Woodward-Clyde, 1991a).

According to Gostin et al (1984), the latest sea transgression, during the Holocene, has resulted in substantial accumulation of sediments around the Gulf coast. Mangroves around Port Pirie lie on these Holocene sediments. According to the Department of Mines and Energy geological map, the sediments within the bounds of Port Pirie are classified as fluviatile gravel, sand and clay of modern drainage channels

Groundwater

Port Pirie lies within the boundary of the Pirie-Torrens basin which is lenticular in shape and covers an area from Port Broughton to the top of Lake Torrens. The basin's boundaries in the south are the Spencer Gulf on the west and the South Flinders Rangers on the east. The largest stream in the southern portion of Pirie-Torrens basin is the Broughton River, which lies south of Port Pirie. The groundwater flows, like the surface flows, from the highland areas towards the coastline, regionally from east to west. Groundwater discharge occurs via evapotranspiration and by seepage along the coastline into the Gulf (AGC Woodward-Clyde, 1991a).

The Quaternary aquifers in the sediments below Port Pirie are likely to be unconfined. The bores located in this area are classified as saline and the high salinity levels support the view that groundwater discharge might be taking place in the area. According to Reilly (pers. comm, 1995), aquifers under the eastern alluvial plains above Port Pirie contain water of good quality. Bores located in this area supply market gardens and farms at Nelshaby, Port Germein and Baroota.

4.2.4 SOCIAL AND ECONOMIC CHARACTERISTICS

The surface transport services for the area consist of all-weather sealed roads, rail links between Port Pirie and the other cities, and a port. Port Pirie has an airport that can handle a variety of aircraft but it is not used extensively due to the city's proximity by road to Adelaide.

Port Pirie's port mainly services the Pasminco smelter and the grain industry. It is a shallow (6.4 metres below datum) enclosed port linked to the Germein Bay by a channel 14 km long. Vessels of up to 20,000 deadweight tonnes can enter or leave the port fully loaded, while vessels of up to 45,000 tonnes can enter and leave the port only partly loaded (Mines and Energy S.A., 1994).

Electricity is supplied by the Northern Power Station at Port Augusta. A natural gas pipeline from the Cooper Basin to Adelaide has a spur link to Port Pirie. The city is served by communications facilities including telephone, microwave, satellite, radiotelephonic, and computer links. There are video links for long-distance education from Adelaide.

Port Pirie's population has declined between the 1986 and the 1991 census although population of infants under the age of four has increased. Low-income families have increased by 6% between the two censuses, and a slight increase of Aboriginal and Torres Strait Islander people was recorded.

According to the Northern Spencer Gulf Resource Processing Strategy (Mines and Energy, 1994) Port Pirie has a 15.8% estimated unemployment rate, the highest in the region, which has increased since the 1986 census. The biggest employment sector is manufacturing, with trade and community services having a significant presence. From 1986 to 1991 the largest number of people have been employed as tradespersons and labourers reflecting the industrial nature of the city.

4.2.5 LAND USE

It is important to note that this region is under two different local councils, Port Pirie City Council and Port Pirie District Council. See Figure 4.11.

The Port Pirie's section of the Development Plan divides the city into different zones for land use and development. The land subject to inundation, on the west side of town, is classified as a rural coastal zone, where no development should interfere with the coastal environment in any adverse way, public access limited and no interference should occur to the natural drainage processes; an urban zone which is mainly subdivided into residential, commercial, industrial and public use; a rural and a buffer zone between the residential and the industrial areas.

According to Mr. Sam Laforgia, the city council's environmental health officer, the town is expanding southward, towards the rural zone. Industrial expansion is limited by the District Council boundaries. Negotiations are underway between the Port Pirie City Council and the District Council of Pirie about the possible establishment of a brass processing plant.

BHAS occupies an area north of the city with its waste slag heaps on the edge of the Pirie River and associated tidal creeks. According to Ward and Young (1982), since 1939 most of the BHAS liquid effluents have been directed to First Creek. The sewage treatment works, sited on land subject to inundation, is located to the west of the city and discharges waste effluent into the Second Creek tidal estuary (McGarry, pers. comm., 1995, EWS, Crystal Brook).

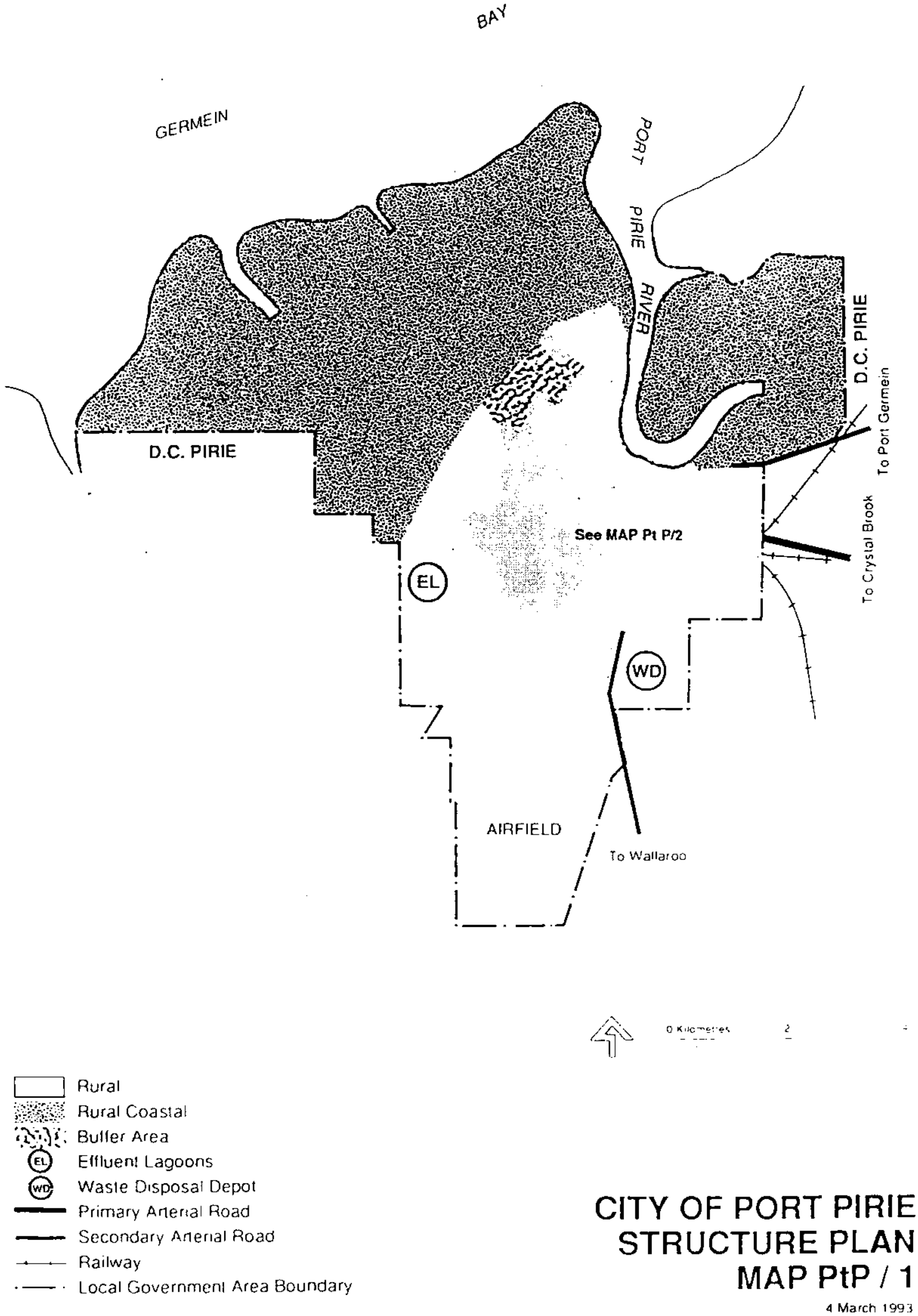


Figure 4.11: District Boundaries, Port Pirie. (source: PAR, PP, 1993).

In August 1990 a Draft Environmental Impact Statement was prepared by Kinhill Engineers Pty Ltd for SX Holdings Ltd regarding the establishment of Stage 3 of a Rare Earths Extraction Plant. SX intended to establish a rare earths plant at Port Pirie. Stages 1 and 2 were already completed when the EIS draft was presented. The proposed plant is to be situated in the industrial zone at the northern extremity of the city.

The proposed development site was previously used for uranium processing (1955-61), the extraction of scandium (1960-62), and monazite cracking (1969-70). The site's title has been transferred to the proponent. The site includes six uranium residue and tailings dams and four smaller tailings dams from earlier operations and is surrounded by levee banks. Most of the residue dams have been filled with 1.5 m of smelter slag, to reduce gamma-radiation dose levels and radon emanation rates (Kinhill Engineers, 1990).

A preliminary feasibility study for an aquaculture development was prepared in 1989 by Australian Groundwater Consultants PTY LTD for Port Pirie Development Committee. It recommended that further investigations be undertaken into the feasibility of establishing an intensive, closed, "factory" system of aquaculture at Port Pirie.

4.2.6 HERITAGE AND AREAS OF CONSERVATION SIGNIFICANCE

The aboriginal people in the Northern Spencer Gulf belong to several community groups. The Adnjamathanha, Kokatha, Barngaria, Nukunu and Wiringu tribes have a long-standing association with the region. The Nukunu occupied the land on the east coast of the Gulf.

The coast and the creeks surrounding Port Pirie are colonised by mangroves. Due to their great environmental importance, mangroves are protected under the Native Vegetation Act and Fisheries Act. Samphire associations are also highly represented in the area and together with other diverse coastal vegetation species (see Appendix 2) the area represents a region of significant biological and botanic importance. A number of seagrass species are also found in the area.

4.2.7 TECHNIQUES APPLIED TO ASSESS VULNERABILITY

The vulnerability assessment of the area was done mainly by using the data produced by the city's council flooding study and two topographic maps, 1:10 000 scale with five metres contour, and two 1:2 500 scale with two metres contour, bought for $7.10 each. The idea of originating new data for the area was abandoned due to the high cost.

Digital Terrain Modelling

The only contour information available for the whole of the Northern Spencer Gulf Study area was in the form of Topographic Cadastral overprint maps with a scale of 1:50 000 and contour intervals of 10 metres.

As this was clearly inadequate to be used for the basis of delineating the effects of an 18 or 44 cm sea-level rise enquires were made into the costs of producing a Digital Terrain Grid by means of aerial photography and photogrammetry.

The Resource Information Group/Image Data Services of the Department of Environment and Natural Resources, South Australia was contacted for a quote for Digital Terrain Modelling of the Port Pirie area which was approximately 5759 hectares in area to provide 0.3 metre contour intervals.

The costs and specifications involved in the subsequent quote were as follows:

Aerial Photography:

Three runs of black and white photography with a super wide angle and focal length of 88.87 mm to a scale of 1:15 000 scale (including one set of prints)

$ 2 500

Surveying:

As there were no existing control points it would have been necessary for a team to lay pre-targets for 24 control points, and supply the co ordinates.

$10 700

Photogrammetry:

To produce a Digital Terrain Grid at 50 metre intervals, with the accuracy of points to be within +/- 0.2 metres. The grid was to be taken to the seaward side of the mangroves where targeting and photogrammetry permitted.

$ 3 450

TOTAL $16 650

To this amount an extra $300 would need to be added if a hard copy (six sheets @ 1:500) was required.

As this was only one small area of the Northern Spencer Gulf and only one of four studies it was realised that it was not viable to collect the detail of levelling that would be required to be able to identify vulnerable areas by this means and the job was not proceeded with. This contrast with False Bay where the contour interval was coarser (0.5m) and the labour costs were less as the job was integrated with work being undertaken by BHP.

Flood Study

The Corporation of the City of Port Pirie commissioned, on 25 September 1990, Lange, Dames and Campbell Australia Pty Ltd, Consulting Engineers and Planners, to undertake a study which aim was to:

- "Produce a drainage strategy that will protect Port Pirie from flooding by storm rainfall, at the same time allowing for high tide level and/or pump failure"

- "Address tidal flooding and engineering protection measures and inter-relation between these and stormwater drainage"

The tidal flooding study adopted the 1 in 100 year tidal event, 2.85 A.H.D., as the standard set by the DENR. An assessment was also made with an added allowance of 0.3 m predicted sea-level rise to the year 2050. The methodology applied in that study comprises:

1. Mapping of areas at risk from inundation. The maps were compiled by the former Lands Department based on low-altitude aerial photography carried out for that study. They are 1:2 500 scale maps with 0.5m contours showing spot heights, buildings outline and features such as road kerbs and railway tracks. The maps produced on film and prints were used as worksheets on which contours for the various tide levels were interpolated The digital information is still held by the Department and would have been available at the cost of $300 per sheet.

2- The location of detention ponds where suitable land was available in order to cause the maximum reduction in drain sizes.

3- The location of drains where possible on natural drainage paths, and such as to most effectively serve the distribution of present and possible future development.

4- Estimation of costs for options of pond locations and drainage standards and comparison in relation to performance and costs to establish the most economically feasible.

5- Calculation of up to 8 hours as a period in which discharge from drains could be blocked by extreme tides.

6- Determination of standard of piped drainage system appropriate to the City Centre. This was done by an economic analysis that took into account the estimate flood in the City Centre, the benefits of a range of pipe system standards, the costs of a range of pipe system standards and the pipe system standard with the highest benefit/cost ratio.

Flood damages were calculated based on a map produced by Port Pirie Council which showed the extent of areas inundated during the 1979 storm, and the 1:2 500 scale maps produced by the former Lands Department. An approximate floodplain map was drawn for the 1979 storm and damages were estimated for property expected to be inundated according to that map. A damage-frequency curve was drawn, adopting a straight line relationship between the 1 in 10 year flood damage and the 1979 flood damage.

Tidal flooding study methodology

Several extreme tidal events have occurred during the last decades that have caused inundation and damage to parts of Port Pirie. DENR has estimated the probable frequency of particular heights of extreme tides by the flood study based on tidal records available since 1919.

Areas at risk of inundation were mapped (as mentioned above). The accuracy of the maps was reviewed in relation to field surveys carried out for the Council and a satisfactory correlation was found. The house floor levels in the inundated area were accurately established by field survey.

The damage costs for 0.3m sea-level rise were also estimated. The areas of inundation were estimated per building by measuring the depth of inundation and the roof area on the 1: 2500 worksheets. This procedure was used for commercial, industrial, tourist accommodation areas and areas set aside for 'public purposes'. A mean capital value of $55,000 per residence was adopted and the 'annual assessed value' taken to be 1/20th of this, on the advice of the Valuer-General's Department.

Cost of clean-up was estimated but no allowance was made for damage to outbuildings, pavements or structures which would be affected by floodwaters, nor was any account taken of the higher damage cost for the many non-residential buildings in the area zones residential. No allowance was made for indirect costs such as loss of business, stress, injury or death resulting from inundation.

According to the study, Broken Hill Associate Smelters (BHAS), that has a major ratepayer and employer in Port Pirie, should also be protected from flooding. BHAS site works were examined in a detailed site inspection, and levels were obtained from its Surveyor to determine a line of protection that could be established through the plant.

According to Sam La Forgia the cost of the flood study and the drainage design was $348,000.

4.2.8 VULNERABILITY ASSESSMENT

Flooding and Sea-Level Rise

The drainage and flooding study done by Lange Dames & Campbell to the Corporation of the City of Port Pirie concluded that a comprehensive drainage system of increased capacity and extent is required for the city. The city is flat, low-lying in relation to natural drainage outlets, which are very poor, with a high and rising groundwater table. According to the study the groundwater table is expected to rise speculatively by 300 mm by 2050.

Port Pirie has experienced disastrous flooding when south westerly wind and high tides combined. The statistical probability of these events is hwon in Table 4.1. With sea-level rising the height of the tidal surge will increase. A one in a hundred year tidal event would inundate 30% of the city (471 ha) and could cause damage to 1,460 homes some by more than 1 metre depth. A sea-level rise of 300 mm by the year 2050 combined with a one in a hundred tidal event could increase the area of inundation of the city to 40% (579 ha) and damage up to 1,820 buildings, some possibly up to 1.5 metres in depth. The damage cost of this last mentioned event was estimated at $30 million, with the worst affected areas being Port Pirie West, the City Centre (Central Business District) and Solomontown. (Refer Figure 4.12).

It was estimated that the cost of damage (mainly stormwater flooding) produced by the 1979 storm, when the City Centre, Solomontown and a few other sites around the city were flooded, was in the order of $1 million. It was inferred that approximately half of the cost of damage would have been incurred within the City Centre, and that another storm with the same magnitude, occurring today, would incur approximately $1.2 million damage in the City Centre.

The study report also concluded that close to the coast the groundwater table will rise to the same level as sea-level. Because the groundwater is saline, salinity in the soil around Port Pirie will increase and this may cause changes in the vegetation. A rise in the water table may also mobilise contaminants that are presently located within sediments above the current water table surface. It is possible that the groundwater discharge zone will occur at the low lying areas within the city.

The response by the city council for the sea-level rising impacts has been to protect. Mr Sam La Forgia, the city's council environmental health officer, in personnel communication, confirmed that the council is proceeding on the plan following its recommendations. The recommendations comprise design standards and flood strategies. The protection work is being funded mainly by State Government grants through the Coast Protection Board. The first priority for flood mitigation and drainage work is to institute a

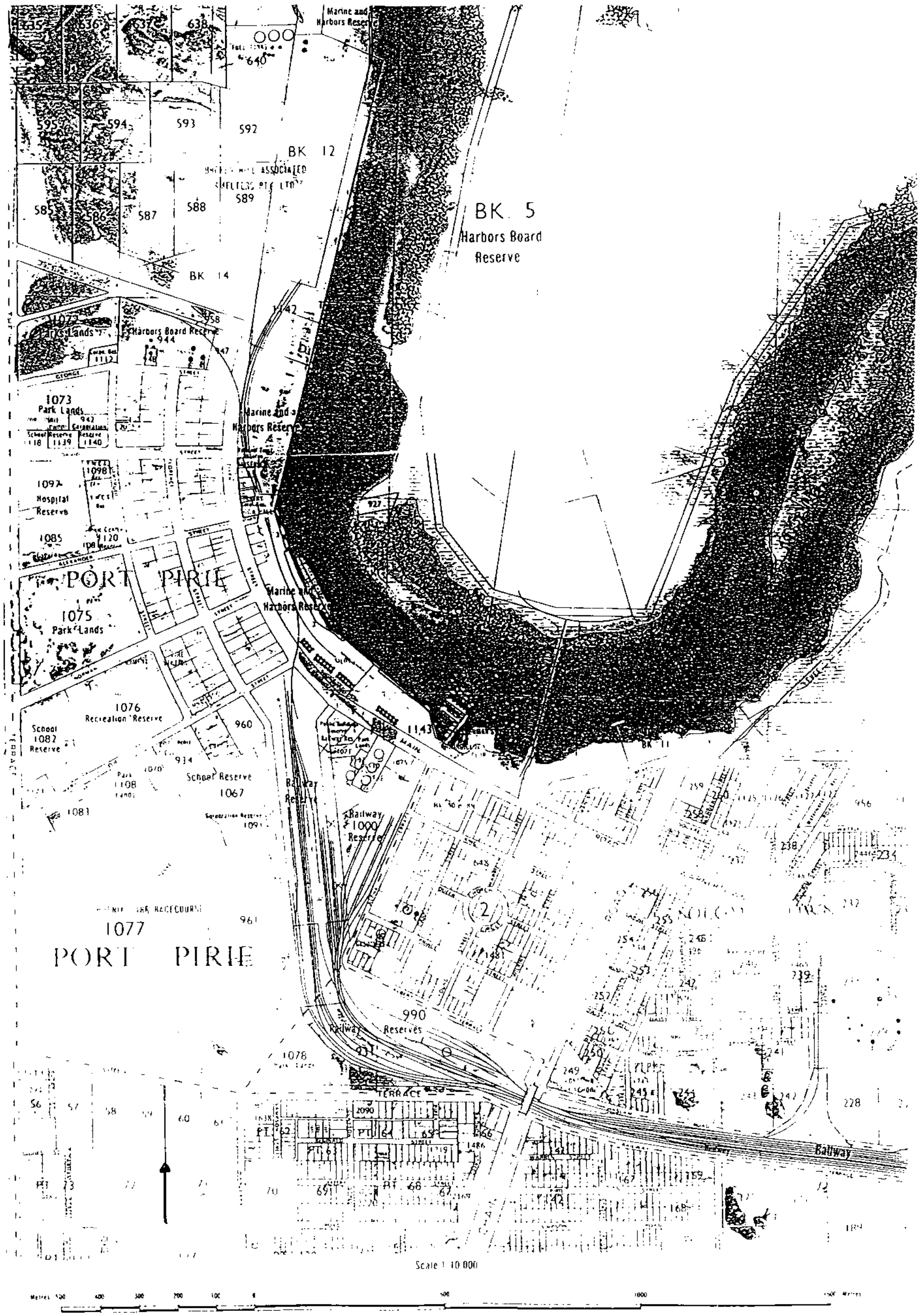


Figure 4.12: Port Pirie.

tidal flood warning system which will give public notice of meteorological and ocean conditions which could lead to extreme high tidal events. Sea defence and levees are seen as a second priority for flood mitigation while drainage works at the city centre as third. Construction of retention pond & drainage systems are recommended for some parts of the city.

Levelling/Biota

A three kilometre transect was levelled across the salt marshes at Port Pirie to assess the potential effect of sea-level rise (using the 18 and 44 cm scenarios) on the vegetation communities. The transect was positioned to provide a comprehensive representation of the plant communities in the area. The vegetation was classified according to the life form/height class and canopy cover of the tallest stratum. Vegetation changes along the transect were mapped in conjunction with the levelling.

Each of the communities are briefly described below.

1. *Atriplex vesicaria / Halosarcia indica low heath* forms a very small community at the start of the transect and on several well elevated ridges.

2. *Halosarcia indica / H. halocnemioides with and without H.pergranulata* occupies almost half of the transect. The community primarily occurs on salt pans. Halosarcia pergranulta does not occur beyond 1400 metres of the profile start. Canopy cover is highly variable.

3. *Atriplex paludosa / H.indica low heath* forms a significant community along the transect. The community occupies elevated creek banks and high ridges generally associated with tidal creek lines.

4. *Halosarcia halocnemioides low heath to open dwarf scrub* occupies similar salt pan habitat to community 2 but in closer proximity to the sea.

5. *Maireana oppositifolia / H.indica / H.halocnemioides low heath* occupies the back part of the ridged terrain which characterises the last 900 metres of the transect. Typically the community occurs on ridge crests.

6. *Halosarcia halocnemioides / Sclerostegia arbuscula low heath* occupies similar habitat to 5 but at lower elevations and in closer proximity to the sea.

7. *Sclerostegia arbuscula / Sarcocornia quinquiflora +- Suaeda australis low heath* forms a compact community tightly fringing the mangroves. It represents only 3.9% of total vegetation cover.

8. *Avicennia marina heath to dense heath* occupies the lowest and most seaward part of the transect. This community extended seaward a further 1000 metres from the transect end.

To stimulate the effect of sea level rise on the resultant profile, two other identical profiles which had been lowered by 18 and 44 cms were superimposed on it. Percentage representation of each community along each profile line was calculated to show potential impact of the sea level rise scenarios as demonstrated in Figure 4.13. From this it can be seen that sea level rise will produce significant changes to the vegetation pattern. Plant communities will shift landward in response to increased seawater flooding. However, levees built behind the salt marshes will prevent further retreat and will cause the loss of some communities. The full methodology and report of the study are reproduced in Appendix 2.

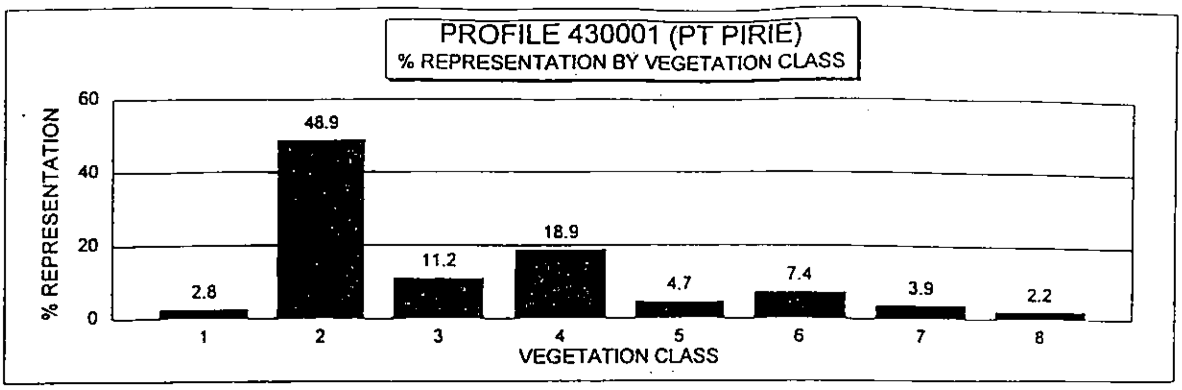
Consideration of further construction of protection levees should take into account the fact that they may act as an obstacle to mangrove retreat.

Pollution

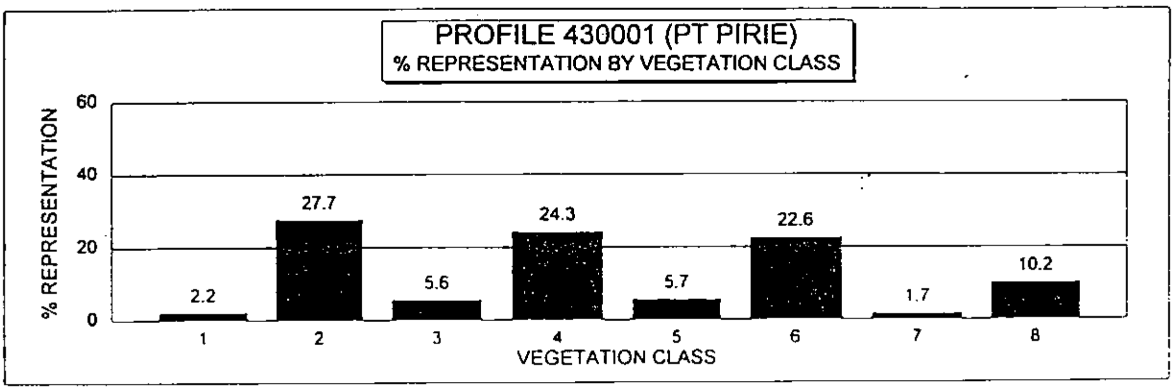
Many pollution problems derive from the industrial developments at Port Pirie. BHAS contributes high levels of lead and zinc to the environment from aerial and liquid waste discharges. According to a report from the former Department of Environment and Planning, in 1988 BHAS was by far the largest individual source of particulate lead in Port Pirie (Body et al. 1988). The Northern Spencer Gulf Resource Processing Strategy listed Pasminco lead smelter as one of the most important sources of heavy metals entering the Gulf (Harbison & Wiltshire, 1993). Its annual discharge of liquid waste to First Creek contains 250 tonnes of zinc and 100 tonnes of lead (Rozenbilds, 1991). This flows across intertidal mudflats more than 1 km wide before reaching subtidal waters (Harbison & Wiltshire, 1993).

Although the effects of heavy metals on the physiology of seagrasses is not well known, many studies have documented their effects on the seagrass community. Ward and Young (1982, p. 137), studying the effects of sediment trace metals and particle size on the community structure of epibenthic seagrass fauna near the outfall of First Creek (where BHAS was directing the liquid effluent from the smelter since 1939), found that 20 common species from seagrass community, mainly fish, "decreased frequencies correlated with the concentration of contaminant metals in the sediments".

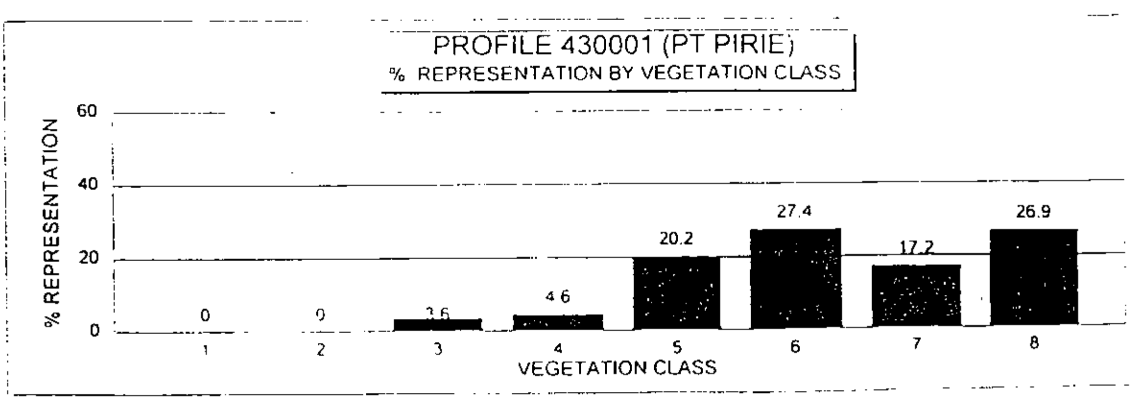
Another source of contaminants to the Gulf has been the tailings and residue dams of the uranium extraction plant that operated in Port Pirie. They were built in the intertidal zone north of the city and the levee banks. According to Kinhill (1990) most of the residue dams have been filled with 1.5 m of smelter slag in order to reduce gamma-radiation dose levels however some still remain uncovered. These contaminants are a potential threat to the region due to the high vulnerability of the sites to flooding. If inundated, the contaminants could be transported to different parts of the study area and ultimately end up at the Gulf.



Graph 1. Existing vegetation representation at present sealevel



Graph 2. Estimated vegetation representation resulting from adjustment to a 0 18 metre sealevel rise



Graph 3. Estimated vegetation representation resulting from adjustment to a 0 44 metre sealevel rise

Figure 4.13: Representation of Salt Marsh Communities. (source: Apendix 2)

Sewage is also a source of pollution to the waters in the Gulf. The sewage treatment works are located on land subject to inundation, on the west part of town. Most of it is treated before being discharged into Second Creek. It is well known that excessivy epiphytic algae growth on seagrasses can result from high nutrient levels. This can result in detrimental affects on the marine environment (Harbison & Wiltshire, 1993).

The Gulf waters receive untreated discharges through stormwater. "Stormwater enters holding sumps which are below the tidal water table. Combined events such as high tides and heavy rainfall can result in overflow of accumulated contaminants into low-lying areas of the city and into the marine ecosystem" (Reilly, 1991, p.10).

4.3 PORT AUGUSTA

4.3.1 BACKGROUND

Port Augusta was chosen as one of the specific study sites in the Northern Spencer Gulf due to its tidal flooding risk. A projected sea-level rise of 0.3 m by 2050 for a 1 in 100 year tide level would inundate around half of the city centre (Lange Dames & Campbell Aust. Pty. Ltd., 1991a).

Port Augusta is located at the head of the Spencer Gulf. It has a population of around 15,000 and it is a transport crossroads for national rail and road links, north-south and east-west across Australia. The city services an extensive area of the state, as the closest major centre for northern agricultural producers and mining areas such as Roxby Downs, Coober Pedy and the Moomba gas field (Mines and Energy, 1994).

The city's main economic activity has been based on Australian National Railways and the Electricity Trust of South Australia (ETSA), although it is also the regional base for the pastoral industry. In 1994 Australian National Railway employed about 600 people in Port Augusta out of a total of about 800 in the northern region.

Tourism is the other major industry in the region with Port Augusta being the gateway to the Flinders Ranges and the northern outback. Even though the water is very shallow at Port Augusta limiting harbour facilities, there are good road and rail connections to the nearby ports at Whyalla and Port Pirie.

4.3.2 PHYSICAL CHARACTERISTICS

Port Augusta (Figure 4.14) is located at the head of the Northern Spencer Gulf, on an area surrounded by mangroves and Samphire. The Planning Act (1982) defines the City of Port Augusta as "the area surrounding the northern tip of Spencer Gulf and extending in an easterly direction to the foothills of the Flinders Ranges in the east, in a westerly direction to the Whyalla Council and to Lincoln Gap".

The city comprises the Hundreds of Copley, Gillen, Davenport and portion of the Hundred of Winninowie. This area includes the coastal areas of Northern Spencer Gulf to the highlands on each side of the Gulf. The township of Stirling North, generally described as the Port Augusta-Stirling North urban area is located on the east side of the Gulf and Port Augusta West on the west side. The areas are linked by the Great Western Bridge (closed to vehicular traffic) and the New Port Augusta Road Bridge.

Port Augusta was built on the banks of the Gulf, on a flat area formerly occupied by mangroves and samphires and subject to periodic tidal inundation. The Australian National Railways has an established railway infrastructure (tracks, workshops, etc) on land on the east side of the Gulf. This area was once occupied by an extensive mangrove forest and is

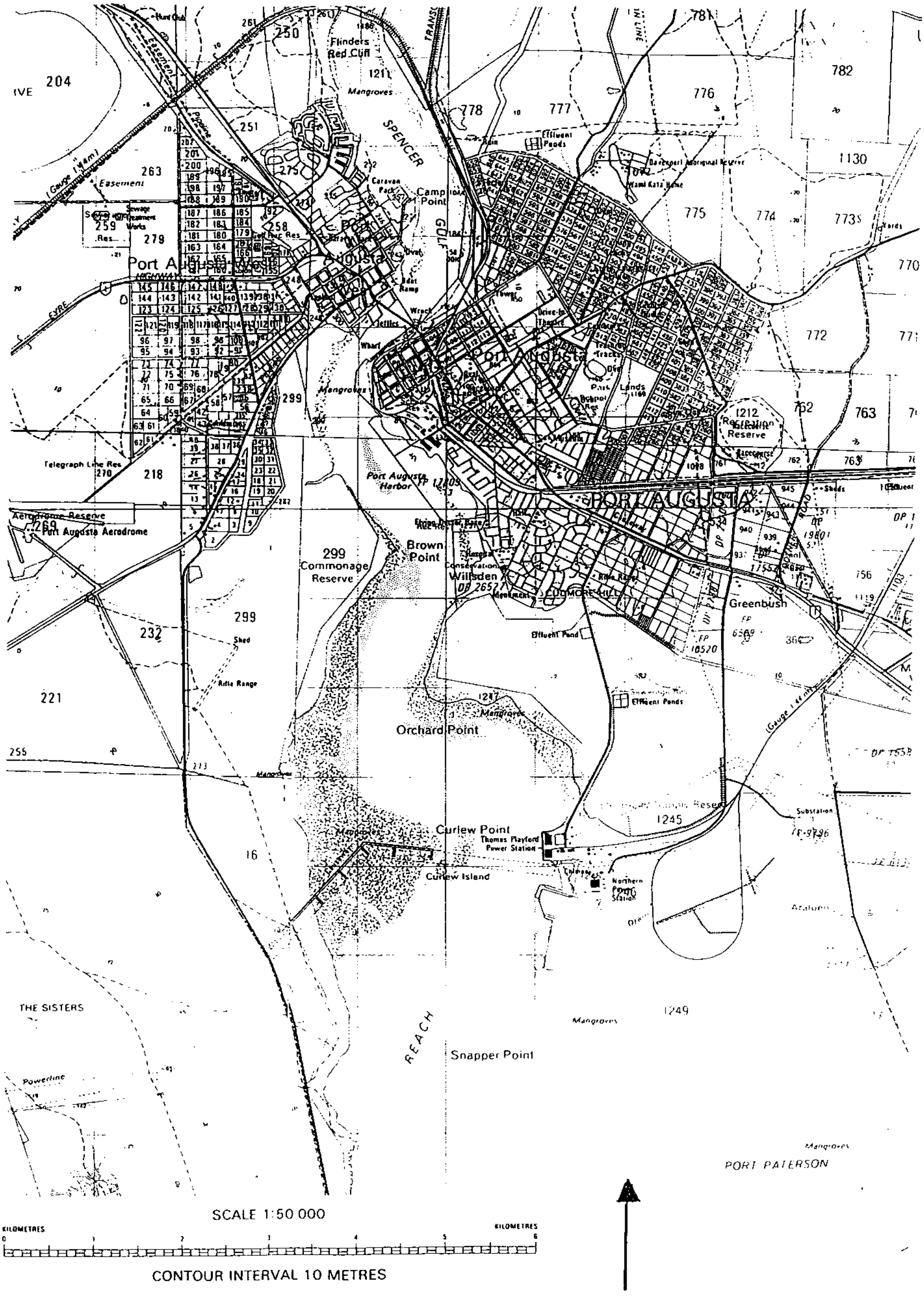


Figure 4.14: Port Augusta.

therefore on land previously subject to tidal inundation. In fact, the existing railway tracks have been built on a levee bank adjacent to a small remnant mangrove stand (See Photograph 2).

The western side of town is also built on a flat area subject to tidal inundation. There are very few mangroves left at this site, and the Augusta Hotel and some residential houses, built adjacent to the Gulf waters, have been subject to flooding during storm surges.

Photograph 2: Mangrove retreat limited by railway embankment, Port Augusta.

4.3.3 CLIMATE

Port Augusta's climate is warm and dry, typically semi-arid. The average annual rainfall is less than 250 mm.

Tides

The Department of Environment and Natural Resources estimated tide levels at Port Augusta (interpolated from Port Pirie tidal records and Port Augusta site observations) associated with various average recurrence intervals. The table below shows the probable highest tide levels that have occurred at the Playford Power Station. This data is derived by DENR from a short period of record at the power station and interpolation from the Port Pirie record.

Table 4.2: Extreme tide levels estimated for the Playford Power Station and their approximate recurrence interval.

YEAR	SEA LEVEL (m AHD)	APPROX. RECURRENCE
1934	3.05	1:100
1953	2.9	1:50
1981	2.9	1:50
1987	2.6	1:10

Tides are expected to be slightly higher at Port Augusta itself due to the funnelling effect at the top of the Gulf. According to the Coastal Management Branch Report on Extreme Tides (1987), observations on the east and west sides indicated a tide of 2.7m to 2.75m, approximately 0.1 to 0.15m higher than the tide measured at the power station gauge. It was also noted that the 1952 tide recorded at Port Augusta was approximately 0.1m higher than that measured at the power station. DENR recommends adoption of 3.15 m AHD for the 100 ARI at Port Augusta

4.3.4 GEOLOGY

Port Augusta lies on Holocene and Pleistocene sediments. Port Augusta east is located in the Adelaide Geosyncline province. The west lies on the Sturt Shelf province which consists of flat-lying Adelaidean sedimentary rocks (less than 1000 million years old) that form flat-topped hills. The Flinders Ranges, to the east, consist of thick sequences of Adelaidean siltstone, calcareous mudstone, limestone, dolomite, magnesite, arkose and quartz arenite that were folded during the early Ordovician period and were subsequently subjected to uplift and erosion (Gostin et al., 1984).

Groundwater

Port Augusta is located within the boundary of the Pirie-Torrens Basin which is the same basin described for Port Pirie. Surface water flows to the west on the eastern side of the city and to the east on the western side. The surface flows originate from the Flinders Ranges to the east and from the Simmens Plateau (Upper Eyre Peninsula) to the south west of Port Augusta (Reilly, pers. comm., 1995).

Groundwater also flows from highland areas towards the coast. It discharges via evapotranspiration and by seepage along the coastline into Gulf waters. It is likely that the local aquifers are unconfined with shallow water levels, between 0.5 and 6 metres (AGC Woodward-Clyde, 1991b).

4.3.5 INFRASTRUCTURE AND SOCIAL CHARACTERISTICS

The city is well served by rail road links. There are limited harbour facilities due to the shallow waters of the Gulf. Even though Port Augusta's airport is small it has frequent air traffic due to the El Alamein and Cultana defence training establishments and an established Flying Doctor base.

The Northern Power Station at Port Augusta supplies energy to all cities in the Northern Spencer Gulf. It has supplied South Australia's power since 1985 and it is considered to be one of the newest and technically advanced power stations of its kind in Australia. It is supplied with coal from Leigh Creek and sea water from the Gulf for its cooling system. The older Thomas Playford B Power Station, which now operates intermittently, is due to be commissioned in 1996 (Mines and Energy, 1994).

The Leigh Creek coal mine is expected to continue production until 2025 and it has provided more than 60 million tonnes of coal for past and present power stations. All coal feedstock is delivered by the Australian National Railway. According to the Northern Spencer Gulf Resource Processing Strategy (Mines and Energy, 1994), Port Augusta's main economic activity has been based on the Australian National Railways and the Electricity Trust of South Australia, and the fact that the city is the regional base for the pastoral industry.

Port Augusta's population rose 17% from 1976 to 1986 but has been in decline since that date. Low-income families represent a growth of 3% between the 1986 and 1991 Census. People of Aboriginal and Torres Strait Island descent make up 9% of the city's population.

According to the 1991 Census 43% of employees in Port Augusta are in the private sector. The Commonwealth Government employs 19% of the city's population, due partly to Australian National Railways. The level of employment has decreased in Port Augusta with an estimated Unemployment Rate of 13.4% (Mines and Energy, 1994). Employment in the community and personal services and wholesale and retail trade sectors has increased while employment in the electricity, gas and water sector, although prominent, is declining. Employment levels at the Australian National Railways continue to decline.

4.3.6 LAND USE

The Port Augusta section of the Development Plan divides the city into different zones for land use and development. Most of the population of the city lives in the urban areas of Port Augusta or Stirling North. The coastal areas on the east side of the Gulf are zoned as industrial, deferred urban, landscape, town centre and business. The coastal west side is zoned as recreation, landscape, business, living, tourist accommodation and conservation.

According to Mr. Geoff Botten, City Council's Administration Manager, the council has recently become part of the Economic Regional Development Board which aims to take a regional perspective and direction in the future. There is not a Coastal Management Plan for the area. There has been local contention on coastal issues especially over the use and management of the coastal environment. Construction of a boat ramp was delayed due to concerns by conservationists and problems with Aboriginal claims over the removal of a stand of mangroves at the proposed site.

The Northern Power Station and the Sewage Treatment Plant are situated on the east side of the Gulf. Both establishments were built on an extensive area of reclaimed coastal land. The hospital and Australian National's facilities are located southeast of the city, also on the eastern side of the Gulf.

The council recognises the area's potential for aquaculture and options are being explored regarding this possible development.

During the recent Resource Processing Strategy.discussions, five areas in Port Augusta were identified for possible mineral processing sites. The exploration of these resources could be done in conjunction with Port Pirie and Whyalla (Botten, pers. comm., 1994).

4.3.7 HERITAGE AND AREAS OF CONSERVATION SIGNIFICANCE

As mentioned before, the aboriginal people in the Northern Spencer Gulf belong to several community groups and have a long-standing association with the area. The Adnjamathanha people came from the Flinders Range in the north. The Kokatha, Wiringu and Barngarla occupied the west coast of the Gulf while the Nukunu the east. These communities still retain strong cultural links with the region.

Port Augusta was and has been built on areas of strong conservation significance. Intertidal sand and mud flats combined with extensive mangroves and samphire communities dominate the area. Seagrass communities have not yet been mapped in the area.

Port Augusta is a popular recreational fishing location with large numbers of blue swimming crabs being taken by recreational fisherman. The Port Augusta Council recognises the importance of the area as nursery ground and would like to see a fishing management plan for the area controlled by the council.

4.3.8 TECHNIQUES APPLIED TO ASSESS VULNERABILITY

The vulnerability assessment of the area was done mainly by using the data produced by the city's council flooding study and topographic maps (one 1:50,000 scale with ten metres contour and ten 1:2,500 scale with two metres contour). The idea of originating new data for the area was abandoned due to the high cost.

Flood Study

The City of Port Augusta commissioned, in September 1990, Lange Dames and Campbell Australia Pty Ltd and planning sub-consultant Hignett and Company to carry out a study which principal aims were to:

"-identify areas at risk of inundation by tidal flooding
-develop strategies for limiting the risk of damage from sea flooding and from stormwater runoff as affected by tidal events
-assess the planning implications of the proposed strategies and formulate planning policies
-appraise the effects of sea level increases on groundwater levels and salinities"

The study identified the areas at risk of inundation due to sea-level rise. In order to do that it assumed a 0.3m sea-level rise by the year 2050 as required by the Department of Environment and Natural Resources with the 1:100 year tide level event.

The study areas comprised Port Augusta East (the City Centre area south of Victoria Parade, and the Conwaytown area bounded to the south by Rupara Street and to the north by the Australian National railway yards) and Port Augusta West (the area approximately between Tiver Street to the south and the Shoreline Caravan Park to the north). The inland limits were the 4.2m AHD contour which was the maximum tide level investigated. The drainage and groundwater appraisals involved a larger area.

Maps of 1:2,500 scale were produced by the former Lands Department from aerial survey and used for the study. The mapping has been presented on two sheets, one covering Port Augusta East and the other Port Augusta West. Maps with contours at 0.5m intervals were incorporated into the study's report. Work sheets with contours at 0.5m intervals, spot levels, locations of buildings, railways and road pavement limits were also produced.

Topographic information from the aerial survey mapping and spot levels from ground surveys were used to assess flooding impacts. Floor levels were estimated from topographic information and surveyed floors.

The study estimated works costs in relation to sea defence priorities to provide protection against a 1 in 100 year event allowing for a 0.3m sea-level rise. Priority 1 comprises costs with sea defence and drainage for the City Centre, Conwaytown and Port Augusta West. The total sea defence cost would be $735,000 and the total drainage cost $195,000.

According to Phill Turvey, Port Augusta Council's planner, the initial cost of the flooding study was $40,000. Another $40,000 is currently being spent on a plan of development being done by Connell Wagner. The community is also being involved on the plan through a phone in advertised through the local radio station.

4.3.9 VULNERABILITY ASSESSMENT

Flooding And Sea-Level Rise

The drainage and flooding study done by Lange Dames & Campbell for the City of Port Augusta concluded that with an estimated 1 in 100 year peak tide level of 3.15m A.H.D. water could just enter the City Centre Area (Port Augusta East) through a path between the wharf and Yuda Street and about one or two buildings would be at risk in Conwaytown (Port Augusta East) with a portion of Railway Parade flooded. About seven buildings including the Augusta Hotel and Augusta West Motel would be inundated in Port Augusta West and about four others would be at risk" (Lange Dames & Campbell, 1991a).

Assuming an increase of 0.3m with the 1 in 100 year tide level for the year 2050 (3.5m AHD), the study concluded that about 50% of the City Centre (Port Augusta East) would be inundated and more than 100 commercial buildings and homes could be damaged. In Conwaytown (Port Augusta East) flooding of Railway Parade would occur to a depth of 0.5 m in the lowest parts, a portion of the Australian National area between McLeay Street and Carlton Parade would also be flooded, one or two buildings could be inundated and about six others would be at risk. In Port Augusta West about fifteen buildings could be inundated and about twenty others would be at risk.

According to the study about 50% of City Centre Area including the central business area (Port Augusta East) is at, or below, 3.0m AHD. With a tide level of 3.6m AHD "water could be flowing into the area from over most of the distance along the railway between Victoria Parade and Flinders Terrace" and with a tide level of 4.2m AHD 60% of the city centre area would be inundated "with depths in the central business area of more than one metre". The study assumes, from aerial survey topographic information and samples taken, that floor levels of buildings are generally within 200 mm of ground levels. Some floor levels of business places in the commercial area are about 3.1m AHD with higher floor levels including the Commercial Bank (3.35m AHD) and the Fourways Hotel

(3.38m AHD). Extensive damage would result in Port Augusta West with a 4.2m AHD.

In fact, a boat ramp has been built in Port Augusta West, south of the bridge, on an area formerly occupied by mangroves which were cleared for this purpose. The clearance of the mangroves initiated a heated discussion between the council and some members of the community. Questions regarding planning procedures prior to the boat ramp construction were heard by the Land and Environment Court. According to Reilly (pers. comm., 1995) the above mentioned site has been subject to constant tidal erosion during the winter of 1995. Sedimentation and turbidity from this erosion are threatening mangroves and seagrasses communities downstream of the boatramp site.

The problems occurring in Port Augusta are clearly identified as due to lack of coastal awareness in the early planning of the city. The city was built on an environment subject to constant flooding and sea-level rise will only increase the flooding impacts. The study's recommendations are to protect the existing development with a combination of levees and walls (See Figure 4.15). It recommends, for example, the extension of sea defence works in Port Augusta East northwards beyond the bridge to protect the City Centre area.

It is important to note that building levees and walls is one of the IPCC options in response to sea-level rise as mentioned in chapter one. Not only can protection be very expensive (approximately $1,000,000 for the flood protection study by Lange, Dames and Campbell and works done by Connel Wagner for the entire city) (Phil Turvey, pers. comm., 1995), but can have different impacts elsewhere on the coast. A Coastal Management Plan should be developed in the region as a way of managing further development. If development occurs on areas not vulnerable to storm surges many problems can be avoided by including the impacts from sea-level rise.

The drainage part of the study concluded that the drains performance will worsen with sea-level rising at all of the study areas. A portion of the City Centre is drained by a pumping installation. The study mentions that the lowest house could be inundated as a result of a storm with 1:40 year interval. The City Centre drains are inadequate by conventional standards while Conwaytown and Port Augusta West are reasonably adequate for present levels.

Other parts of the city are drained by gravity. According to the study, damage could be caused by runoff in excess of pipe capacity which would pond behind sea defence works. Additional gravity drainage capacity under these works is proposed as a general strategy for limiting flood

Figure 4.15: Levee Banks, Port Augusta. (source: Lange Dames & Campbell Aust. Pty. Ltd., 1991a).

damage risk. Even though this strategy is recommended, a more detailed analysis has to be done in order to determine the works required to enable the systems to function effectively under higher sea levels.

The groundwater investigation indicates that if sea-level rises 0.3m, groundwater will also rise 0.3m in time. The main consequence of this rising would be higher soil salinity levels what would certainly have an impact on fauna and flora.

Mangroves would suffer from lack of space to retreat in case of sea-level rise. Certain areas of the city are built immediately adjacent to the mangroves and future levees and walls built for protection could worsen this scenario. Samphires would suffer from the same problem.

Pollution

There are different sources of pollution in the area and sea-level rise could result in increased pollution reaching the Gulf. The Council is trying to encourage the shifting of the sewage ponds on the east side to the landward side of the highway in order to meet EPA guidelines and also because of their potential pollution of the Gulf. At present sewage outfall into the Gulf is subjected to primary treatment only (Botten, pers. comm., 1994).

The Australian National is a threat to the Gulf due to the hazard of heavy metal pollution. "For ten years, mangrove and seagrass destruction has been recorded to the outlet drains from Australian National premises. Workshops for cleaning and servicing locomotives are situated on Gulf foreshore and discharge oils, detergents, dispersants, grease inhibitors and other substances into sumps which have been known to overflow directly into Gulf waters" (Reilly, 1991).

Dieback and loss of mangroves have been reported to occur in patches on their seaward margin at the Hospital Creek site. According to Bayard (1993) an area of approximately 62.50 m^2 has been lost since 1991 at a rate of 31.25 m^2 per year and the size of the areas of loss at this site is increasing.

The two ETSA power stations, the Thomas Playford Power Station and the Northern Power Station are situated on the east side of the Gulf. The latter was responsible for a recent chlorine spill (Botten, pers. comm., 1994). The ash handling water discharged from the power stations are considered to be a source of heavy metal to the Gulf (Harbison & Wiltshire, 1993). Although mangroves adjacent to the ash disposal ponds at the power stations have had dieback between 1984 and 1993, results of a recent study have shown that there are signs of recovery (Bayard, 1993).

The thermal outfall, which increases water temperature in the Gulf, can cause some impacts in the area. Although Ainslie et al (1994) have concluded that there was no "deterioration" in the growth of seagrass *P. sinuosa* around the outfall, their research paper has recommended the continuing monitoring of the area due to a minor reduction in total standing biomass.

4.4 BLANCHE HARBOUR

4.4.1 BACKGROUND

Blanche Harbour is an area of coastline extending from 8 to 28 kilometres south of Port Augusta on the western side of NSG. (See Figure 4.16). Blanche Harbour has been chosen as a study area in order to assess the vulnerability of 280 shacks developed in the area. It is characterised as a tidal flat environment with sandy beaches, dunes and mangroves.

The terrestrial access to the area is by way of a gravel road off the main sealed road. According to Port Augusta Council, Blanche Harbour is a recreational resource for local, tourist and hinterland population. The 280 shack sites are located in small groups along the 20 km coastline.

In November 1990, a final management plan for the area was prepared by the Corporation of the City of Port Augusta for submission to the Minister of Lands and has been approved.

4.4.2 BLANCHE HARBOUR - DOUGLAS BANK AQUATIC RESERVE

Blanche Harbour - Douglas Bank Aquatic Reserve comprises an area of 3160 ha, extending 10 km south from Blanche Harbour to Douglas Bank. It was established in December 1980 in order to protect the mangrove, seagrass communities and the associated fish nursery areas. Activities permitted in the area include boating and the use of hand spears for the taking of finfish and shark, while collecting and removing all marine organisms by any method other than by hand spear are prohibited.

As noted the mangroves and seagrass habitats are important feeding and nursery areas for the most economically important species. For this reason, some of these areas have been established as aquatic reserves by the South Australia government.

Several different major types of habitat are incorporated in the Blanche Harbour-Douglas Bank Aquatic Reserve. On the landward side are samphire flats, which are flushed by extreme high spring tides. Seaward of the samphires is a mangrove intertidal zone, intertidal sand and mudflats, subtidal seagrass meadows and coarse sand and shell tidal channel areas.

According to Shepherd (1983), six seagrass communities are recognised in the reserve with two algal and three animal assemblages described in deep water. The algal flora is characterised by those with cool temperate affinities while the benthic epifauna contains endemic species, with tropical and sub-tropical affinities. The association of the sandwaves and megaripples with a typical fauna is unique to this area.

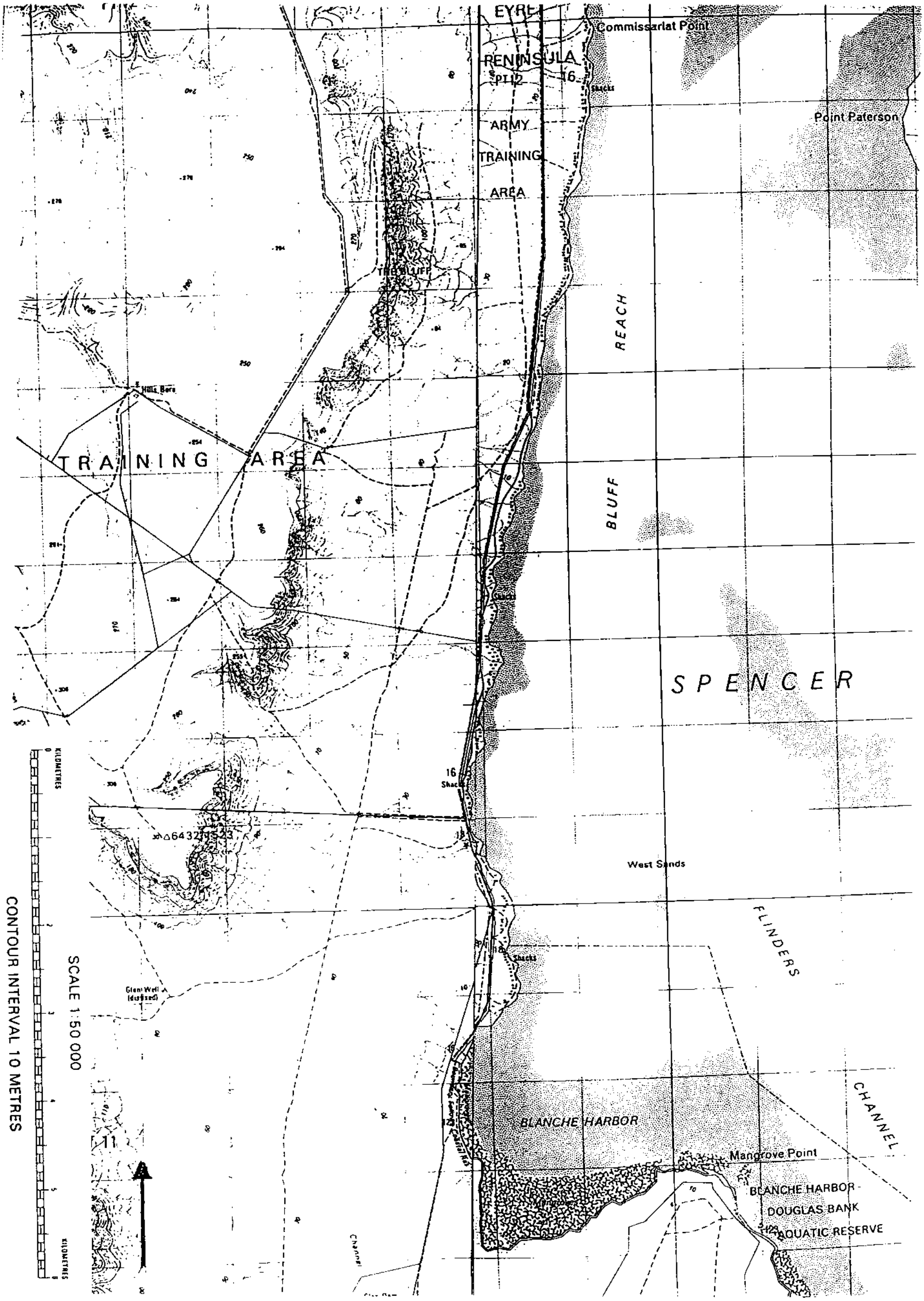


Figure 4.16: Blanche Harbour

Shepherd (1983) also pointed out that the sub-littoral zone on the western side of the Gulf, including Blanche Harbour, was once rich in the razor shell (*Pinna bicolor*). It provides an important substrate for colonisation by other organisms. The former South Australia Department of Fisheries has imposed a moratorium on the harvest of these animals, in this area, since 1989.

4.4.3 DEVELOPMENT AND OWNERSHIP

The Government Road, maintained by Port Augusta Council, is the primary access to Blanche Harbour. For short distances, local access tracks run parallel to the coast, some of them on the dunes and beach front area.

The 280 shacks in the area are served by an ETSA transmission line, and Telecom has provided a telephone service to some houses. Water is supplied by roof collection. Waste water disposal is undertaken by septic tanks, pit toilets and absorption methods.

As the area is heavily used for recreational purposes, boatramps, moorings and jetties are found along the coastline adjacent to the shacks. Fishing, boating, water skiing and crabbing are some of the recreational activities enjoyed by residents and visitors. According to the 1990 management plan, uncertainties over tenure have resulted in an accumulation of rubbish in some areas and some residences have been allowed to deteriorate.

4.4.4 FREEHOLDING AND WASTE DISPOSAL

Two basic scenarios exist in order to bring the waterfront area under local control: freeholding and leasing. Freeholding was assessed on site level only and was approved for 200 shacks above 2.96 m A.H.D. The remaining 79 shacks were not granted the right to freehold. According to a summary report by the Shack Site Freeholding Committee in November 1994, the shacks have not been assessed by the committee in relation to coastal hazards (tide and wave inundation and susceptibility to shore erosion). The figure of 2.96 m AHD did not include an allowance for wave effect or sea-level rise. Presently recommended minimum site and floor levels for the area are 3.65 m and 3.90 m AHD respectively. (pers. comm. Coastal Mangement Section).

A Land Management Agreement is being prepared for the 200 shack sites, and the 79 remaining shacks could be reassessed under this new agreement. Under this agreement shacks will have to obtain specific approval in relation to any effluent systems that are installed. Among the management plan's proposals, is a proposal that the area should be declared a septic tank zone and placed under the control of the South Australian Health Commission and the Local Board of Health.

According to a Report on the Treatment & Disposal of Domestic Wastes from The Blanche Harbour Holiday Homes, prepared as a supplement to the Blanche Harbour Holiday Homes Management Plan, there are three broad types of soil in which the disposal areas will be constructed: 1- shellgrit, 2-impermeable soil below the shellgrit layer, and 3- poor or good soakage soils where no shellgrit exists.

Approximately 149 homes are on type 1 soils, 120 on type 2 soils, and 11 on type 3 soils. Although most of the existing holiday homes are sited on shellgrit and apparently discharge wastes into this layer without causing pollution problems, Reilly (pers. comm., 1995) believes that the presence of significant quantities of the algae *Ulva* (a bio-indicator) indicates an increased level of nutrient is leeching into this zone.

Only 10% of the shacks already have septic tanks and disposal systems installed.

4.4.5 TECHNIQUE TO ASSESS COASTAL VULNERABILITY

Port Augusta Council, in 1985, engaged McGay Surveys Pty. Ltd., an independent survey company, to investigate the vulnerability of the 280 shacks sites at Blanche Harbour to the 1 to 50 year storm event. This event is a set of circumstances that could damage many holiday houses as it happened in the historical 1934 storm. The main aim of the survey was to find out the areas where development should be avoided and sites likely to be affected. This was a crucial point to the possible long term tenure options and the legal liability implications.

A subsequent detailed survey was carried out by the Coastal Management Branch of the Department of Environment and Natural Resources. The study indicated that the 2.96 A.H.D. level represents an approximate 1 in 50 year event.

According to the surveys, 170 shacks of the 280 meet the site level of 2.96 A.H.D. eligible for freeholding; 13 are in the situation of having one corner of a site being below 2.96 A.H.D. and one corner of the site being above 2.96 A.H.D., but are also considered eligible for freeholding; 18 have site levels below 2.96 A.H.D. but floor levels which are highly elevated, so considered eligible for freeholding. Out of the 280 shacks, 79 sites do not meet the criteria for freeholding because site and floor levels are below the 2.96 A.H.D.

Considering the 2.96 A.H.D. level at the survey's time, (now ammended, refer p. 107) the Port Augusta Council's Management Plan concluded that 28% shacks are not suitable for freeholding while 72 % are considered eligible for freeholding. It was also pointed out by the survey that new sites should at least be 30m from the waterfront and preferably 50m.

4.4.6 VULNERABILITY ASSESSMENT

Flooding And Sea-Level Rise

The waterfront houses are built behind and very close to the mangroves as they occupy the sand dunes areas. The Port Augusta Council's Management Plan has reported that some shacks are subject to inundation by tidal waters.

During large tidal surges that have occurred in the region, low-lying areas in the Northern Spencer Gulf were flooded. These events are more likely to occur during winter, when combined meteorological and hydrological conditions favour these events. Tidal surge reported in 1981 at the Playford Power Station was 2.9 m A.H.D. In 1934 a storm surge reached 3.05 A.H.D. The frequency of these tidal surges are predicted to increase with rising sea levels.

One of the council's management plan proposals states that fences will not be permitted either on leasehold or freehold allotments, but it does not mention sea walls. If sea- level rises, it is likely sea walls or levees may be constructed, which could have an impact on the intertidal ecosystems and cause a redistribution of sediments in the area.

The shacks vulnerable to sea-level rise, but this area of the coast is quite "strong" and future seawall building is unlikely to be an issue. As the ground rises quite rapidly inland from the coast mangrove and samphire retreat is limited.

Pollution

Reilly, in his report on possible sources of marine contaminants to the Northern Spencer Gulf, 1991, has noted that the development of shacks in Blanche Harbour area contribute significant levels of heavy metals to the marine environment. It appears that shack and boat owners have been dumping car bodies and other waste scrap into the Gulf to create artificial fish habitats. Metals leach into the Gulf waters from this source. Septic and pit toilets are also expected to be contributing significant levels of heavy metals and nutrients to the Gulf through seepage and overflow. Photograph 3 illustrates the stockpiling of metals which may be used for the creation of an artifical reef within an aquatic reserve.

As there is an impermeable layer under the shellgrit, pollution of the shore and waters could occur from effluent discharging into shellgrit.

Discharged water would travel laterally along the surface of the impermeable sub layer and pollute the shore or water body. In order to cope with this problem, it is recommended, by the report on the Treatment & Disposal of Domestic Wastes from the Blanche Harbour Holiday Homes, the total quantity of water available be limited and the highly polluted proportion of water discharged be minimised. A split system is also recommended in shellgrit disposal areas as it is less likely to cause pollution problems.

Photograph 3: Shack residents stockpiling metal for creating artificial reefs in Aquatic Reserve.

Blanche Harbour is exempted from the Regional Coastal Areas Policy-Supplementary Development Plan in relation to principle 7, among others, which states: "Effluent disposal systems incorporating soakage trenches or a similar system should be located not less than 100 m or greater where it is necessary to avoid effluent migration onto the inter-tidal zone, the 100 m to be measured from: (a) the mean high water mark at spring tide adjusted for any subsidence for the first 50 years of development plus a sea-level rise of 1.0 m; or (b) the nearest boundary of any erosion buffer determined in accordance with principle 27, whichever is the greater. Except where health commission standards can be met by a lesser setback".

This exemption presents a threat to the ecosystems at the intertidal zone as effluent migration to this zone is likely to increase with sea-level rise.

CHAPTER 5 - CURRENT GOVERNMENT POLICY.

5.1 COMMONWEALTH RESPONSIBILITIES

The Commonwealth, through its responsibilities under the external affairs powers is required to ensure that Australia's obligations under international treaties and conventions are met. Examples which relate to the Northern Spencer Gulf include:

Protection of the Sea (Civil Liability) Act 1981
Protection of the Sea (Powers of Intervention) Act 1981
Protection of the Sea (Prevention of Pollution from Ships) Act 1985

The Commonwealth government is also party to international agreements that are directly related to climate change and coastal zone management. Australia is a signatory to the UN Framework Convention of Climate Change which calls for coastal states to develop programs for coastal zone management to address the impacts of climate change. Policy responses also occur with respect to the activities of the Intergovernmental Panel on Climate Change (IPCC) and the National Greenhouse Response Strategy (NGRS). Australia has also contributed to a number of other international bodies related to climate change such as the Geosphere Program (IGBP) and the Organisation for Economic Co-operation and Development (OECD), Environment Policy Committee. Australia has endorsed the document *Agenda 21: Programme of Action for Sustainable Development* which resulted from the UN Conference on Environment and Development (UNCED). Chapter 17 of *Agenda 21* expressed the urgent need for coastal states to develop capabilities for national Integrated Coastal Zone Management (ICZM).

Coastal Zone Management is also relevant to the Convention for the Conservation of Biodiversity, The Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention) 1971, the China-Australia Migratory Bird Agreement (CAMBA) and the Japan-Australia Migratory Birds Agreement (JAMBA).

Other federal legislation that impacts on the coastal areas of the Northern Spencer Gulf includes:

Australian Heritage Commission Act 1975
Environment Protection (Impact of Proposals) Act 1974
Fisheries Management Act 1991
National Parks and Wildlife Conservation Act 1975
World Heritage Properties Conservation Act 1985

5.2 STATE POLICIES

The State government department which has greatest responsibility for the coastal zone is the Department of Environment and Natural Resources (DENR). Within this department is the Coastal Management Section (CMB), which carries out the executive functions of the Coast Protection Board as outlined in the *Coast Protection Act 1972.* The general duties of the Board and hence the CMB are to protect and restore the coast from erosion, damage, deterioration and other misuse. Other duties include research of coastal management matters, guidance in the development of coastal areas in an environmentally sound manner and working through local government to provide advice and funding on flooding and erosion issues.

The Environment Protection Authority (EPA) is also located within DENR and its responsibilities to the coast relate to the monitoring of marine discharges of wastewater and stormwater and general environmental quality monitoring under the *Environment Protection Act, 1994.* Under the provisions of the act Environmental Improvement Plans must be prepared and operating by 2001 for any enterprises which discharge wastes into the marine environment Initial plans have been prepared for BHP, BHAS, ETSA and water treatment plants in the region. Many other Branches of DENR also are relevant to coastal zone management such as the State Heritage Branch, the Resource Conservation and Management Group, the Resource Information Group, the Water Resources Management Group, the Land Services Group, State Heritage Branch, and the Natural Resources Council. Legislation administered by the department includes:

Coast Protection Act 1972
Environment Protection Act 1994
National Parks and Wildlife Act 1972
Water Resources Act 1990
Native Vegetation Management Act 1991
Wilderness Protection Act 1992
Aboriginal Heritage Act 1988
Heritage Act 1995
South Australian Heritage Act 1978
The Crown Lands Act 1929

The Department of Housing and Urban Development is responsible for the administration of *The Development Act, 1995* and hence the planning system in South Australia. The way the system is currently operating is addressed in the following section.

Other government departments with responsibilities in the coastal zone relevant to the Northern Spencer Gulf include the Department of Primary Industries, with the divisions of Fisheries and Agriculture, the Department of Transport which includes the Marine and Harbours Agency, Mines and Energy S.A., the South Australian Research and Development Institute, the South Australian Tourism Commission, the Department of Aboriginal Affairs, The Electricity Trust of South Australia, Engineering and Water Supply, the Pipelines Authority of South Australia and the Department of Premier and Cabinet.

Legislation that these departments are responsible for administering in addition to that listed above includes:

Development Act 1995
Electricity Trust Act of South Australia 1946
Fisheries Act 1982
Harbours Act 1956
Mining Act 1971
Pipelines Authority Act of South Australia 1969
Soil Conservation and Land Care Act 1989
Local Government Act 1954
National Environment Protection Council (South Australia)Act 1995

It should be noted that many of these departments and their agencies have overlapping functions and jurisdictions in the coastal zone. Lack of co-ordination between key agencies has been identified as a constraint to integrated coastal zone management.

Policies related to the impacts of climate change

In 1991, the Coast Protection Board issued a *Policy on Coast Protection and New Coastal Development*, which was endorsed by the then state government.

Sea-level and coastal hazard policies have subsequently been included in planning principles for the State through the Regional Coastal Areas Policies Plan Amendment Report which was authorised in September 1994. Country-wide principles from this report are included in Appendix 3.

Essentially development needs to be safe for a 0.3 m rise in sea-level (1.0 m in special circumstances) and needs to be safe, or capable of being protected against 100 years of coastal erosion, allowing for the erosion that a 0.3 m sea-level rise would cause. Protection must not compromise the coastal environment or cause damage to adjacent property, and guarantees may need to be in place to ensure that it is built when needed and funded by the property owner. Figure 5.1 illustrates these guidelines.

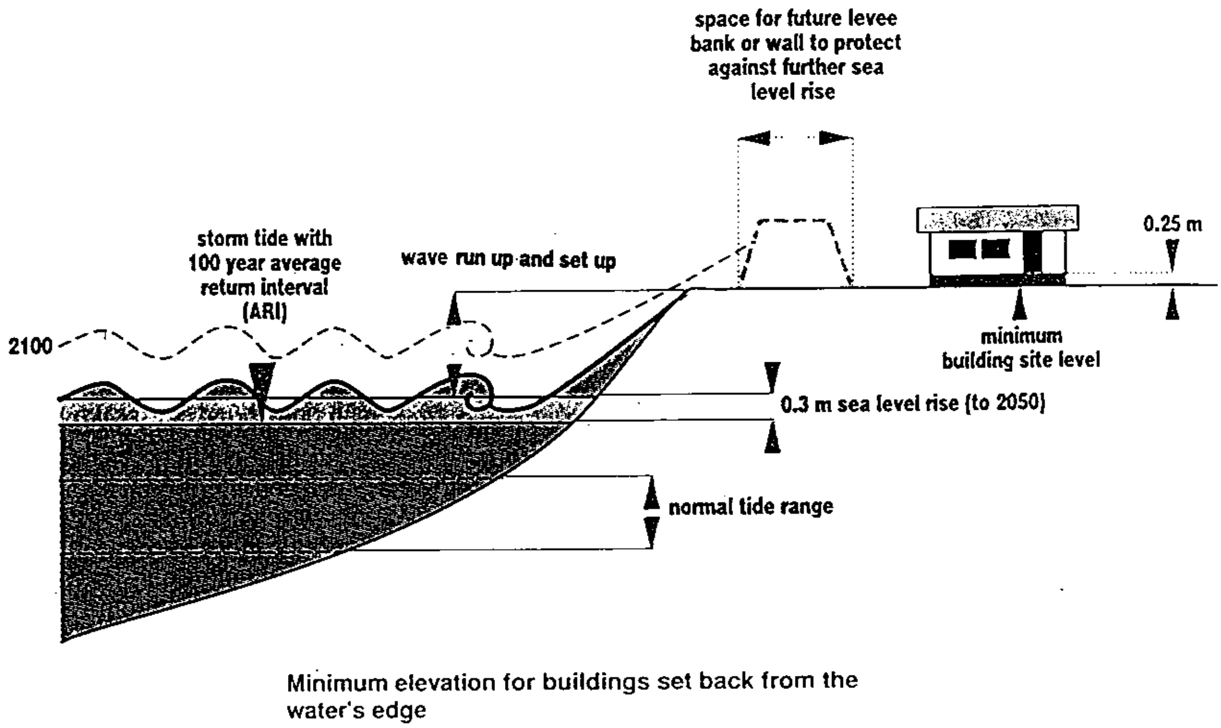


Figure 5.1: Sea Level and Flooding Standards (source: Coast Protection Board, 1991)

5.3 CURRENT PLANNING SYSTEM

From the 15th January 1994 the development and planning process in South Australia has operated under the Development Act, 1995 (& Regulations) which is administered by councils and the Minister for Housing & Urban Development (DHUD). Prior to this the Planning Act, 1982 applied. The new system allows for the on-going integration of various pieces of legislation relating to development assessment and aims to provide a 'one-stop-shop' development assessment procedure for its users.

Under the new planning system local government is given greater responsibility for assessing development. Local councils are the first point of contact for lodging land-use development applications, which are compared with the Regulations to define the nature of development to be assessed in the appropriate manner. The application is then either assessed against the objectives of the Development Plan and/or the Building Rules or forwarded to the Development Assessment

Commission (DAC) for assessment. Applications involving land division, land outside council areas or development undertaken by councils must be lodged with the Commission.

Development projects that are judged to be of major social, economic or environmental significance are subject to the Environmental Impact Statement (EIS) process. Reference is made to policy documents (ie. the Planning Strategy and the Development Plan) and where relevant the Coast Protection Board is consulted during the EIS process.

Where the council is deemed to be the relevant authority an application must be compared with the Development Plan to determine whether the proposed development is complying, non-complying or to be judged on merit. Complying developments are listed in the Regulations or more extensively described in the relevant Development Plan and generally include building works (ie. minor alterations, demolition and/or reconstruction of a building, fencing or construction of a water tank), land division (ie. for road widening or single allotment division/alteration) or special cemetery buildings.

Non-complying development is of a particular nature listed in the Development Plan that is generally deemed to be inappropriate and must be considered as to whether it is seriously at variance with the objectives and principles for a particular zone or policy area. Where a development is not listed as complying or non-complying it is considered on its merit and assessed having regard to the objectives and principles of the Development Plan.

Referral to Coast Protection Board

For development near the coast a council must refer an application to the Coast Protection Board for comment, which must be taken into account when a decision on an application for approval is made. Consultation may also involve Ministers (ie. government departments) who are responsible for State heritage items, Aboriginal heritage, water resources, mining, and activities of environmental significance as required by the Act and Regulations.

However, complying development and some relatively minor forms of development, such as the construction, alteration or addition to a farm building, alteration to or construction of a building to facilitate the use of existing building, are exempt from referral.

The Coast Protection Board frequently recommends conditions of approval such as minimum building site and floor levels and set backs for erosion. However, these are not mandatory. Schedules 2 and 8 of the Development Regulations provide stronger powers on excavating and filling at the coast (79 cubic metres) and on coast protection works of all kinds. These are defined as development for which the Board has a power of direction over the desicions of a planning authority.

Government Policy on the Coast

Previously coastal issues were addressed through the preparation of Coast Protection District Management Plans under the Coast Protection Act, 1972. Although the Plans had no legal status as policy documents, their coastal policies were often included into the Council parts of the Development Plan under the Planning Act, 1982. This proved to be an important tool for promoting wise coastal development and avoided the costly mistakes of the past. However, this was done on an ad-hoc basis and was not consistent across all councils, especially those that did not have a Management Plan prepared, such as the Spencer District which includes the Northern Spencer Gulf. There were also difficulties in keeping existing plans up to date and concerns that they were not contributing greatly to improving management of the coast.

The inclusion of development principles with in the State's Development Plan was seen as a more effective way to encourage appropriate use and development of the coast. Coastal development policy and standards were progressively incorporated into Council Sections through Supplementary Development Plans (SDP's). However, this has resulted in a situation where the Development Plan has gaps, inconsistencies and duplications between the Regional and Council parts.

Regional Coastal Areas Policies Plan Amendment (1994)

The Regional Parts of the Development Plan previously contained few references to coastal development and did not provide adequate policy on the form and location of development, protection of the environment, the provision of coastal protection works or coastal hazard and sea-level rise implications. More importantly, they did not provide a sufficient framework for council's preparation of detailed council-wide and zone policies. The Council-wide sections also varied considerably and were inadequate compared with current Government policy.

Thus, the Regional Coastal Areas Policies Plan Amendment was prepared to establish broad regional objectives for coastal development and to introduce uniform general objectives and principles of development control in the council-wide sections for all coastal areas in the State. The Plan Amendment incorporated aspects of existing Development Plan policies, Coastal Management Plan policies, Flooding/Erosion policies of the Coast Protection Board, the Policy on Coast Protection and New Coastal Development (1991), planning reports, and Government comments into a single policy.

Development Plan Amendment Process

A council can amend a Development Plan by preparing a Planning Assessment Report (PAR), which replaces the Supplementary Development Plan (SDP) process under the Planning Act, 1982. A PAR may be prepared either by council, a group of councils or the Minister for Housing and Urban Development for the whole, or part of, a council area to address general or specific issues. Amendments could include changes to zoning or lists of complying/non-complying development or policies relating to housing design, industry areas and centres, residential, commercial or open space areas and environmental protection. The Development Plan may adopt, wholly or partially, any plan, policy, standard, document or code prepared or published under the current or any other Act, or by a body prescribed by the regulations.

All councils are now required to review their policies by the end of 1996, with a first review completed after 5 years and subsequent reviews every 5 years.

Relevance to the Northern Spencer Gulf

The prescribed amendments in the Regional Coastal Areas Plan Amendment have now been incorporated by all five District Councils of the Northern Spencer Gulf into both the Regional and council-wide sections of the Development Plan. As previously noted, exemptions have been made for the Blanche Harbor area.

However, the planning system in South Australia is currently in a transitional phase while the functions of the Development Act, 1995 replace those of the Planning Act, 1982. The Planning Strategy is now the key policy reference that provides guidance on issues of regional significance and outlines goals and strategies for areas of importance to the State, such as the coast.

A Planning Strategy for Country South Australia was produced by the Department of Premier and Cabinet in January, 1994. This incorporates the objectives of the regional sections of the Development Plan. As regional planning strategies are prepared they will supersede the relevant sections of this volume of the Planning Strategy.

The Regional Coastal Areas Policies are set out in the Regional and Council-wide parts of the Development Plan and affect all councils located on the coast or areas which could be affected by coastal processes. The policies relate to:

- Sea level rise,
- Hazard risk,
- Protection of important environmental areas,
- Preservation of sites of heritage, cultural, scientific or landscape importance,
- Maintenance of access to the coast,
- Consideration of the costs of development on hazard risk areas and the principle that the community should not bear this, and
- Protection of key economic and physical resources of the coast.

When the Regional Coastal Areas Policies Plan Amendment was authorised it was envisaged that Regional and Local Strategy Plans would need to be prepared to complement the policies in the Development Plan. It is envisaged that local and regional groupings of councils would prepare regional and local strategies, identify site specific approaches to management of development on the coast and create specific zones and policies to facilitate orderly and planned development in local areas.

Effectiveness of the Current System

The Regional Coastal Areas Policies provides the opportunity to address the inconsistencies and gaps across local planning policies that have arisen in the past and establishes wide ranging, updated policies which are generally consistent for all council areas.

Local councils have been given greater responsibility for determining development applications, although any decisions made by council for development on coastal land need to have regard to the recommendations of the Coast Protection Board (especially for excavating/filling land or coast protection works) and any other relevant government department. Complying development is exempt from referral.

Therefore, the effectiveness of implementing the policies of the Regional Coastal Areas Policies Plan Amendment is dependent on :

- councils having regard to the policies in the Development Plan when making a decision on 'minor' development applications,

- councils having due regard to the recommendations of the Coast Protection Board where required to by legislation,

- councils referring applications involving land division or more serious planning implications to the Development Assessment Commission or the Environmental Impact Assessment Branch (DHUD),

- councils regularly amending the Development Plan to include the most current coastal policies as determined by the Coast Protection Board,

- councils referring to the Planning Strategy during the PAR process (ie. to ensure uniform policy is adopted), and

- councils consulting with the Coast Protection Board on issues relating to the coast when preparing PAR's.

5.4 LOCAL GOVERNMENT POLICY

There are five local government areas with responsibilities for the Northern Spencer Gulf. These are the District Council of Port Pirie, the City of Port Pirie, the District Council of Mount Remarkable, the City of Port Augusta and the City of Whyalla. The local government authorities are primarily responsible for the care, control and management of coastal lands under their jurisdiction. This includes all crown land to 50 metres from high-water mark, or the nearest freehold boundary. However, any approval for development within this zone must be undertaken through the provisions of the *Development Act 1995.* As noted above the Regional Coastal Area Policies should now be included in Planning Amendment Reports of all the coastal council areas.

The Cities of Port Pirie, Port Augusta and Whyalla have not produced their own coastal management plans relating state objectives to local conditions. However, the City of Whyalla in conjunction with the then Department of Lands has produced the *Fitzgerald/False Bay Management Plan* in 1989. The aim of the plan is to "maintain and enhance the environmental quality of the False Bay to Douglas Point coastal region, by the effective management of the area's use and development for recreational purposes'. Further development in the False Bay woodland, waterfront and residential development in the Fitzgerald Bay-Douglas Point area or the Point Lowly peninsula has been prohibited (Department of Lands, 1988).

The City of Port Augusta produced a *Holiday House and Beachfront Management Plan, Areas 95 -101, Blanche Harbour.* in November, 1990. This plan is exempt from some of the objectives of the Regional Coastal Areas Policy as discussed in Section 2 and Section 4.

The Cities of Port Augusta and Port Pirie have undertaken tidal flood studies from Langes, Dames and Australia Pty. Ltd., in 1991. While Port Pirie is proceeding with the recommended work Port Augusta is undertaking further studies before initiating protection works.

5.5 REVIEW OF COAST PROTECTION ACT

In 1992 there was a review of coastal management arrangements in South Australia which included the objectives and issue and requiring extensive public consultation. A Green Paper was published in 1992 but funding became an issue. This was only resolved in January 1995 with the signing of a coastal management agreement between State Government and the Local Government Association. Completion of a White Paper and a draft Bill is presently being deferred pending completion of a new review into protection and sand management for the Adelaide Coast. Legislation is anticipated in 1996.

Caton, 1994, notes that the public response to the Green Paper did not demand radical changes to coastal management, rather it looked to a continuation of existing arrangements. Since these had evolved sectorally over the previous two decades a continuation would not lead to a more integrated approach: such a change would have to be proposed by the Review Group. But it was the circumstances of the Review which dictated the agenda. In the twelve months prior to the Green Paper the State had drastically cut funds to coastal management, a move which greatly angered seaside councils, especially metropolitan ones, who were thereby placed under pressure to increase their own spending.

The reaction to this considerable weakening of state effort was felt in the review, where the role of the Coast Protection Board and the Coastal Management Section was strongly supported by local government and community groups. However, the financial pressures led to a focus of attention on the division of financial responsibility for coastal management between State and Local Government. At the same time of sharp funding cuts government departments saw their priority as maintainance of core functions: integration of the coastal management activity between a number of state agencies was not a high priority at that time. Caton concluded that until this situation changed, planning and action for co-ordination of Agencies must be driven from 'below', relying on the community, local government and regional support.

5.6 SHACK POLICY

In December, 1994 the State Government approved as policy the freeholding of a number of shack sites on Crown land along the coast of South Australia. A number of criteria related to issues such as public health/effluent disposal, creation of allotments/land division and allotment size, erosion and flooding, legal and public access, environmental considerations and freeholding costs have been addressed by the Shack Site Freeholding Committee and must be met by shack owners prior to freeeholding occurring.

It will be a requirement that before a freehold title will be issued, the lessee of any shack site should sign a legally binding agreement that indemnifies the Crown and Local Government against any future claim resulting from erosion or flooding. It will also be a requirement that where protection works are required these must comply with planning criteria, (refer Appendix 3) and they must be funded at the shack owners expense.

If the Coast Protection Board is to give weight to protection of the coastal environment, it may need to direct that approval of seawalls be refused at Blanche Harbor and some of the other shack settlements in the region. Given expectations following freeholding, this could lead to a difficult political decision in which the environment could be the loser.

The need to exempt the shack areas from provisions of the development plan or to alter the plan to apply to lesser standards also raise difficulties and could result in a lowering of coastal development standards, especially in relation to safety against erosion and flooding due to sea-level rise.

This situation is already exemplified in the Northern Spencer Gulf where the provisions of the Blanche Harbour Management Plan have been exempt from parts of the Regional Coastal Areas Policies Plan Amendment. To be consistent with the latter plan building sites should be approximately 0.6 metres above the level adopted for freeholding.

The Blanche Harbour Management Plan is also exempt from three of the basic principles (7, 15 and 25 of Attachment C) of the Coastal Areas Policy. These relate to the location of effluent disposal systems, a 50 metre buffer zone, and increased site height to account of future sea level rise as outlined in the CPB policy (i.e., 0.3 metres to 2050).

The response option of relocation has been considered for the area, but was found not to be a practical or economic solution. According to the management plan, the cost/benefit equation falls in favour of retaining the holiday house status quo. The costs to relocate an average home of 80 square metres would be about $15,000 and the benefits applicable about $7,000, while the market value of a home in the area is about $20,000. However, the management plan does not outline what these benefits are likely to be.

The shack sites at Blanche Harbour were excluded by the Shack Site Freeholding Committee's review due to the proposed Blanche Harbour Management Plan.

CHAPTER 6 - CONCLUSIONS AND RECOMMENDATIONS

The study area for the South Australian Coastal Vulnerability Assessment Study was selected based on a perceived opportunity to integrate the study with a major regional economic strategic study which was being undertaken for the region. However, the strategic study rapidly changed its focus and became much broader than just the Northern Spencer Gulf. This change, together with a strong emphasis on economic factors meant that coastal matters were given a low priority.

In attempting to use the Kay and Waterman revised methodology, it became apparent that their stages 1-4 were not mutually exclusive and did not necessarily progress from one stage to the next. For example, given the regional approach of the NSG study, one of the first steps was to examine the regional perspective including the socio-economic aspects and the interconnectedness of the coastal zone with the overall region. Based on this perspective, the study then approached the delineation of the impact zone.

The NSG study also took a broader approach to impact assessment than the Kay and Waterman methodology, which is directed to the impacts of climate change and sea-level rise. The NSG is perhaps unusual in that it has a Holocene geological record of sea-level fall, which has also been identified in the Port Pirie tidal data. However, coastal flooding, oil spills, industrial pollution and inappropriate planning all contribute to coastal vulnerability in the area. It is likely that many anthropogenic impacts on the coast could outweigh any predicted impacts from climate change and sea-level rise.

The NSG study attempted to incorporate aspects of ICZM as outlined in the World Coast Conference 1993 Report, but this proved difficult because South Australia, like most other States of Australia, does not have an integrated coastal zone management system. The study confirmed the observations which Mr Caton, Chairman of the South Australian Coast Protection Board made at the 1994 National Coastal Managment Conference.

The South Australian Coastal Vulnerability Assessment Study was conducted in one of Australia's few inverse estuaries, the Northern Spencer Gulf. The region is in an arid environment with a relatively sheltered coast, unaffected by swell waves. There are wide mudflats, sand and sea-grass banks, mangroves and extensive supratidal areas subject to tidal flooding. Potential sea-level changes are important for the area given existing flooding problems in two of the three cities in the region.

The study produced an overview of the biophysical and socio-economic characteristics of the region drawing on aspects of regional strategic studies funded by the Commonwealth and State governments. In particular, it noted the dominance of industrial and economic activity in the three cities, Whyalla, Port Pirie and Port Augusta. The study examined coastal vulnerability using existing contour data, flooding data, tidal studies, and biophysical information stored on GIS databases. For example, previous tidal studies indicated the general north-south movement of tides in the region but also showed some complex tidal gyres around Lowly Point and some of the sand banks. This complexity in flow pattern indicated the need for further model studies in relation to sea-level variations, in particular for studying the impacts on the prawn industry in the area.

Further vulnerability data were collected from four coastal sites; two industrial cities with sheltered coastal environments and extensive intertidal and supratidal deposits in the north and eastern part of the Gulf; one less developed holiday shack area on the north-western side of the Gulf; and a south facing bay of conservation value and low scale industrial usage.

First, at Port Pirie, an industrial city with a flood history, flooding studies had resulted in construction of protective works across the supratidal flats. A detailed levelling and vegetation survey provided an insight into the potential effects of sea-level change on vegetation communities in the area. Second, at Port Augusta, a flood hazard study had been conducted following previous coastal flooding problems. The response in that city, like Port Pirie is to construct protective works. .

Third, Blanche Harbour on the northwestern side of the Gulf has extensive holiday shack development where building levels are inconsistent with State government coastal hazard policies. Options for relocation are too expensive and private protection works may cause future problems if allowed.

Fourth, False Bay, near Whyalla is flanked by industrial development but is an important conservation area for prawn larvae. At this site aerial photogrammetry together with ground based survey was used to produce a detailed contour map with 0.5m intervals. Results indicated the restricted areas, caused by levee construction for salt production, available for mangrove and samphire migration in the event of sea-level rise. This technique was relatively expensive.

Another technique investigated was the use of detailed GIS based Holocene geological maps, to identify levels of susceptibility to coastal flooding. This technique could be relatively inexpensive, accessible and useful for coastal managers around Australia, where there are low gradient intertidal and supratidal deposits.

The four sites selected illustrated aspects of the IPCC response strategies of protection, relocation and adaptation in response to sea-level rise. At Port Pirie and Port Augusta, where residential and industrial areas are at risk there has been a response of protection. At Blanche Harbour, the strategy of relocation was considered but ruled out because of its expense. As a result, the adaptaion has been by way of a policy compromise. At False Bay, the low level industrial use requires flooded areas for salt production. At present, the levees are there to contain the water rather than prevent intrusion.

Interaction with community groups and local government, indicated pockets of expertise which would benefit from further interaction with State and Commonwealth coastal programs. Existing State coastal policies appear appropriate for responding to sea-level rise scenarios but are compromised by conflicting policy decisions on shack freeholding. In addition, the success of the policies rely to a large extent on implementation and monitoring by local councils.

The NSG study has generated interest and momentum in addressing the issue of coastal vulnerability. There will be an immediate flow on in terms of seminars and presentations and further studies. What is important is information flow between State government departments and the local coastal managers. At present there are a number of natural resource related departments with coastal interests. These need to have strong linkages with planning and economic development sections of government.

While it would be useful to provide additional resources for coordination of coastal matters within the various government departments, this is unlikely given the fact that most of these departments have recently suffered staff cutbacks. The most practical solutions will be low cost cooperative efforts using existing or redirected resources from the State government, perhaps with capacity building monies contributed from the Commonwealth government in line with its recently released Coastal Policy.

RECOMMENDATIONS

A number of recommendations have been drawn from this study. These are grouped into four categories.

1 Techniques and Methodology

1.1 There should be an initial 'scoping' of coastal vulnerability issues to determine priority areas or priority sites within a region.

1.2 Priority sites or areas should be defined on the basis of both biophysical significance and economic importance, and should not be restricted to climate change and sea-level rise impacts.

1.3 There should be a pragmatic approach to the acquisition and use of existing coastal vulnerability data (these data may determine the types of techniques to be used in the study).

1.4 There should be an attempt to use easily accessible and nationally available information such as geological GIS data bases, to provide local coastal managers with a broad overview of coastal vulnerability for their area of responsibility.

1.5 Detailed coastal vulnerability assessment techniques should be selected according to the issues and their priority. (For example, the levelling and vegetation survey technique will be applicable for areas of conservation significance. The detailed aerial photogrammetry, ground-truth surveying and GIS manipulation is relatively expensive and is more suited to areas of high economic value).

1.6 Coastal processes data should be collated for vulnerable areas as an important supplement to data on sea-level variation, and where possible detailed coastal models developed.

2 Administrative and Capacity Building

2.1 There should be greater attention given to the notion of Integrated Coastal Zone Management in South Australia. This could be achieved in conjunction with the Natural Resources Council in its push for 'integrated natural resource management', provided that it incorporates planning and economic strategic planning.

2.2 There should be a series of coastal workshops provided for local coastal managers and community groups about the implementation and monitoring of South Australia's coastal hazard policy and responses to coastal vulnerability. This should be supplemented with coastal information in Local Government newsletters and electronically on their Information Network (such information might for example, include infromation on the recreational use of samphire and mangrove communities and the effects of protection works on mangrove retreat).

2.4 There needs to be enforcement of EPA legislation to ensure that point sources of pollution are kept to a minimum. For example, one of the major hazards for the area is the pollution emanating from BHP and BHAS, both of which are operating under an indemnity

3 Integrated Coastal Zone Management

3.1 ICZM related conditions should be considered between the State and Commonwealth Government in relation to coastal funding to the State government.

3.2 The Commonwealth government should provide support staff to disseminate information and resources to facilitate the implementation of ICZM.

3.3 The Coastal Management Section should investigate mechanisms for integrating detailed information on the coastal hazards of Northern Spencer Gulf (including the effects of potential climate change) into management plans for the area.

3.4 The Natural Resources Council should take an active role in ICZM as part of its integrated natural resource management approach, in particular paying attention to the separation of the environment and planning portfolios.

3.5 Local government should establish a mechanism for incorporating community and indigenous group perspectives as part of the ICZM approach.

4 Further Studies in South Australia

4.1 In South Australia there should be additional vulnerability studies conducted for high energy coasts experiencing swell waves, in particular, cliffed coasts and sand barrier coasts.

4.2 Further studies are required on seagrasses, pollution, oceanographic studies to determine complexity of potential changes to flow patterns and their effects.

4.3 There is a need for an integrated oil pollution plan which includes costs and mechanisms of monitoring. In adition there needs to be immediate and direct access to accurate modelling of oil spills which can be incorporated into response strategies.

BIBLIOGRAPHY

AG Consulting Group Pty. Ltd. (1989a). *Port Pirie Development Committee Aquaculture at Port Pirie: A Preliminary Feasibility Study.*

AG Consulting Group Pty. Ltd. (1989b). *Whyalla Investment Park Declaration of Environmental Factors.* Report for the Office for Technology and Special Projects, Dept. of State Development & Technology, S.A.

AGC Woodward-Clyde. (1991a). *Greenhouse Effect on Groundwater Levels at Port Pirie.* . Report for Lange Dames & Campbell, S.A.

AGC Woodward-Clyde. (1991b). *Greenhouse Effect on Groundwater Levels at Port Augusta* . Report for Lange Dames & Campbell, S.A.

Ainslie, R. (1988). "Potential Greenhouse Impacts on the Biology of the Shallow Waters of the South Australian Gulfs, and on the Grey Mangrove, *Avicennia marina*.". In *Proceedings of the Greenhouse'88, Planning for Climate Change Conference* , chapter 5, Coastal and Marine Systems; Adelaide, South Australia; pp.93-98.

Ainslie, R. C., Johnston, D. A., & Offler, E. W. (1989). "Intertidal Communities of Northern Spencer Gulf, South Australia." *Trans. R. Soc. S. Aust.* **113:** 69-83.

Ainslie, R. C., Johnston, D. A., & Offler, E. W. (1994). "Growth of the Seagrass *Posidonia sinuosa* Cambridge *et* Kuo at Locations near to, and Remote from, a Power Station Thermal Outfall in Northern Spencer Gulf, South Australia." *Trans. R. Soc. S. Aust.* **118**(3): 197-206.

Assessments Branch (1992). *Titanium Dioxide Manufacturing Plant, Whyalla; Assessment Report.* Department of Environment and Planning, SA.

Bayard, A. (1993). *An Investigation of Mangrove Dieback and Loss at the Northern Power Station Unit, Port Augusta.* A report compiled as a consultancy to the South Australian Fisheries Department in conjunction with ETSA.

Belperio, A. (1993). "Land Subsidence and Sea Level Rise in the Port Adelaide Estuary: Implications for Monitoring the Greenhouse Effect." *Australian Journal of Earth Sciences,,* **40**: 359-368.

Belperio, A., Hails, J., Gostin, V., & Polach, H. (1984). "The Stratigraphy of Coastal Carbonate Banks and Holocene Sea Levels of Northern Spencer Gulf, South Australia." *Marine Geology*, **61:** 297-313.

Body, P.E., Inglis, G.R. & Mulcahy, D.E. 1988. Lead Contamination in Port Pirie - South Australia. A report for the Department of Environment and Planning, South Australia.

Bullock, D. (1975). "The General Water Ciculation of the Spencer Gulf, South Australia in the Period February to May." *Trans. R. Soc. S. Aust.* **99:** 43-55.

Burne, R.V. & Colwell, J.B. (1982). "Temperate Carbonate Sediments of Northern Spencer Gulf, South Australia: a High Salinity 'Foramol' Province." *Sedimentology*, 29: 223-238.

Bye, J. (1981). "Exchange Processes for Upper Spencer Gulf, South Australia." *Trans. R. Soc. Aust.* **105** (2): 59-66.

Caton, B. (1994). "Coastal Management Arrangements: A State's Prespective". In *Proceedings of the Coast to Coast '94, A National Coastal Management Conference*, Hobart, Tasmania; pp. 31-33.

Caton, B. & Elliot, I. (1993). "Coastal Hazard Policy Development and the Australian Federal System." *Vulnerability Assessment of Sea Level Rise and Cosatal Zone Management;* Proceedings of the IPCC Eastern Hemisphere Workshop, 3-6 August; Tsukuba, Japan; pp. 417-427.

Coast Protection Board. (1991). *Policy on Coastal Protection and New Coastal Development.* Government of South Australia.

Coast Protection Board. (1992). *Coastline: Coastal Erosion, Flooding, & Sea Level Rise Standards and Protection Policy.* **26.** Government of South Australia.

Coastal Investigations Unit (1992). *Victorian Coastal Vulnerability Study.* Port of Melbourne Authority, Victoria.

Corporation of The City of Port Augusta. (1990). *Holiday House & Beachfront Management Plan; Areas 95 to 101, Blanche Harbour.*

Dames & Moore Pty. Ltd. (1991). *Draft Environmental Impact Statement; Titanium Dioxide Manufacturing Plant.* Prepared for Tioxide Australia Pty. Ltd.

Department of Environment and Planning. (1987). *Whyalla Boat Harbour Development-Assessment Report.* Government of South Australia.

Department of Lands (1988). *Fitzgerald/False Bay Management Plan.* Government of South Australia.

Department of Marine & Harbors (1993). *Northern Spencer Gulf Resource Processing Strategy; Working Paper 3: Marine Safety Strategy.,* S.A.

Easton, A. (1978). A Reappraisal of the Tides in Spencer Gulf, South Australia. *Aust. J. of Mar. Freshw. Res.* **29:** 467-77.

Environmental Impact Assessments Branch (1993). *Spencer Gulf Ferry Proposal: Assessment Report.* Department of Housing and Urban Development, Government of South Australia.

Environmental Resources of Australia (1973). *Hydrological Survey - Northern Spencer Gulf.* Prepared for the Petrochemical Consortium of SA.

Goodwins, K., Rowe, K., & Nicolson, K. (1993). *Northern Spencer Gulf Resource Processing Strategy; Working Paper 1: Land Suitability.* GIS Section, Dept. of Housing & Urban Development, Government of South Australia.

Gostin, V., Hails, J., & Belperio, A. (1984). "The Sedimentary Framework of Northern Spencer Gulf, South Australia." *Marine Geology,* **61** (2/4): 111-138.

Green, H. (1984). "Fluid Transport Processes in Upper Spencer Gulf." *Marine Geology,* **61:** 181-196.

Hails, J., Belperio, A., & Gostin, V. (1984). "Quaternary Sea Levels, Northern Spencer Gulf, Australia." *Marine Geology,* **61:** 373-390.

Hails, J. & Gostin, V. (1978). "Stranded Shingle Beach Ridges, Upper Spencer Gulf, South Australia: Evidence for High Wave Energy Dissipation During the Late Pleistocene." *Trans. R. Soc. S. Aust.* **102:** 169-173.

Hails, J. , Gostin, V., & Sargent, G. (1980). "The Significance of the Submarine Geology of the Upper Spencer Gulf, South Australia to Environmental Decision-Making." *Search* **11** (4): 115-116.

Harbison, I.P. (1980). *Metal Industry Wastes in Intertidal Sediments.* Unpublished thesis submitted for the degree of Master of Environmental Studies, University of Adelaide, South Australia.

Harbison, I.P. & Wiltshire, D. (1993). *Northern Spencer Gulf Resource Processing Strategy;Working Paper 2: Marine Environment Protection.* Ph Consulting and Social and Ecological Assessments, S.A.

Harvey, N. & Belperio, T. (1994). "Implications of Climate Change for the South Australian Coastline." *Trans. R. Soc. S. Aust.* **118**(1): 45-52.

Hay, J. & Kay, R. (1993). "Possible Future Directions for Integrated Coastal Zone Management: A Discussion Paper." *Vulnerability Assessment of Sea Level Rise and Coastal Zone Management;* Proceedings of the IPCC Eastern Hemisphere Workshop, 3-6 August; Tsukuba, Japan; pp. 351-366.

Intergovernmental Panel on Climate Change (IPCC) (1991). *The Seven Steps to the Assessment of theVulnerability of Coastal Areas to Sea Level Rise; A Common Methodology.* Response Strategies Working Group, Advisory Committee on the Assessment of Vulnerability to Sea Level Rise and Coastal Management; Revision No. 1.

Intergovernmental Panel on Climate Change (IPCC) (1992). *Global Climate Change and the Rising Challenge of the Sea.* Response Strategies Working Group, Coastal Zone Management Subgroup.

Intergovernmental Panel on Climate Change (IPCC) (1995) Working Group 11, Second Assessment Report - March 1994-.

Johnson, J. (1981). *Hydrological Data for Upper Spencer Gulf 1975-1978.* Fisheries Research Paper N. 3., SA Dept. of Fisheries.

Johnson, J. , Lewis, R.K., & Jones, G.K. (1988). "Predictions on the Greenhouse Effect on Fisheries in South Australia." In *Proceedings of the Greenhouse'88, Planning for Climate Change Conference ,* chapter 5, Coastal and Marine Systems; Adelaide, South Australia; pp.99-102.

Kay, R., Eliot, I., & Klem, G. (1992). *Analysis of the IPCC Sea Level Rise Vulnerability Assessment Methodology using Geographe Bay, SW Australia as a case study.* Proceedings of the IPCC-CZMS Workshop-Venezuela.

Kay, R. & Hay, J. (1993). "A Decision Support Approach to Coastal Vulnerability and Resilience Assessment: A Tool for Integrated Coastal Zone Management." *Vulnerability Assessment ot Sea Level Rise and Cosatal Zone Management;* Proceedings of the IPCC Eastern Hemisphere Workshop, 3-6 August; Tsukuba, Japan; pp. 213-225.

Kay, R. & Waterman, P. (1993). "Review of the Applicability of the 'Common Methodology for Assessment of Vulnerability to Sea Level Rise' to the Australian Coastal Zone." *Vulnerability Assessment of Sea Level Rise and Coastal Zone Management;* Proceedings of the IPCC Eastern Hemisphere Workshop, 3-6 August; Tsukuba, Japan; pp. 237-248.

Kelly, L. (1979). *Tidal Characteristics of Spencer Gulf , South Australia.* Unpublished thesis submitted for the degree of BSc. (Hons.) at Flinders University, South Australia.

Kinhill Engineers Pty. Ltd. (1990). *Port Pirie Rare Earth Plant Stage 3; Draft Environmental Impact Statement.* Report prepared for SX Holdings Ltd.

Kinhill Stearns (1986a). *Whyalla Boat Harbour Development; Draft Environmental Impact Statement.* Report prepared for the Corporation of the City of Whyalla.

Kinhill Stearns (1986b). *Northern Power Station Unit 3; Supplement to t he Draft Environmental Impact Statement.* Report prepared for ETSA, SA

Kinhill Engineers Pty Ltd. (1990). *Port Pirie Rare Earths Plant Stage 3-Draft Environmental Impact Statement.* Report prepared for SX Holdings Ltd.

Lange Dames & Campbell Aust. Pty. Ltd. (1991a). *Tidal Flooding Study, for the City of Port Augusta.* SA. Report prepared for the City of Port Augusta.

Lange Dames & Campbell Aust. Pty. Ltd. (1991b). *Tidal Flooding Study, for the City of Port Pirie.* SA. Report prepared for the city of Port Pirie.

Lennon, G., Bowers, D., & Nunes, R. (1987). "Gravity Currents and the Release of Salt from an Inverse Estuary." *Nature*, **327**: 695-697.

McInnes, K.L., & Hubbert, G.D. (1995). *Extreme Events and the Impacts of Climate Change on Victoria's Coastline.* Report prepared to EPA (Victoria) and Melbourne Water, CSIRO Division of Atmospheric Research and Global Environmental Modelling Services.

McLean, R. & Woodroffe, C. (1993). *Vulnerability of Atolls to Accelerated Sea-Level Rise: A Case Study of Australia's Cocos (Keeling) Islands.* Proceedings of the IPCC Eastern Hemisphere Workshop, 3-6 August; Tsukuba, Japan; pp. 99-108.

Marine Environment Protection Committee. (1993). *First Report to the Minister of Environment and Land Mangement, Monitoring the effects of the Era Oil Spill* . Environment Protection Council of South Australia, Adelaide.

Mines and Energy South Australia. (1994). *Northern Spencer Gulf Resource Processing Strategy.* Government of South Australia.

Molloy, J., Nelson, J., & Ball, K. (1993). *Northern Spencer Gulf Resource Processing Strategy; Working Paper 5: Economic and Social Profile.* The South Australian Centre for Economic Studies, SA.

Morvell, G. (1993). "An Australian Institutional Perspective on Vulnerability Assessment."*Vulnerability Assessment of Sea Level Rise and Coastal Zone Management;* Proceedings of the IPCC Eastern Hemisphere Workshop, 3-6 August; Tsukuba, Japan; pp. 79-87.

Noye, J. (1984). "Physical Processes and Pollution in the Waters of Spencer Gulf." *Marine Geology,* **61:** 197-220.

Noye, J.B., Bills, P.J., I'Anson,K. & Wong, C.C. (1992). Prediction of Prawn Larvae Movement in a Coastal Sea." In Noye, B.J., Benjamin, B.R. & Colgan, L.H. (eds.), *Computational Techniques and Applications: CTAC-91* , Computational Mathematics Group AMS.

Noye, J., Bills, P., & Lewis, G. (1994). "Prediction of Oil Slick Movement in Northern Spencer Gulf." In Stewart, D., Gardner, H., & Singleton, D. (eds.). *Computational Techniques and Applications: CTAC-93,* World Scientific Publishing, pp. 320-328.

Nunes, R. (1985). *Catalogue of data from a systematic programme of oceanographic measurements in Northern Spencer gulf from 1982-1985.* FIAMS Rept. N.10., Flinders University of South Australia.

Nunes, R. & Lennon, G. (1986). "Physical Property Distributions and Seasonal Trends in Spencer Gulf, South Australia: An Inverse Estuary." *Aust. J. Mar. Freshw. Res.* **37:** 39-53.

Nunes Vaz, R., Lennon, G., & Bowers, D. (1989). "Physical Behaviour of a Large Negative or Inverse Estuary." *Cont. Shelf Research* **10** (3): 227-304.

Nunes Vaz, R., Lennon, G., & Samarasinghe, J. (1989). "The Negative Role of Turbulence in Estuarine Mass Transport." *Estuarine, Coastal and Shelf Science* **28:** 361-377.

Reilly, J. (1991). *Possible Sources of Marine Contaminants, Upper Spencer Gulf;Future Proposals - Possible Addtional Sources of Marine Pollution-Draft II.* Unpublished report, Environmental Research Station, Chinaman Creek, Winninowie Conservation Park.

Rozenbilds, G. (1991). *A Review of Marine Pollution in South Australia: The Case for Monitoring.* Unpublished thesis submitted for the degree of Master of Environmental Studies, Mawson Graduate Centre for Environmental Studies, University of Adelaide, SA.

Shepherd, S.A. (1983). Benthic Communities of Upper Spencer Gulf, South Australia. *Trans. R. Soc. S. Aust.* **107**: 69-85.

Social & Ecological Assessment Pty Ltd (SEA) (1981a). *Draft Environmental Impact Statement for Port and Terminal Facilities at Stony Point, South Australia.* Report prepared for Santos Ltd, SA.

Social & Ecological Assessment Pty Ltd (SEA) (1981b). *Draft Environmental Impact Statement for Port and Terminal Facilities at Stony Point, South Australia; Background Papers.* Report prepared for Santos Ltd, SA.

Steedman, R.K. & Associates (1983). *Review of Northern Spencer Gulf Water Circulation and Dispersion.* Report prepared for the Department of Environment and Planning, Government of South Australia.

Ward, T.J. & Young, P.C. (1982). Effects of Sediment Trace Metals and Particle Size on the Community Structure of Epibenthic Seagrass Fauna near a Lead Smelter, South Australia. Marine Ecology-Progress Series, **9**: 137-146.

Wardrop, J.A., Wagstaff, B., Connolly, R & Leeder, J. (1993). *The Distribution and Persistence of Petroleum Hydrocarbons in Mangrove Swamps Impacted By the "Era" Oil spill (September, 1992),.* Report prepared by Woodward-Clyde for the Environment Protection Council, Adelaide, South Australia.

Whetton, P., Mullan A., & Pittock, A., (1994). *Climate Change Scenarios for Australia and New Zealand,* Paper presented at 'Greenhouse 94" 10-14 October, Wellington, New Zealand.

World Coast Conference (WCC) (1993). *Preparing to Meet the Coastal Challenges of the 21st Century.* Conference Report. Intergovernmental Panel on Climate Change (IPCC).

Wu, J. (1990). *Environmental Factors Affecting the Survival and Growth of the Western King Prawn (Penaeus latisulcatus) under Aquaculture Conditions in Spencer Gulf South Australia.* Unpublished thesis submitted for the degree of Master of Environmental Studies, University of Adelaide, South Australia.

Wynne, A.A. (1987). *Extreme Tides at Port Pirie, Port Augusta and Blanche Harbour and Recommended Levels for Development at Blanche Harbour.* Coastal Management Section, Department of Environment & Heritage, Adelaide, South Australia.

Zann, L.P. (1995). *Major Findings of the State of the Marine Environment Report for Australia.* Department of the Environment, Sport and Territories, Canberra.

Zann, L.P. & Sutton, D. (eds.) (1995). *State of the Marine Environment Report for Australia, Technical Annex 2 (Pollution).* Department of the Environment, Sport and Territories, Canberra.

TIDAL CURRENTS IN NORTHERN SPENCER GULF; MATHEMATICAL MODELLING

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To gain a greater understanding of the complexities of tidal circulation in the Northern Spencer Gulf the results of mathematical modelling of the area are described in this section. There is a lack of observed data on the oceanographic characteristics of the area and hence it has not been possible to incorporate potential changes in these features with known topography of the area to predict the impacts of sea-level rise. The modelling is useful in its application for predicting the movement of pollutants, prawn larvae dispersal and the trajectory of oil spills as outlined in Section 2.

INTRODUCTION

The current vectors presented are taken from two numerical models. One is a 900 element model of the northern one-third of the gulf, from Port Broughton in the south to Port Augusta in the north and the other is a 6000 element model of the region from Whyalla to the top of Fitzgerald Bay, which includes Point Lowly and Ward Spit. In the coarse grid model of Section 1, each model element (or grid box) represents an area about 2 km square, while in the fine grid model of Section 2, each element represents an area about 400m square.

In the finer grid model the shape of the coastal boundary is more accurately represented and resolves fine details of the flow. The depth of each element is taken from Hydrographic Chart **Aus 778**. The information to run the model is taken both from observed tidal constants at Whyalla and information about the across-Gulf variation in these constants extracted from the results of another coarse grid numerical model of the whole Gulf with elements approximately 6 km square.

On any day, current strengths are greatest approximately halfway between high water and low water. The strongest currents occur at times of "spring" tides, when the tidal range is greatest. Current strengths fall to zero at times of slack tide, which generally coincides with maximum or minimum tide-height levels and may occur up to four times a day.

The model is capable of predicting *surface* current strengths and directions, as well as currents further down in the water column. It can predict currents at every grid element at relative depth levels, such as "*halfway* between the surface and the sea bed", and at absolute depth levels such as '5m *below* the surface level" or "0.5m *above* the sea bed". In the Figures to follow the depth-average current is shown.

Elements that stippled grey in colour correspond to elements of the model which are *not* covered by water. According to the model, the tide here has receded enough for these particular regions to become exposed or "dry'. These elements are called 'tidal flat elements'. Thus the model allows for the covering and uncovering of tidal flats and sandbars. In fact, it correctly predicts the uncovering and covering of Ward Spit for brief periods of about one hour during times of lowest spring tides. Cockle Spit uncovers for longer periods and does so more frequently than does Ward Spit.

Some of the vector plots demonstrate an eddy in the tidal motions, either just south of Point Lowly or just north of it. This important and interesting feature is reported in the observational evidence of several scientists. The strength of the eddy depends on the strength of the flood and ebb tides moving up and down the Gulf; in other words, it varies according to the spring-neap cycle of the tides in the Gulf. When tidal currents are weak (during neaps) the eddy may not even form. When the tides are strong (during springs) the eddy forms just before high water or low water.

The model clearly portrays the complicated pattern of tidal flow in the vicinity of Point Lowly and Ward Spit. However, there is not enough information to predict what impact a higher sea-level would have on these features and how changes in tidal flows may affect the rest of the Gulf.

1. COARSE GRID NORTHERN SPENCER GULF TIDAL MODEL

Figure 1.1 shows the bathymetry used in the coarse grid Northern Spencer Gulf model. The purple regions next to the coast represent tidal flats which are uncovered at low spring tides and covered at high spring tides. The red area denotes the deepest water in the region, which is about 24 m relative to Mean Sea Level (MSL).

Figure 1.2 shows tidal currents represented as vectors on the left-hand map, with the direction of the current indicated by the arrow head and its strength by the length of the vector. The figure portrays an ebb flow at spring tide, with strong currents occurring and some tidal flats exposed. The flow in False Bay, north of Whyalla, is particularly complex and can only be resolved using a finer grid. In this model the currents are computed approximately 2 km apart. The right-hand map shows tide-height above MSL, which varies from 0.1 m in the south to 1 m at port Augusta. At this time the sea surface is falling everywhere.

Figure 1.3 depicts the situation 6 hours later, with the tide now on the flood and with many areas of tidal flats exposed, including Ward Spit near Port Germein (see left-hand map). The tide-height (see right-hand map) varies from 1 m below MSL at Port Augusta to 0.5 m below MSL at the southern boundary, and is rising.

2. FINE GRID NORTHERN SPENCER GULF TIDAL MODEL

The region from Whyalla in the south to a point north of Port Germein has been modelled using a fine grid, so currents and tide heights can be computed approximately 400 m apart. The area involved and its bathymetry is shown in Figure 2.1. Note the extensive regions of tidal flats on the west in False Bay, on the eastern side near Port Germein and Port Pirie, and at Ward Spit and Cockle Spit. The deepest water in this area is near Point Lowly to the east of Port Bonython and is more than 24 m below MSL.

Figure 2.2 shows tidal currents on an ebb flow in the vicinity of Port Bonython. Note the clockwise eddy which appears centred on the end of the jetty (the black line in the figure), which currents on the landward side of the end of the jetty directed north-east and those south of the end of the jetty directed south-west. The complicated pattern of currents from the centre of the figure to the top right-hand corner is due to the presence of Ward Spit which is just covered at this time.

Figure 2.3 shows the situation about three hours later, with the tide on the flood, the current direction being approximately northward. The eddy shown in the previous figure has disappeared and the influence of the southern end of Ward Spit is seen at the centre of the figure. About three hours later the continuing flood produces the current pattern shown in Figure 2.4. An anti-clockwise eddy now appears in Fitzgerald Bay, north of Port Bonython. Again the influence of Ward Spit, still covered, is seen in the right hand part of the figure.

Figure 2.5 shows ebb flow on a spring tide with the tide level falling in the vicinity of Port Germein. The is very complex flow both sides of, and over, Ward Spit. Three hours later, just on the turn of the tide, vast areas of coastal tidal flats have been uncovered, and Ward Spit and Cockle Spit are both exposed (see Figure 2.6). The situation two hours later, seen in Figure 2.7 shows that Ward Spit is now covered with flow occurring onto the Spit from both the north and south. The strong flow northward around the end of the Spit is caused by the fact that, even though it is covered, the Spit still acts as a barrier to the flooding tide, in the same way that it acted as a barrier to the ebbing tide in Figure 2.5. Cockle Spit is still exposed and water is flooding towards the north-east on both sides of the spit, in Figure 2.7.

3. THE SPENCER GULF PRAWN DISPERSION

The mathematical models can be used to simulate the dispersal of prawn larvae in the Spencer Gulf. Noye et al have produced a model that takes account of larvae position within the water column as they are known to be photonegative. Then the influence of tidal currents on larvae dispersion is examined by considering their effect on larvae hatched at the peak spawing times of 15 December 1988 and 15 February 1989. Wind effect is taken into account looking first at the typical general south to south-east wind which occurs in summer when spawning occurs and secondly at the situation if a north to north-east wind occurs along the axis of the gulf. In the northern region, Yarraville Shoals is the main breeding grounds and the model predicts that after 21 days that 60% of coastal settlement will occur on the north west coast while 40% will occur on the north east coast.

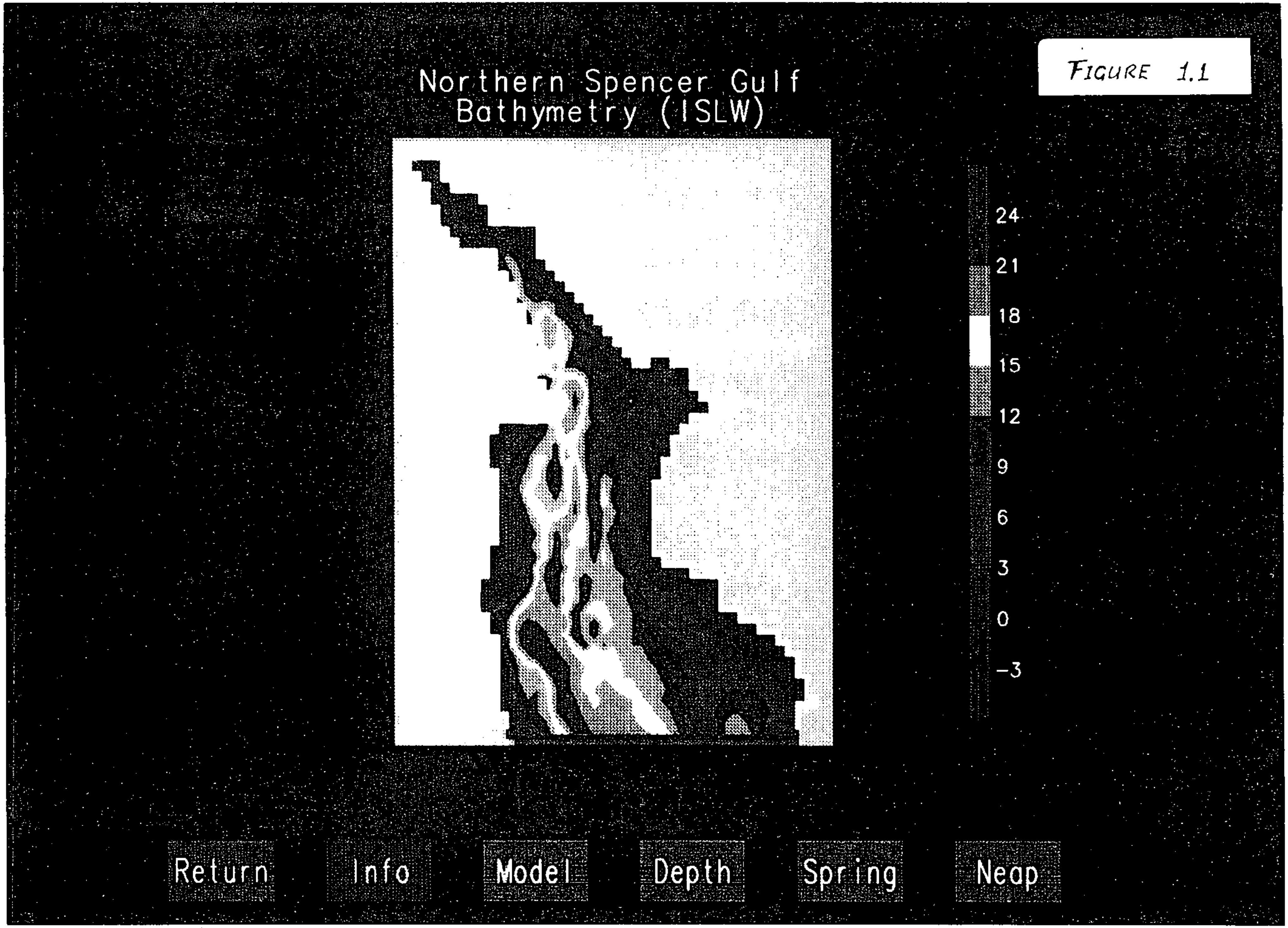

Northern Spencer Gulf
Bathymetry (ISLW)
24
21
18
15
12
9
6
3
0
−3
Return
Info
Model
Depth
Spring
Neap

FIGURE 1.1

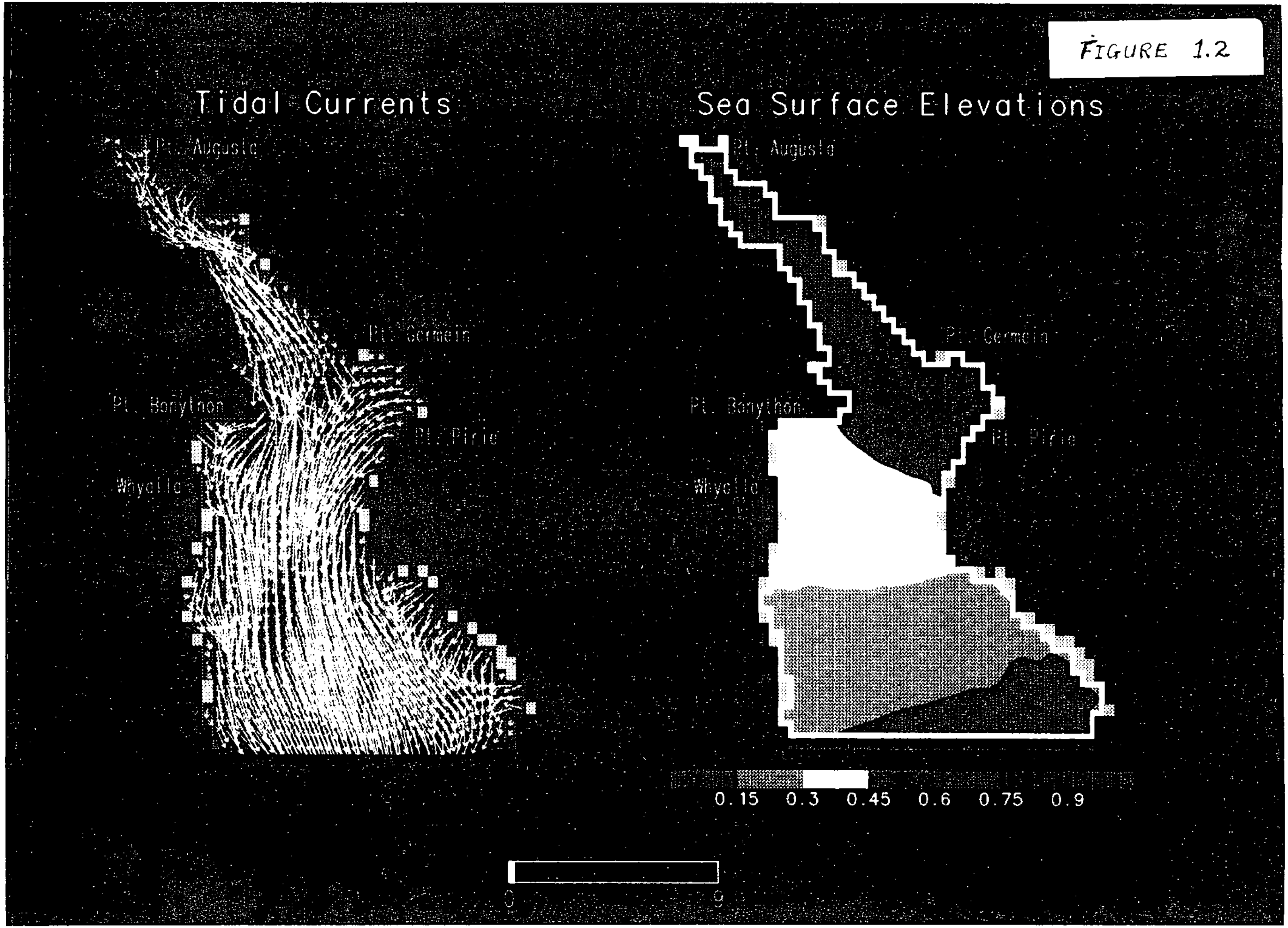
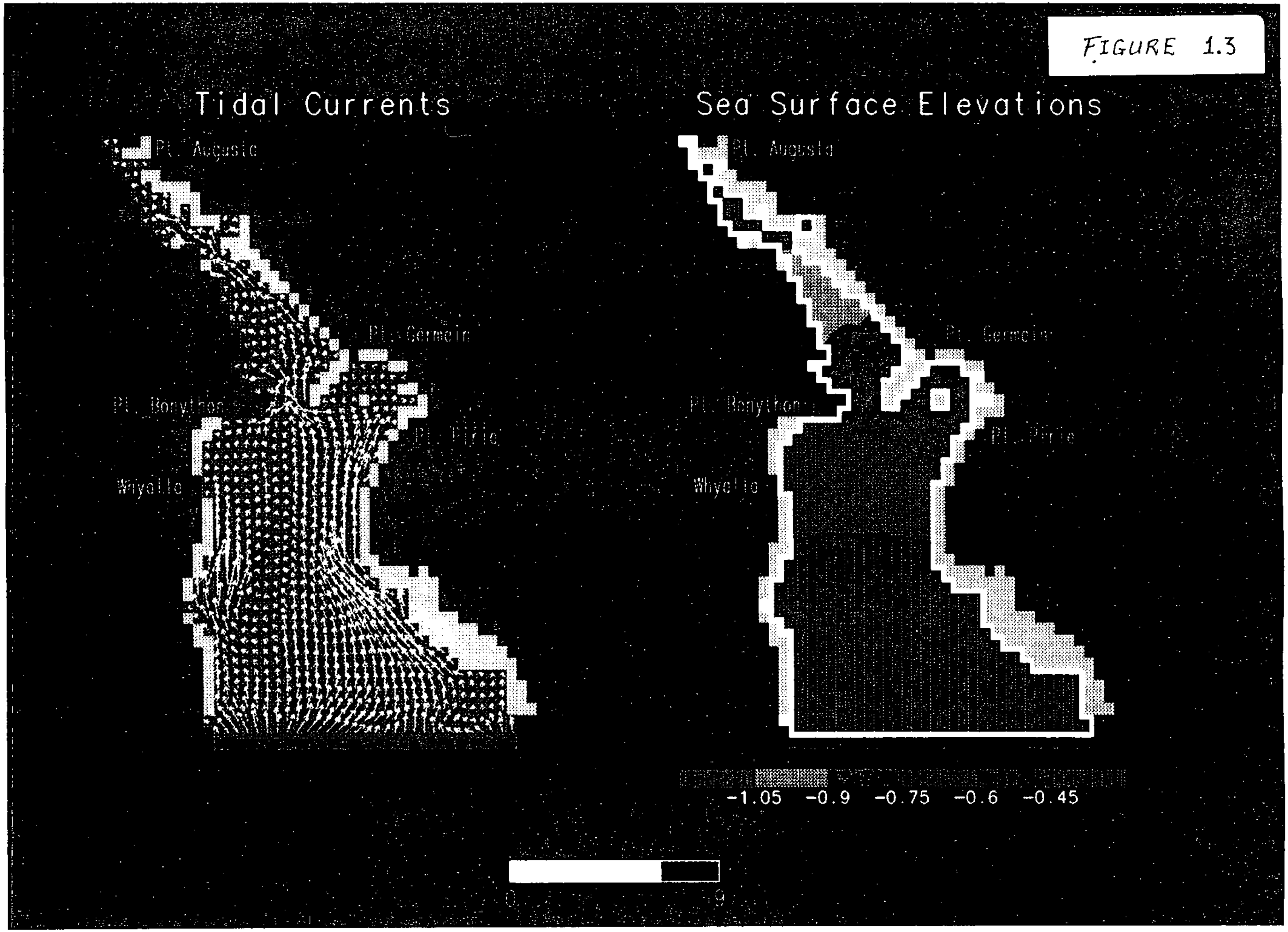


FIGURE 1.2
Tidal Currents
Sea Surface Elevations
Pt. Augusta
Pt. Germein
Pt. Bonython
Pt. Pirie
Whyalla
0.15
0.3
0.45
0.6
0.75
0.9
0
9

FIGURE 1.3


Tidal Currents
Sea Surface Elevations
Pt. Augusta
Pt. Germein
Pt. Bonython
Pt. Pirie
Whyalla
Pt. Augusta
Pt. Germein
Pt. Bonython
Pt. Pirie
Whyalla
-1.05
-0.9
-0.75
-0.6
-0.45
0
.9

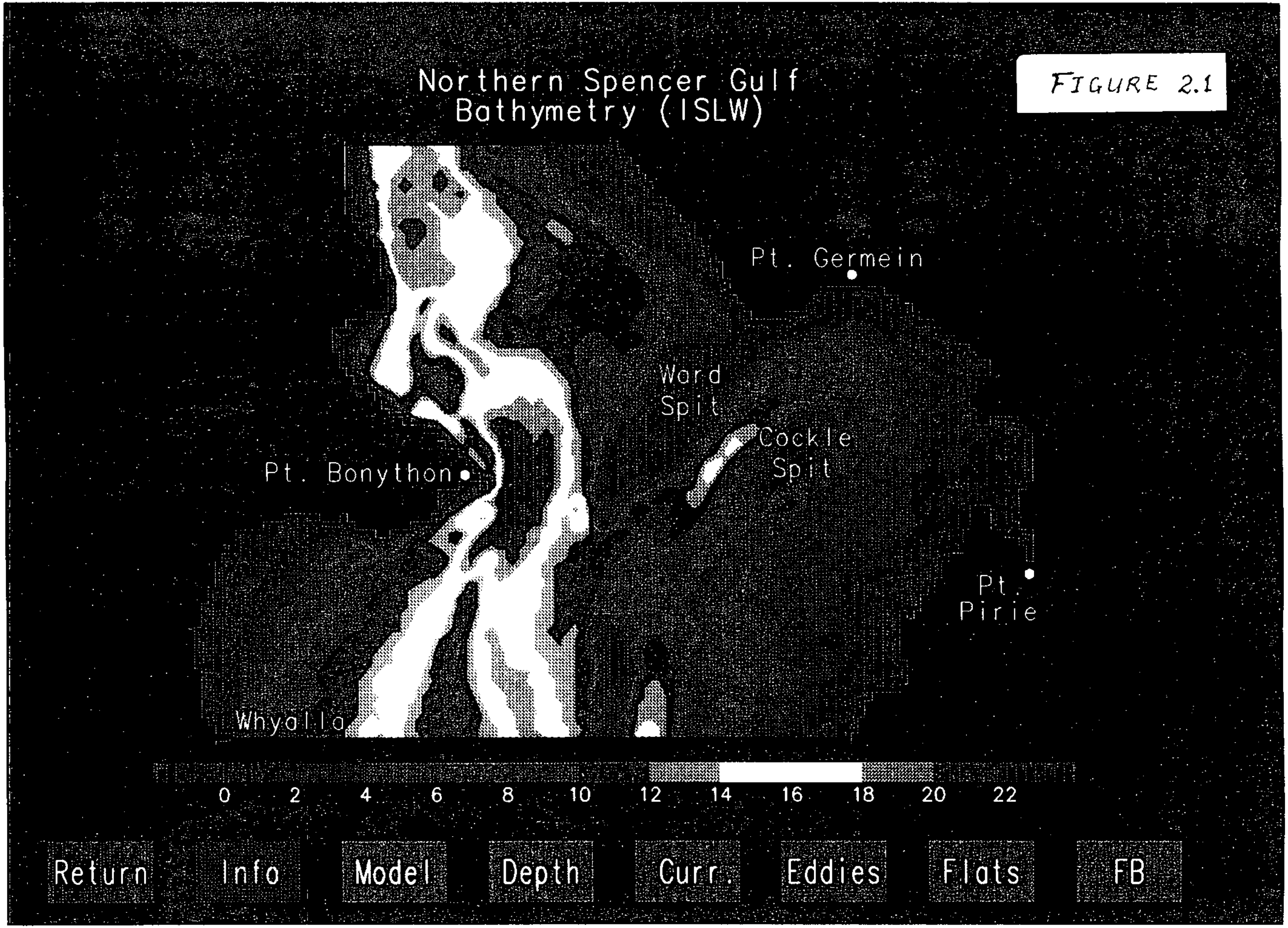


FIGURE 2.1
Northern Spencer Gulf
Bathymetry (ISLW)
Pt. Germein
Ward
Spit
Cockle
Spit
Pt. Bonython
Pt.
Pirie
Whyalla
0 2 4 6 8 10 12 14 16 18 20 22
Return
Info
Model
Depth
Curr.
Eddies
Flats
FB

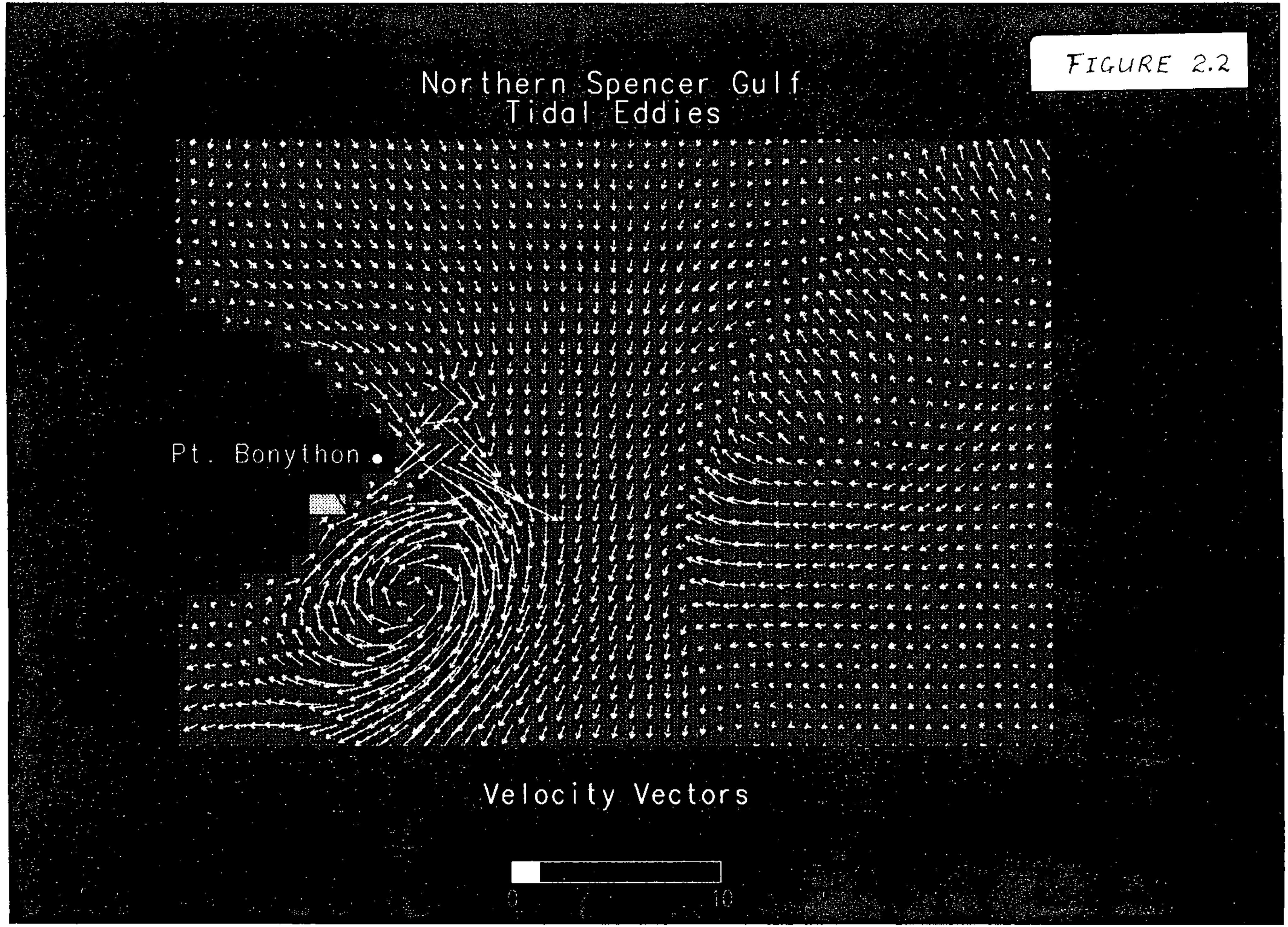


FIGURE 2.2
Northern Spencer Gulf
Tidal Eddies
Pt. Bonython
Velocity Vectors
0
10

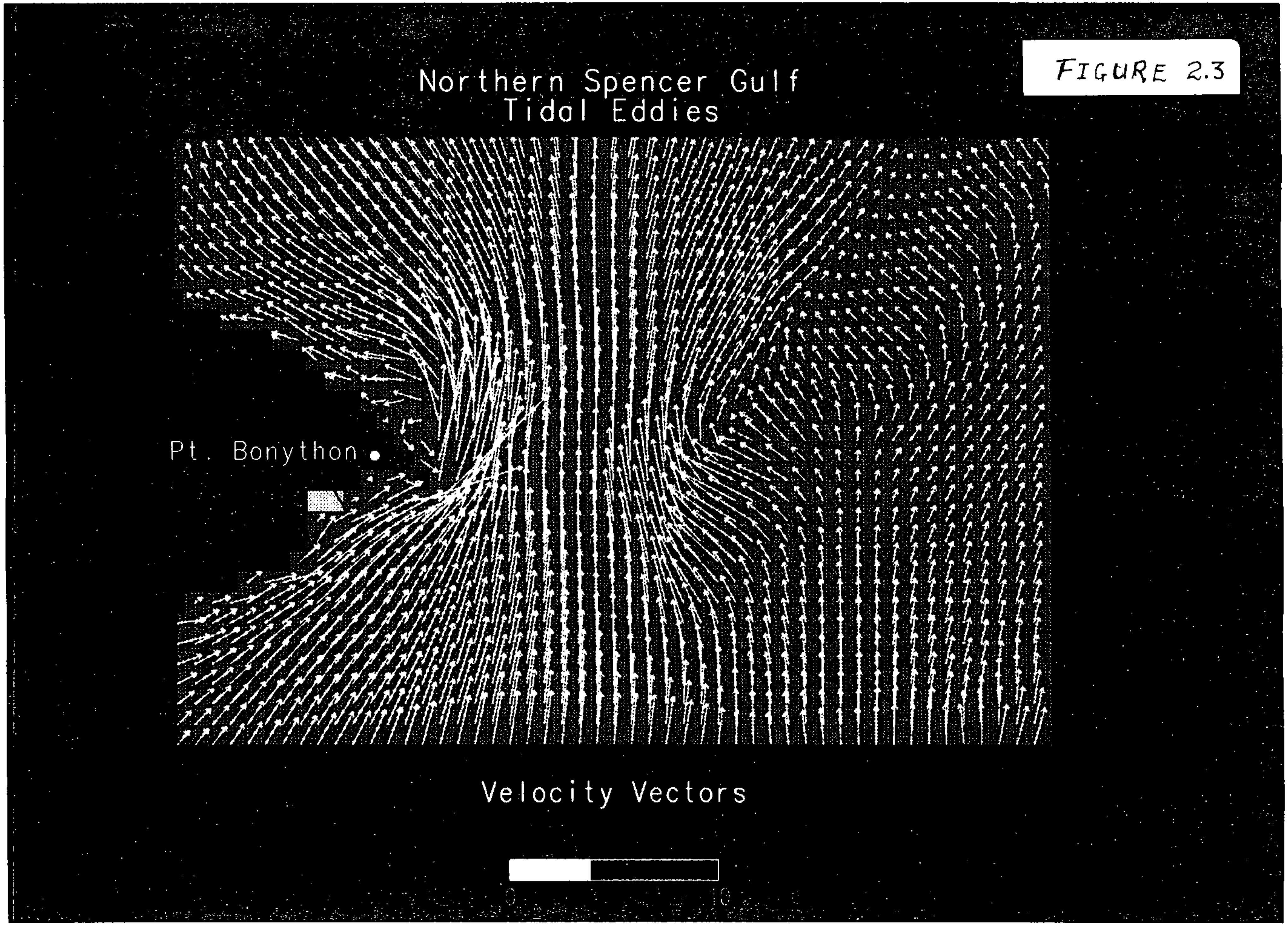

Northern Spencer Gulf
Tidal Eddies
Pt. Bonython
Velocity Vectors

FIGURE 2.3

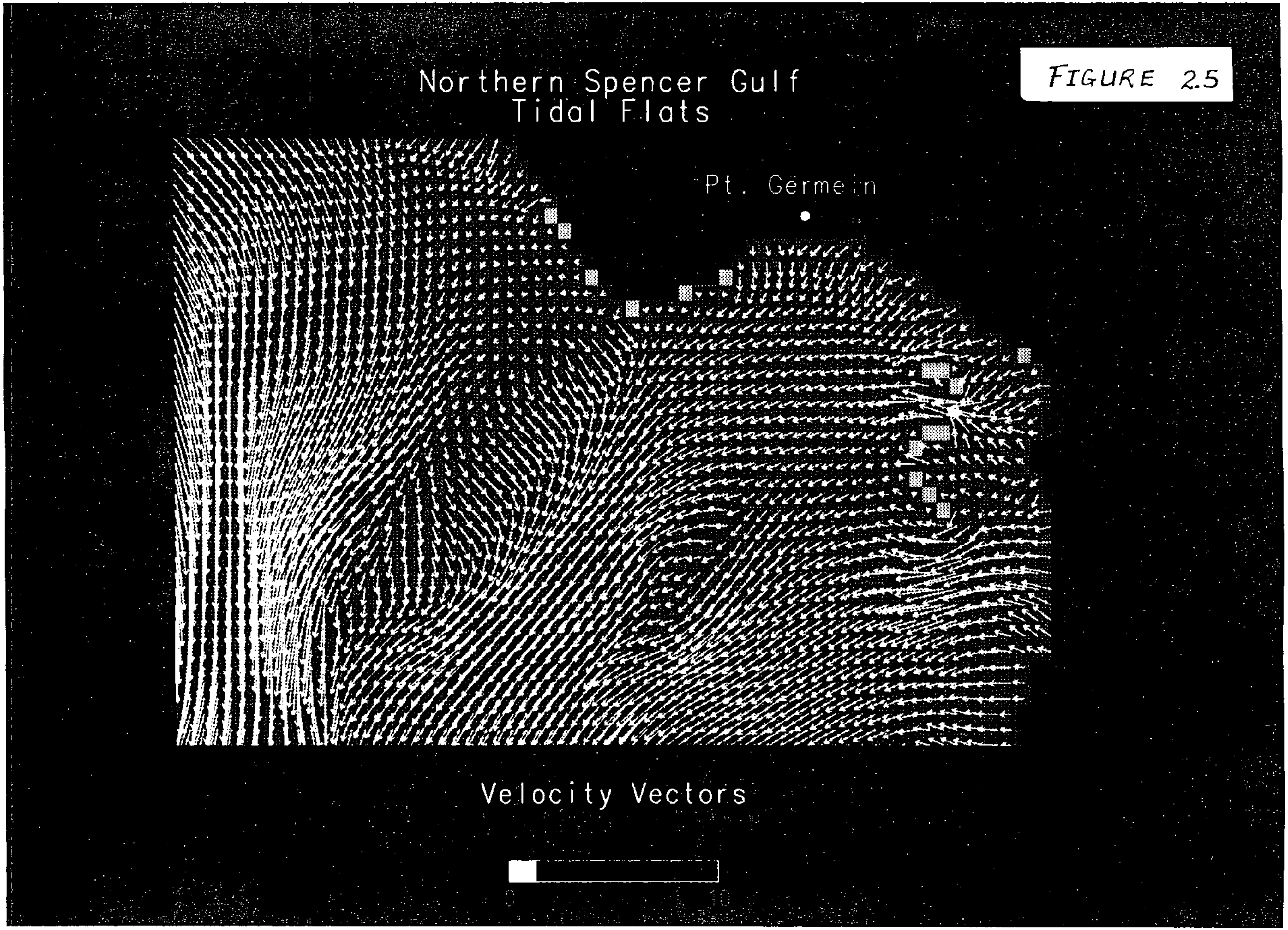
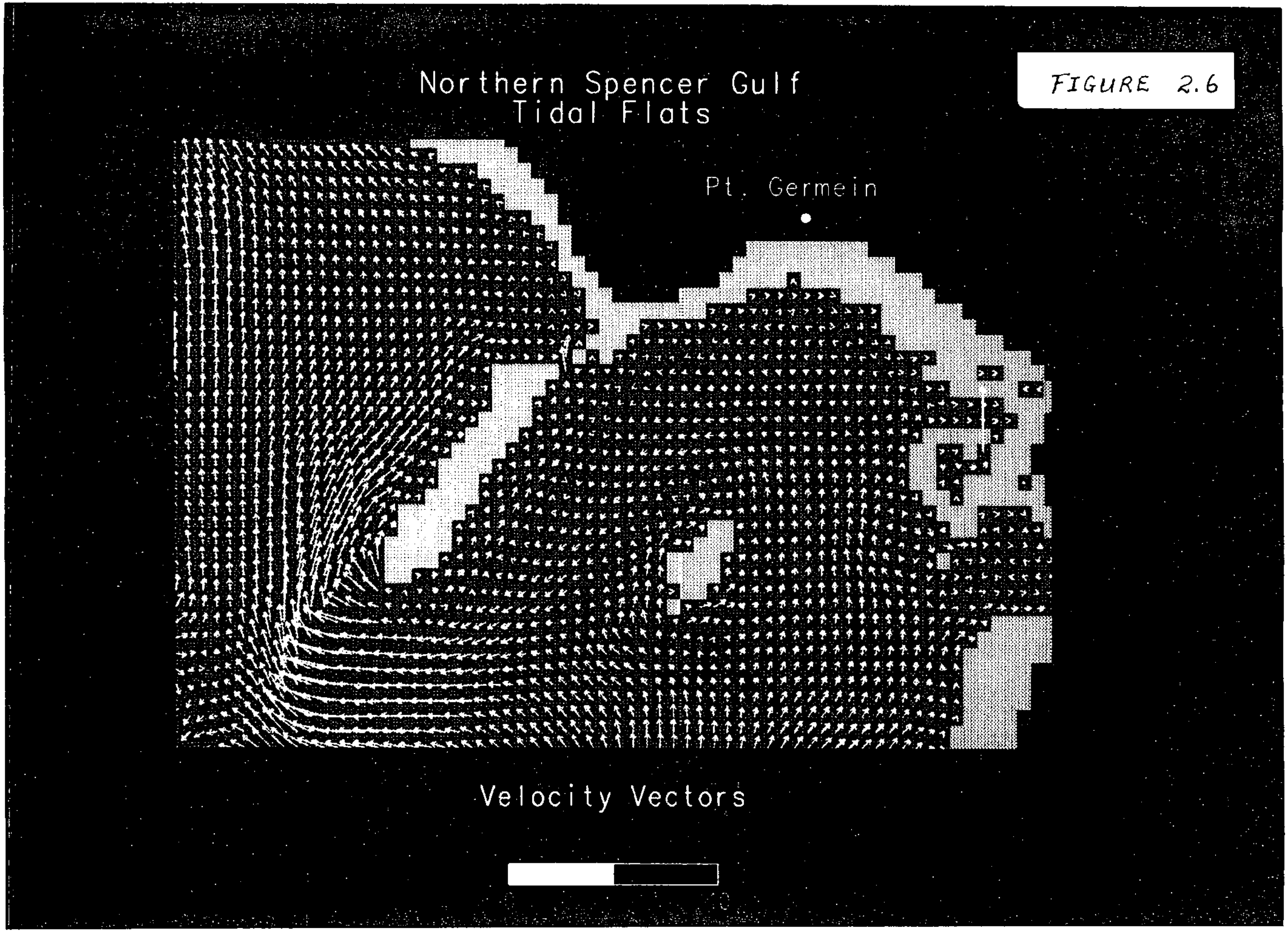
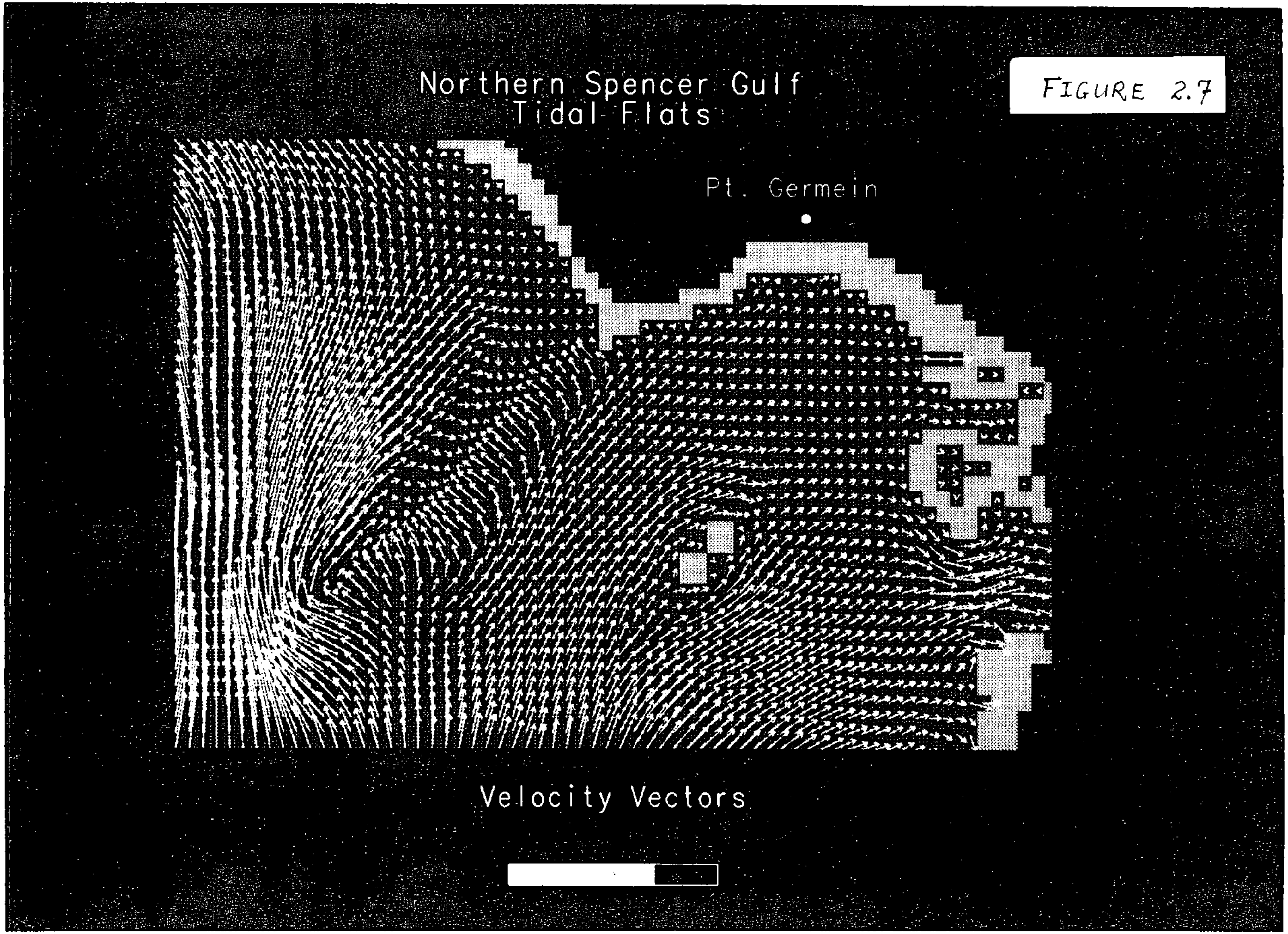

Northern Spencer Gulf
Tidal Flats
Pt. Germein
Velocity Vectors
0
10

FIGURE 2.5


Northern Spencer Gulf
Tidal Flats
Pt. Germein
Velocity Vectors
FIGURE 2.6


Northern Spencer Gulf
Tidal Flats
FIGURE 2.7
Pt. Germein
Velocity Vectors

POSSIBLE IMPACT OF TWO SEA-LEVEL RISE SCENARIOS ON SALT MARSH COMMUNITIES AT PORT PIRIE, SOUTH AUSTRALIA

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Department of Environment and Natural Resources

Appendix 2

INTRODUCTION.

A 3 km transect levelled across salt marshes at Pt Pirie is used to assess the potential effect of two sea level scenarios on the vegetation communities. Figure 1 shows the location of the transect. The transect extends from the flood protection levee on the outskirts of Pt Pirie to the mangrove edge.

The investigation was undertaken as part of the Spencer Gulf Vulnerability Study. which examines the potential impact of sea level rise on the social, economic and physical environment of the Spencer Gulf region. Pt Pirie is one of 3 sites selected for in depth studies within the region. The sea level rise scenarios used in the study, a rise of 18 cms by 2030 and 44 cms by 2070 are best estimates selected by the Intergovernmental Panel on Climate Change (IPCC) in 1990.

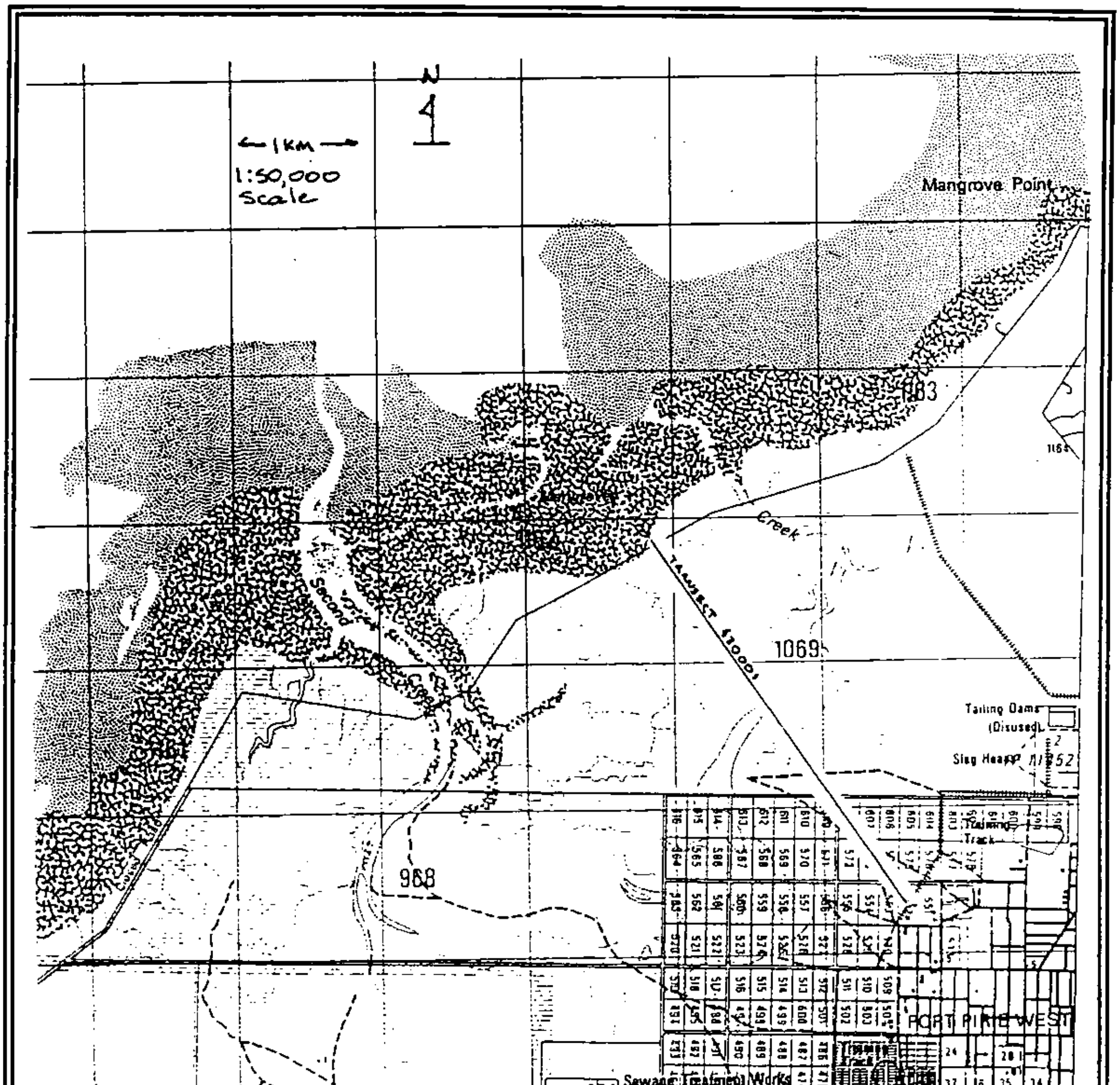


Figure 1. Study area and location of transect line.

ENVIRONMENTAL PARAMETERS.

Tides

Tides within Spencer Gulf are semi diurnal to mixed tides with two low and two high waters at springs to virtual cancellations at neap tides. Due to weather conditions actual tides are often different from predicted tides.

Burne and Colwell (1982) calculated from the 1974 Pt Pirie tide guage records the percent of time that sea level exceeds various elevations. The graph they compiled from the data is shown in figure 2. The graph shows that sea water inundation is very infrequent above 1.5 metres Australian Height Datum.

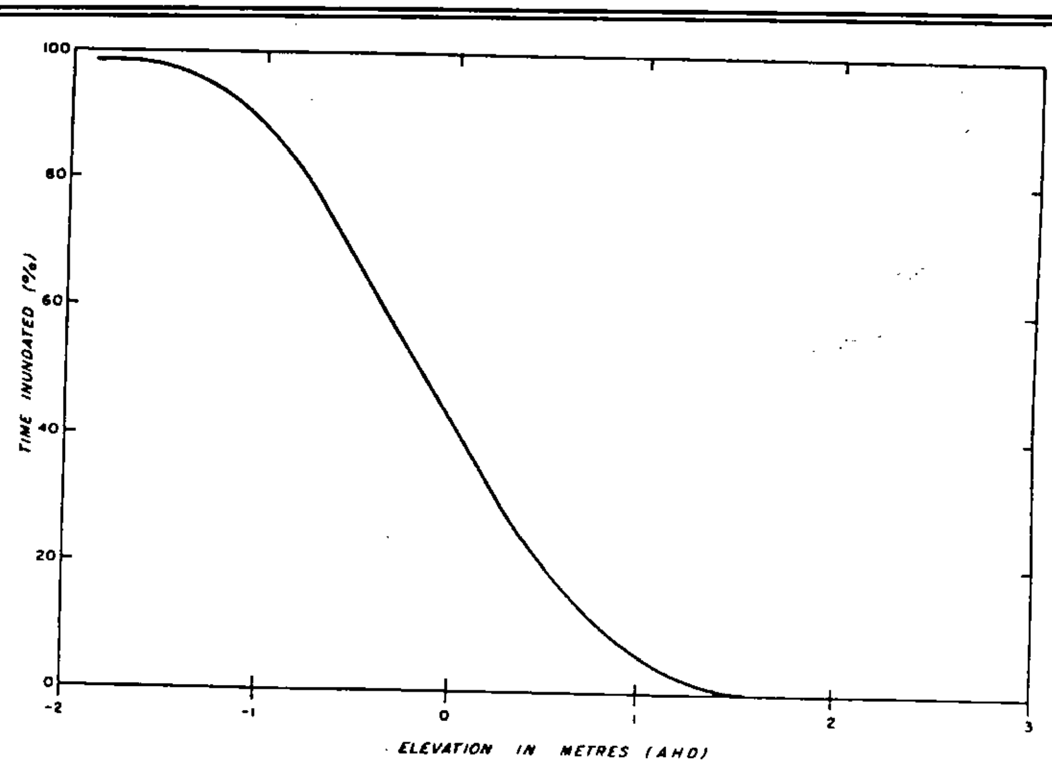


Figure 2. Graph showing sea level exceedence for various elevations as a cumulative percentage. (from Burnes and Colwell 1982)

Tectonic Change

Belperio et al (1984) in their statigraphic study of Northern Spencer Gulf found evidence of tectonic uplift. Harvey and Belperio (1994) adjusted Pt Pirie tide guage data by 0.5 mm per year to account for the effects of local tectonic uplift.

METHODOLOGY.

Transect selection.

Colour aerial photography at 1:15,000 scale flown in 1981 was used to select the transect location. A complex mosaic of salt marsh communities around Pt Pirie was clearly evident from the tonal patterns. The transect was positioned to provide a comprehensive representation of the plant communities. Another factor which influenced the transect location was the proximity of survey marks to transfer elevation and geographic position to the transect start point and from there along the transect line.

Levelling

A Geodimeter 422LR survey instrument was used to carry out survey measurements. Distances were measured electro magnetically. Measurements were kept within a distance of 400 metres from the instrument to maintain consistent vertical accuracy. This necessitated several station shifts during the course of the survey.

Two 3rd order survey marks were used to coordinate the start point of the transect and to transfer height. Elevation was recorded in Australian Height Datum (AHD). An existing survey mark midway along the traverse was used as a check.

Vegetation classification and mapping

A structural dominance method utilising Muirs Code has been used to classify vegetation. Muirs structural classification shown in table 1 is based on the life form/height class and canopy cover of the tallest stratum. Vegetation changes along the transect were mapped in conjunction with the levelling. Vegetation boundaries were logged with position and elevation information on the survey instruments logger, with codes indicating overstory species. Quadrat sites 30 x 30 metres were located within each mapping unit to provide structural and composition data.

Sea level rise impact

To simulate the effect of sea level rise on the profile the existing profile with the vegetation mapped on it was superimposed over two other identical profiles which had been lowered by 18 and 44 cms. Horizontal lines which intersected the maximum and minimum elevations within each of the existing communities were used to transfer the communities onto each of the sea level adjusted profiles. Percentage representation of each community along each profile line was calculated to show potential impact of the sea level rise scenarios..

Life form/height class	Canopy cover ©			
S	Dense d 70 - 100%	Mid Dense c 30 - 70%	Sparse i 10 - 30%	Very Sparse r 1 - 10%
T Trees > 30m	Dense tall forest	Tall forest	Tall woodland	Open tall woodland
M Trees 15 - 30m	Dense forest	Forest	Woodland	Open woodland
LA Trees 5 - 15 m	Dense low forest A	Low forest A	Low woodland A	Open Low woodland A
LB Trees <5 m	Dense low forest B	Low forest B	Low woodland B	Open Low woodland B
KT Mallee tree form (>3m)	Dense tree mallee	Tree mallee	Open tree mallee	Very open tree mallee
KS Mallee shrub form(<3m)	Dense shrub mallee	Shrub mallee	Open shrub mallee	Very open shrub mallee
S shrubs >2m	Dense Thicket	Thicket	Scrub	Open scrub
SA Shrubs 1.5 - 2.0 m	Dense heath A	Heath A	Low scrub A	Open low scrub A
SB shrubs 1 - 1.5 m	Dense heath B	Heath B	Low scrub B	Open low scrub B
SC shrubs 0.5 - 1.0m	Dense low heath C	Low heath C	Dwarf scrub C	Open dwarf scrub C
SD Shrubs 0 - 0.5 m	Dense low heath D	Low heath D	Dwarf Scrub D	Open dwarf scrub D
P Mat plants(single plant)	Dense mat plants	Mat plants	Open mat plants	Very open mat plants
H Hummock grass	Dense hummock grass	Mid densehummock grass	Hummock grass	Open hummock grass
GT Bunch grass >0.5m	Dense tall grass	Tall grass	Open tall grass	Very open tall grass
GL Bunch grass <0.5m	Dense low grass	Low grass	Open low grass	Very open low grass
J Herbaceous spp.	Dense herbs	Herbs	Open herbs	Very open herbs
VT Sedges >0.5m	Dense tall sedges	Tall sedges	Open tall sedges	Very open tall sedges
VL Sedges <0.5m	Dense low sedges	Low sedges	Open low sedges	Very open low sedges
V Vines(twiners)	Dense vines	Vines	Open vines	Very open vines
MI Mistletoes	Dense Mistletoes	Mistletoes	Open Mistletoes	Very open Mistletoes
X Ferns	Dense ferns	Ferns	Open ferns	Very open ferns
MO Mosses, liverwort	Dense Mosses	Mosses	Open Mosses	Very open mosses
LI Lichens	Dense lichens	Lichens	Open Lichens	Very open lichens

Table 1. Vegetation association classification based on Muirs Code. (after Muir 1977)

RESULTS.

Figure 3 shows a profile plot of the levelling traverse. Two tidal creeks are shown on the plot each characterised by high mounds and low depressions producing a complex terrain on either side of the creeks. Similar complexity occurs over the last 900 metres of the profile where regular tidal inundation occurs. Over the full distance the gradient averages approximately 1:1700 however a significant steepening of the slope is evident 600 metres from the profile end. Seaward of this point the gradient averages 1:800, landward the gradient is much flatter averaging 1:2300. Reference to figure 2 shows that the lowest elevation on the transect is inundated by the sea no more than 20% of the year and the highest point less than 1%. Approximately 50% of the transect is sufficiently elevated to be inundated less than 1% of the year.

Table 2 lists the 8 vegetation communities that have been classified along the traverse using Muirs Code. The table also shows the distribution of the communities in relation to the transect start and also the percentage representation of each vegetation class along the traverse. Plant species recorded in each of the vegetation classes is shown in table 3.

Communities 1 to 4 occupy the extensive supratidal zone and represent 81% of the vegetation cover along the transect. Seawater flooding of this zone is infrequent due to high elevations and also distance from the sea. Community 5 occupies a mid zone and represents less than 5% of the vegetation cover. Communities 6 to 8 occupy a low marsh zone where tidal flooding is regular. These communities represent 13.5% of the vegetation cover.

Each of the communities are briefly described below.

1. *Atriplex vesicaria / Halosarcia indica low heath* forms a very small community at the start of the transect and on several well elevated ridges.

2. *Halosarcia indica / H. halocnemioides with and without H.pergranulata* occupies almost half of the transect. The community primarily occurs on salt pans. Halosarcia pergranulta does not occur beyond 1400 metres of the profile start. Canopy cover is highly variable.

3. *Atriplex paludosa / H.indica low heath* forms a significant community along the transect. The community occupies elevated creek banks and high ridges generally associated with tidal creek lines.

4. *Halosarcia halocnemioides low heath to open dwarf scrub* occupies similar salt pan habitat to community 2 but in closer proximity to the sea.

5. *Maireana oppositifolia / H.indica / H.halocnemioides low heath* occupies the back part of the ridged terrain which characterises the last 900 metres of the transect. Typically the community occurs on ridge crests.

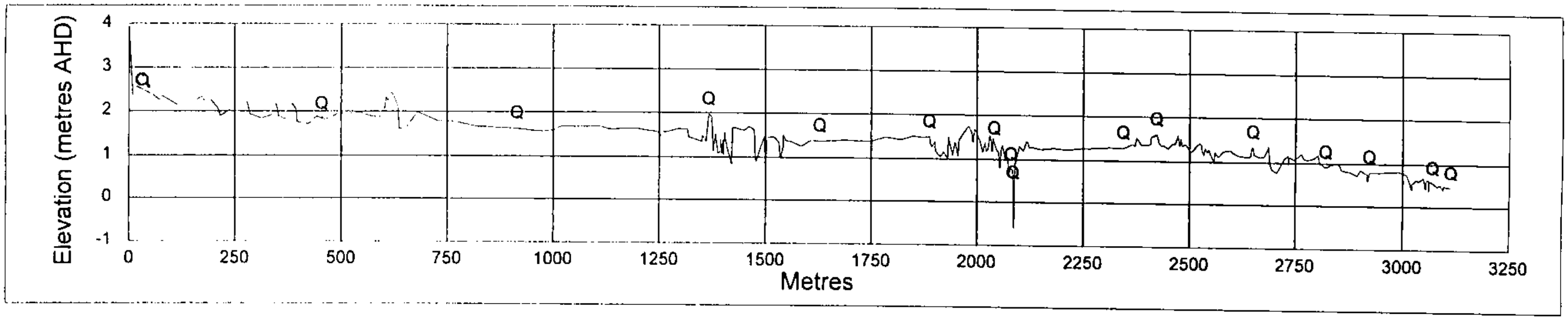


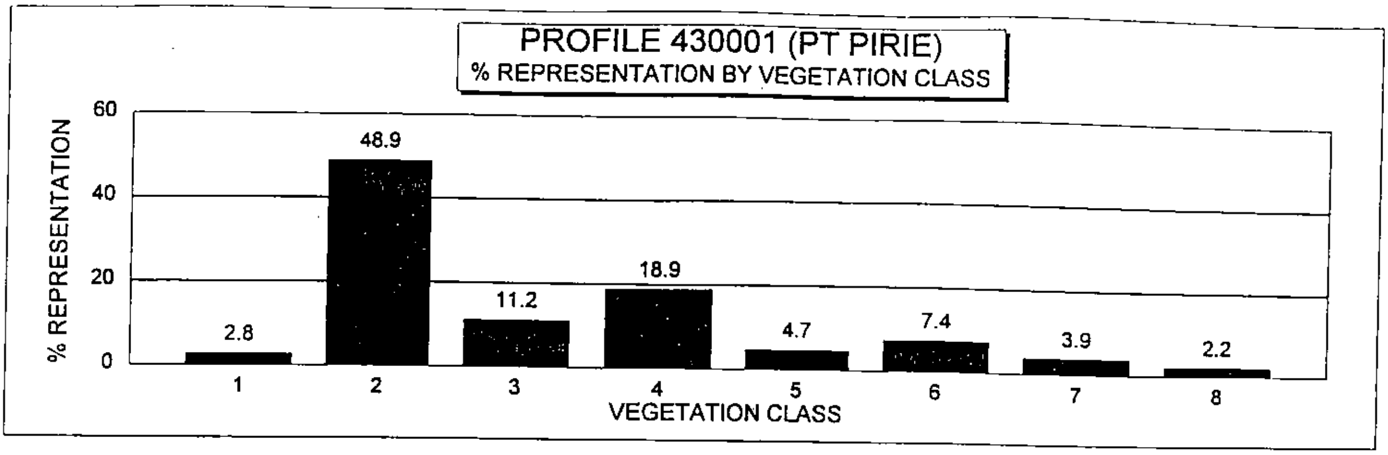
Figure 3. Profile plot of Pt Pirie levelling traverse. Vegetation quadrat sites are also shown.

Vegetation class	**Distribution in relation to transect start (metres)**	**Percent representa tion over transect**
1. *Atriplex vesicaria / Halosarcia indica* low heath	(9.45-78.5), (335.6-353)	2.8%
2. *Halosarcia indica / H.halocnemioides* +- *H.pergranulata* low heath to dwarf scrub	(77.5-335.6), (353-620), (636.7-1360.5), (1524.1-1542.5), (1781.6-1929.5), (2059.9-2076), (2343-2386)	48.9%
3. *Atriplex paludosa / Halosarcia indica* dense low heath to low heath	(620-636.7), (1360.5-1408.8), (1420.8-1473.5), (1476.2-1497), (1499.5-1524.1), (1929.5-2059.9), (2088.6-2122.5), (2458-2478.5)	11.2%
4. *Halosarcia halocnemioides* low heath to open dwarf scrub	(1408.8-1420.8), (1473.5-1476.2), (1497-1499.5), (1542.5-1781.6), (2122.5-2343), (2528-2534.8), (2539.9-2579), (2601.8-2643.6), (2665.6-2676), (3008.3-3019.4)	18.9%
5. *Maireana oppositifolia / Halosarcia indica / H.halocnemioides* low heath	(2076-2082.5), (2386-2422.5), (2448.6-2458), (2478.5-2489.3), (2505.8-2528), (2534.8-2539.9)	4.7%
6. *Halosarcia halocnemioides / Sclerostegia arbuscula* low heath	(2688-2918.7)	7.4%
7. *Sclerostegia arbuscula / Sarcocornia quinquiflora* +- *Suaeda australis* low heath	(2918.7-3008.3), (3019.4-3050.4)	3.9%
8. *Avicennia marina* +- *Sclerostegia arbuscula* +- *Sarcocornia quinquiflora*	2082.5-2088.6, 3050.4-3112.4	2.2%

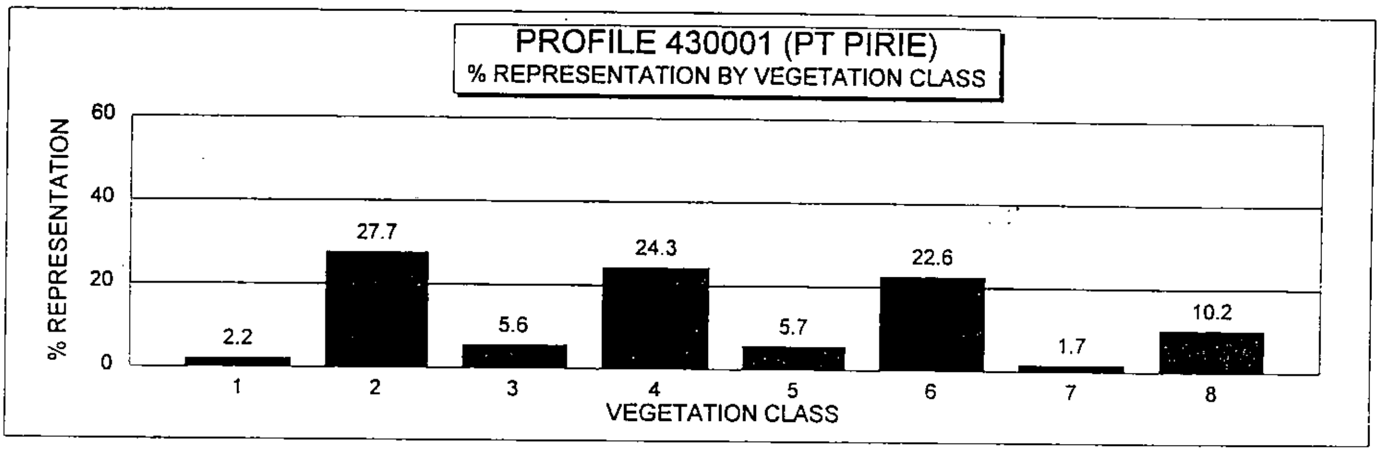
Table 2 . Vegetation communities their distribution and percemntage representation along the Pt Pirie transect.

PLANT SPECIES	1	2	3	4	5	6	7	8
Atriplex paludosa ssp cordata			X					
Atriplex vesicaria ssp sphaerocarpa	X							
Avena barbata	X							
Avicennia marina var resinifera								X
Disphyma crassifolium	X	X	X					
Dissocarpos biflorus var biflorus	X							
Frankenia pauciflora var fruitcosa			X					
Frankenia sessilis		X	X		X			
grass	X							
Halosarcia halocnemoides var halocnemoides		X	X	X	X	X		
Halosarcia indica var leiostachya	X	X	X		X			
Halosarcia pergranulata var pergranulata		X						
Hemichroa pentandra			X					
Hymenolobus procumbens			X					
Maireana oppositifolia	X		X		X			
Medicago sp	X							
Parapholis incurva		X	X					
Sarcocornia blackiana		X	X					
Sarcocornia quinquiflora							X	X
Sclerostegia arbuscula						X	X	X
Senecio glossanthus	X							
Suaeda australis							X	X
Wilsonia humilus			X		X			

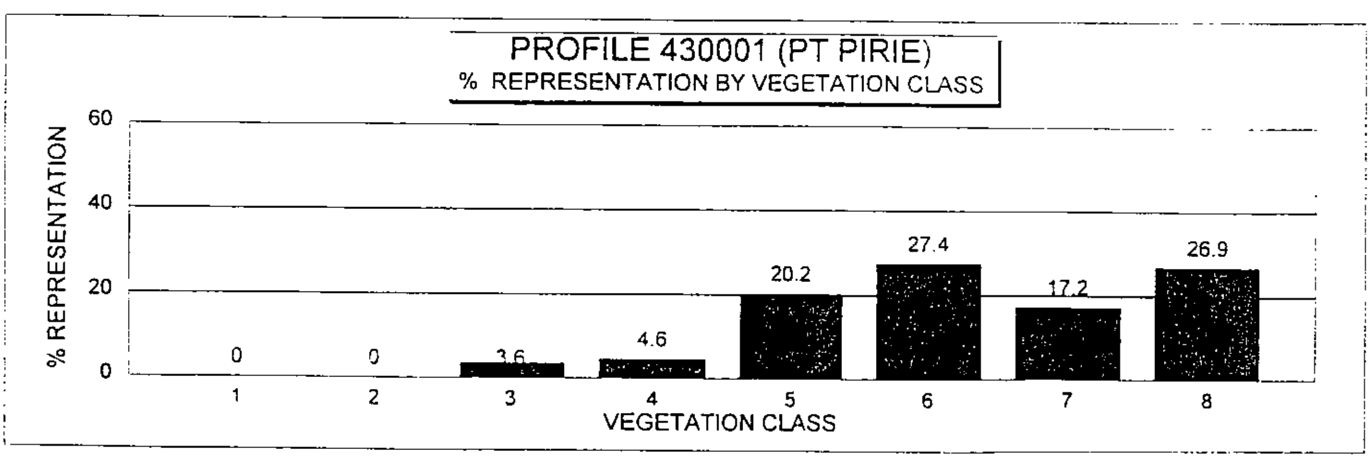
Table 3. Plant species recorded for each vegetation class along the Pt Pirie transect.



Graph 1. Existing vegetation representation at present sealevel



Graph 2. Estimated vegetation representation resulting from adjustment to a 0.18 metre sealevel rise



Graph 3. Estimated vegetation representation resulting from adjustment to a 0.44 metre sealevel rise

Figure 4. Percent representation of salt marsh communities for present sea level and for a rise of 18 and 44 c

6. *Halosarcia halocnemioides / Sclerostegia arbuscula low heath* occupies similar habitat to 5 but at lower elevations and in closer proximity to the sea.

7. *Sclerostegia arbuscula / Sarcocornia quinquiflora +- Suaeda australis low heath* forms a compact community tightly fringing the mangroves. It represents only 3.9% of total vegetation cover.

8. *Avicennia marina heath to dense heath* occupies the lowest and most seaward part of the transect. This community extended seaward a further 1000 metres from the transect end.

Figure 4 shows the percentage representation of salt marsh communities along the transect for present sea level, and for a rise of 18 and 44 cms. With sea level rise significant changes to the vegetation cover can be seen. An 18 cm sea level rise results in greater representation of lower salt marsh communities at the expense of those in the supratidal zone. Greatest loss occurs to community 2 which is replaced by community 4. A 44 cm sea level rise results in a very significant loss of the supratidal communities including total loss of communities 1 and 2 which are unable to retreat due to the backing levee bank. Mid and low salt marsh zone communities represent 92% of the total vegetation cover compared with the present representation of 18%.

DISCUSSION.

There is a close relationship between the distribution of salt marsh communities and the frequency of sea water inundation. Salt marsh halophytes vary considerably in their tolerance to soil waterlogging and soil salinity. Distance from the sea (and tidal creeks) and elevation are the two factors which are largely producing the vegetation pattern along the transect. Poor drainage in the salt pans also results in higher soil salinities than surrounding sites and also influences the vegetation pattern.

The physiography of the salt marsh is likely to alter with sea level rise and this will influence the vegetation pattern. Flat parts of the salt marsh when subject to regular seawater inundation will develop an undulating terrain of low hummocks and depressions. Tidal creeks and tributary channels will further develop in response to higher water loads.

Due to the considerable difficulty of predicting physiographic changes with sea level rise this assessment does not take this factor into account. This will largely effect the relative representation of the various communities within the mid and low marsh zones rather than any change in representation between those communities and the those within the supratidal zone.

CONCLUSION.

An 18 and 44 cm sea level rise on the flat gradients that characterise the extensive saltmarsh communities around Pt Pirie will produce significant changes to the vegetation pattern. Plant communities will shift landward in response to increased seawater flooding. Levees built behind the salt marshes that prevent further retreat will cause the loss of some communities due to the seawater transgression.

REFERENCES.

Belperio A.P., Hails J.R., Gostin V.A. and Polach H.A. (1984) "The stratigraphy of coastal carbonate banks and Holocene sea levels of Northern Spencer Gulf, South Australia." Marine Geology 61 297-313.

Burne R.V. and Colwell J.B. (1982) "Temperate carbonate sediments of Northern Spencer Gulf, South Australia: a high salinity 'foramol' province". Sedimentology 29, 223-238.

Harvey N. and Belperio A.P. (1994) "Implications of climate change to the South Australian coastline". Trans Royal Soc South Australia 118 (1) 45-52.

Muir B.G.(1977) " Biological survey of the Western Australian Wheatbelt. Part 2: Vegetation and habitat of Bendering Reserve". Records of the Western Australian Museum, Supplement No 3 WA Museum, Perth.

APPENDIX 1.

Pt Pirie transect with overlying vegetation cover. Lower transects are also shown representing 18 and 44 cm sea level rises.

1. = *Atriplex vesicaria / Halosarcia indica low heath*

2. = *Halosarcia indica / H. halocnemioides with and without H.pergranulata*

3. = *Atriplex paludosa / H.indica low heath*

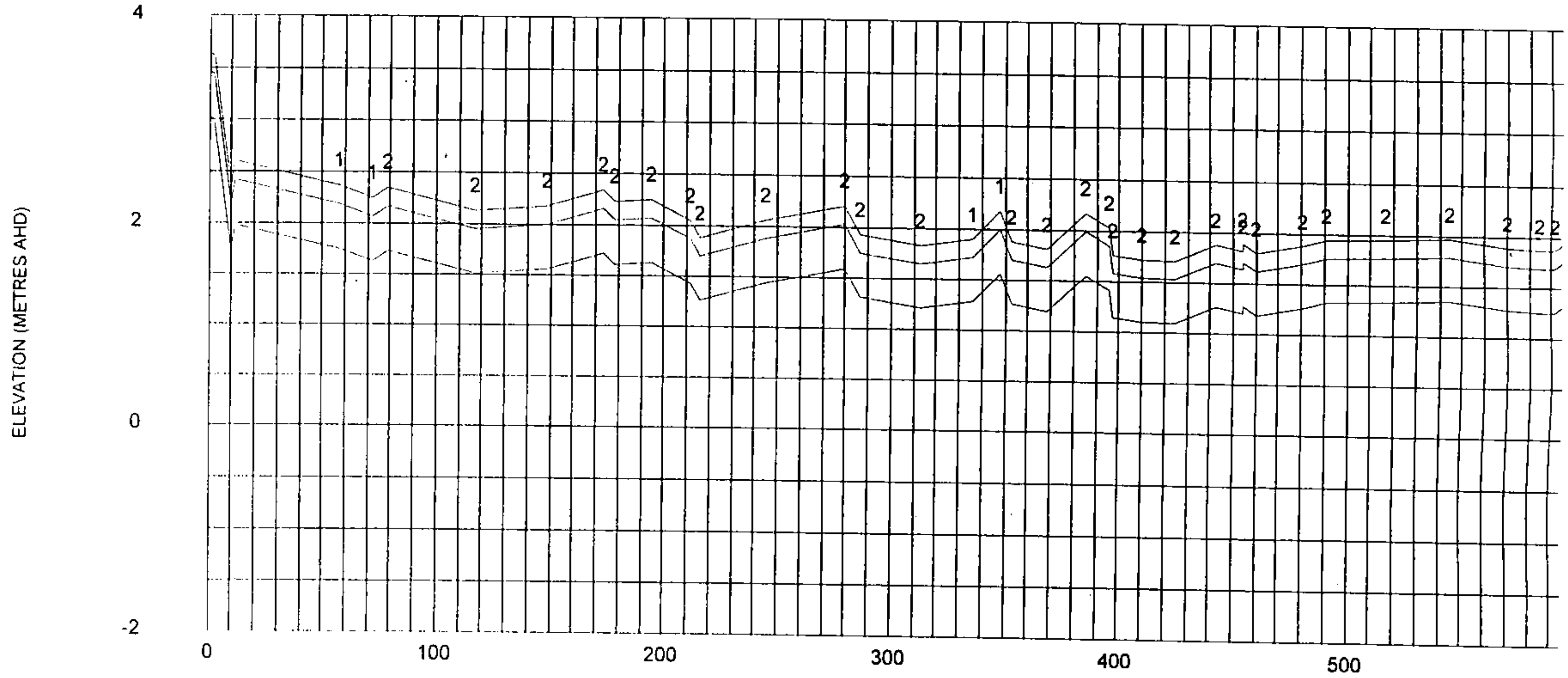
4. = *Halosarcia halocnemioides low heath to open dwarf scrub*

5. = *Maireana oppositifolia / H.indica / H.halocnemioides low heath*

6. = *Halosarcia halocnemioides / Sclerostegia arbuscula low heath*

7. = *Sclerostegia arbuscula / Sarcocornia quinquiflora +- Suaeda australis low heath*

8. = *Avicennia marina heath to dense heath*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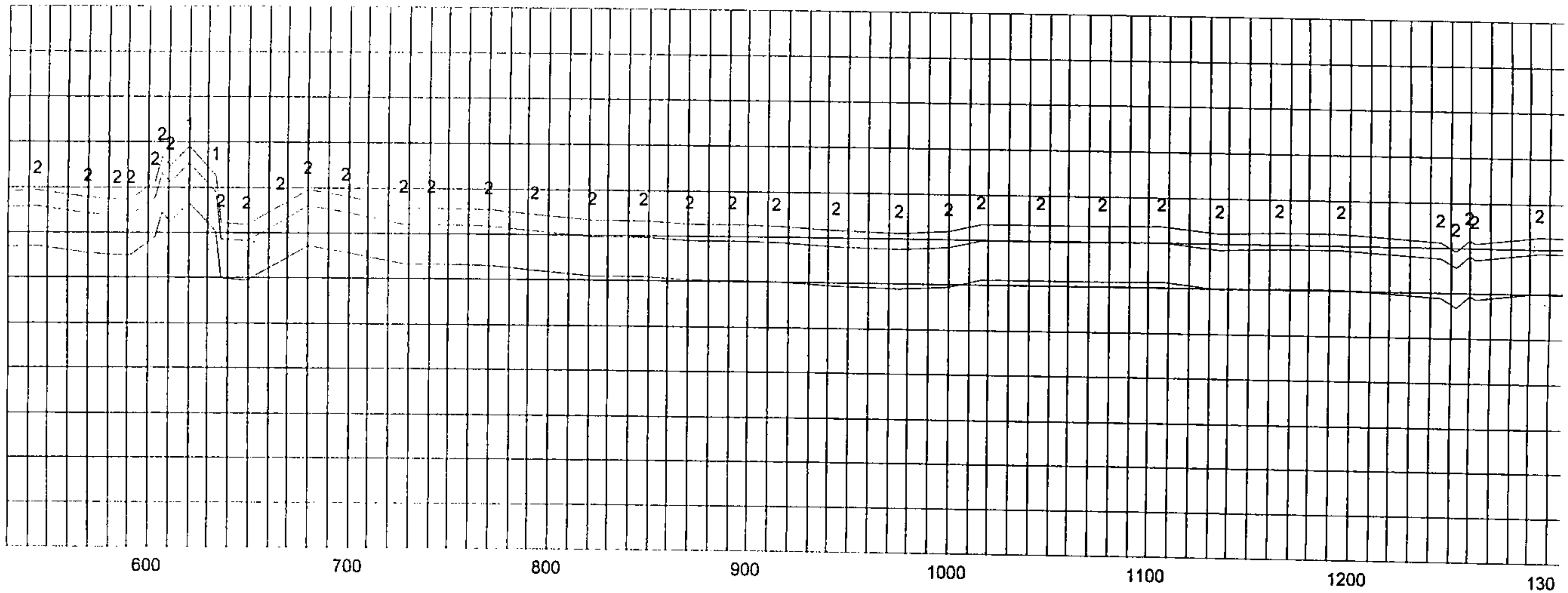
2
0
-2
0
100
200
300
400
500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700
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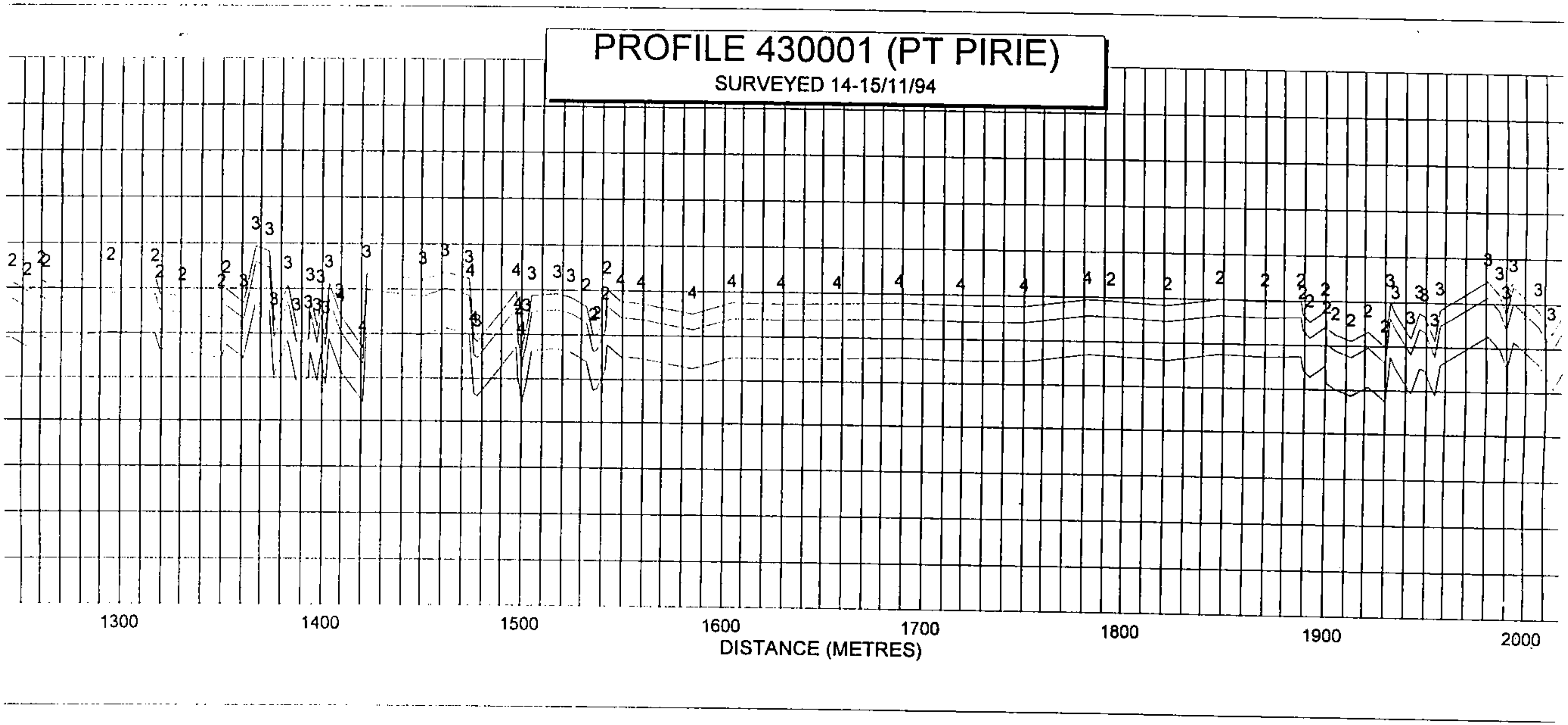
900
1000
1100
1200
130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SURVEYED 14-15/11/94
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1600
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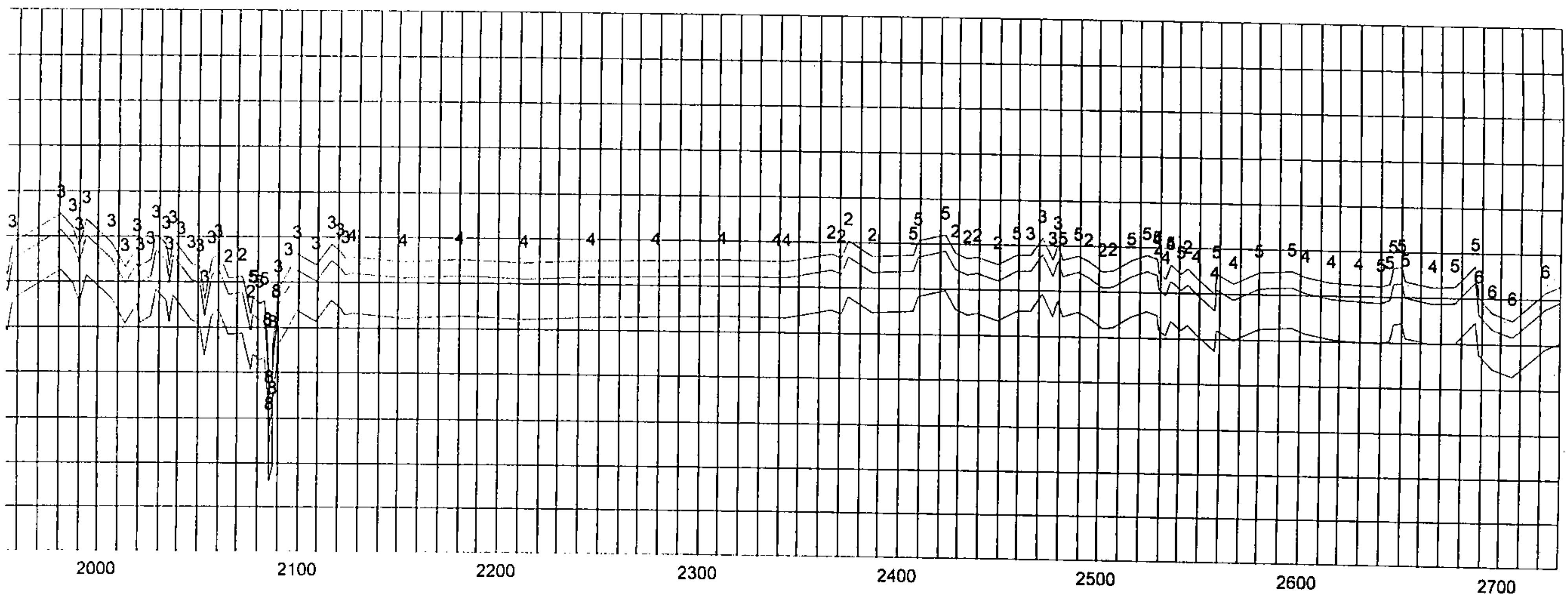
2000
DISTANCE (METRES)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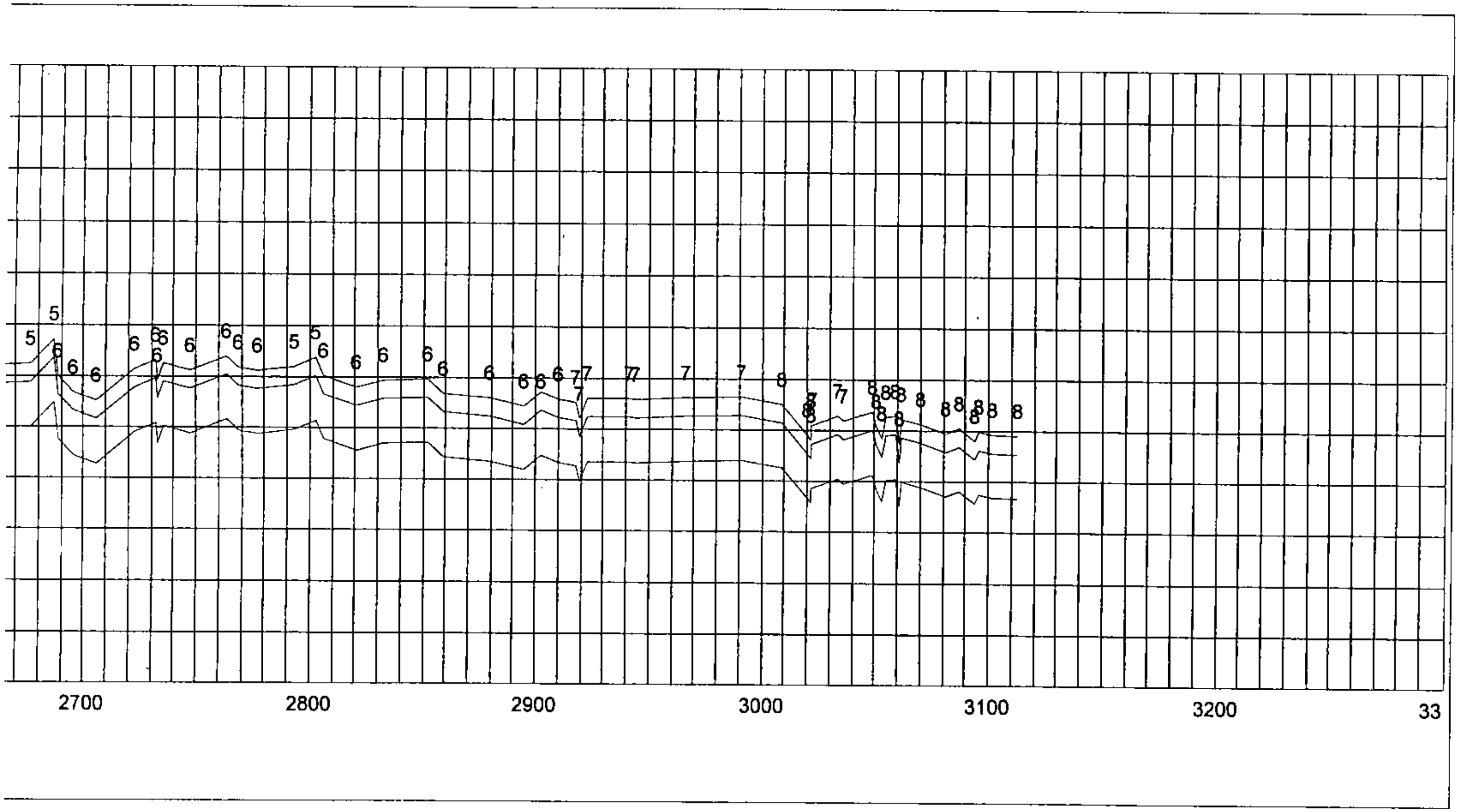
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2800
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3200
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REGIONAL COASTAL AREAS POLICIES:

AMENDMENT TO THE DEVELOPMENT PLAN
SEPTEMBER 1994

A: GENERAL COUNTRY REGIONAL OBJECTIVES

B: COUNTRY COUNCIL-WIDE OBJECTIVES

C: COUNTRY COUNCIL-WIDE PRINCIPLES

Appendix 3

REGIONAL COASTAL AREAS POLICIES:

AMENDMENT TO THE DEVELOPMENT PLAN
SEPTEMBER 1994

A: GENERAL COUNTRY REGIONAL OBJECTIVES

B: COUNTRY COUNCIL-WIDE OBJECTIVES

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REGIONAL COASTAL AREAS POLICIES:

AMENDMENT TO THE DEVELOPMENT PLAN
SEPTEMBER 1994

A: GENERAL COUNTRY REGIONAL OBJECTIVES

B: COUNTRY COUNCIL-WIDE OBJECTIVES

C: COUNTRY COUNCIL-WIDE PRINCIPLES

ATTACHMENT "A"

(General Country Regional Objectives)

COASTAL AREAS

The regional coastal policies that follow set a framework for the preparation of council-wide objectives and principles of control for development which could affect coastal areas or could be affected by coastal processes. Off-shore islands, beaches, sand dunes, cliffs, wetlands, nearshore waters and lands that form part of the coastal landscape ;and ecosystems are included.

The policies include objectives and principles to manage Hazard Risk in coastal areas which may be affected by sea level rise, erosion or other hazards common to coastal areas. They provide a framework for the local policies within specific coastal zones or other zones which may be affected by coastal processes.

Objective 1: Sustain or enhance the natural coastal environment in South Australia.

The coastal areas of the State are important for their onshore and marine environmental and landscape values, as well as for developed uses such as towns (including holiday settlements), tourism, marinas, commercial farming, aquaculture and recreation. Development a considerable distance from the coast (mainland or island) can affect all these areas if it influences the environment, general character and amenity of the coastal area or interferes with coastal processes such as erosion, tide and storm flooding or sand drift.

Much of the coast is subjected to the forces of waves, tides and sea-currents, particularly during storms. 'Soft' coasts develop a balance between the sea and the land which changes with the seasons, a so called dynamic equilibrium. For example, beach and sand dunes built up during months of relative calm will be eroded during stormy seasons, only to be built up again after the storms have passed. As well, wave action and currents are continually moving sand along the shore, often resulting in a net drift of material in one direction. Development can either directly or indirectly, interfere with these processes for example by changing surface and ground-water flows, and result in permanent loss of beach and dunes.

Not only may the shore environment be degraded and the amenity and recreation use of the beach be lost, but the development which caused the problem may become at risk. Even though there are policies to avoid public funding for protection of private development, public costs are often incurred on emergency works and protection of affected public land. The protection measures themselves (sea walls) often cause further loss of the beach and detract from public enjoyment of the coast.

In other areas coastal processes may be naturally eroding soft cliffs. Development located too close to such cliffs is not only at risk but could aggrevate the erosion through increased stormwater run-off if it is of poor design.

Objective 2: Preserve and manage the environmentally important features of coastal areas, including mangroves, wetlands, dune areas, stands of native vegetation, wildlife habitats and estuarine areas.

The interface between sea and land is a very active area for the movement of water and sand or other matter. It is usually very rich in plants and animals, both marine and terrestial and is an important breeding ground for many species. Such a biologically diverse environment is important in sustaining the biological resource base, particularly of the sea. Areas of conservation significance should be protected from development and zoned accordingly. If necessary the conservation effectiveness of coastal areas can be enhanced by linking them to other natural environments with linear parks.

The area and shape of allotments can be important for facilitating the management of environmentally sensitive areas and minimising the impact of development on them. Linear features such as dunes and lagoons are best managed when they have a single owner. Conservation reserves are best protected when abutting land is not closely divided.

The coast is continaully at risk of being badly polluted as it is at the receiving end of land drainage systems. Experience has shown that this poses a significant risk to marine life and sea-food resources. Land based animals and people who eat contaminated sea-food also suffer. Wetlands, which are often found behind sand dunes, and tidal flats not only provide a rich wildlife habitat, and are known to be a valuable natural treatment area for organic matter carried by rivers.

Objective 3: Preserve sites of heritage, cultural, scientific, environmental, educational or landscape importance.

Coastal areas often include sites of aboriginal heritage and were usually those first settled by the nineteenth century immigrants. Seacliffs can provide valuable geological exposures and beaches are often a source of rich and varied biological material which is important for scientific research and education.

The landscape value of the coast is important to both beach-users and people on the sea Even somewhat distant backdrops to the coast can affect the amenity. Policies for land clearly visible from the beach or near shore waters should reflect this.

Objective 4 Maintain and improve public access to the coast in keeping with other objectives

Since the first surveys the South Australian coast has been seen as a public resource for the enjoyment of all It is important that public access to the coast, particularly to beaches, is maintained and improved in a way that is consistent with the other objectives It is essential that development does not preclude or restrict public access along the coast and that conservation and public reserves are not damaged or alienated by the location or design of abutting development Where necessary, areas important to public recreation in coastal areas should be zoned accordingly Unless capable of a dual purpose, conservation reserves should not be used for public access purposes, nor should they be regarded as expendable erosion protection areas

Spur roads to the coast and lookouts are favoured over esplanades as they usually have less impact on coastal environment In environmentally suitable parts of coastal areas away from the coast, it may be possible to use loop roads to allow visitors to arrive and depart by different routes

Objective 5 Development which recognises and allows for hazards to coastal development such as inundation by storm tides or combined storm tides and stormwater, coastal erosion and sand drift; including an allowance for changes in sea-level due to natural subsidence and predicted climate change during the first 100 years of the development

The most common situation in coastal areas is subsidence. Rates of subsidence are significant in some places, especially in low-lying areas where soft sediments may still be compacting. This should be taken into account when estimating the probable changes in relative sea-level in a locality over the life of a development. Possible effects of climate change should also be considered. The allowance that should be made for climate change is discussed below.

If the coast is retreating, the foreshore, dunes, and wetlands contained in any coastal reserve could retreat also, unless they are prevented by natural or man-made features. Hence any erosion buffer should be additional to the coastal reserve.

Unstable sand dunes, land in the path of mobile dunes or close to soft erodible cliffs are also likely to be unsuitable for development.

Objective 6: Developers bearing the costs of protecting private development from the effects of coastal processes or the environment from the effects of development rather than the community

Low lying land which is now or in the future, subject to inundation by storm tides or stormwater should not be zoned or developed for urban/tourist development unless environmentally sound mitigation and protection works are formally and securely guaranteed by the council or the proponents of development.

Erosion mitigation works should only be considered in those instances where:

(a) a buffer cannot be provided;

(b) the works will not have an adverse effect on adjacent coastal areas and processes; and

(c) the works are guaranteed by the council or the proponent.

The storm tide. stormwater and erosion protection requirements need to be based on an anticipated sea-level rise due to global warming of 0.3 m between 1991 and 2050 Development should also be capable of being protected against a further sea-level rise, and associated erosion, of 0.7 m between 2050 and 2100. This rise is based on the historic and currently observed rate of sea-level rise for South Australia with an allowance for the nationally agreed most-likely predicted additional rise due to global climate change

Applications for the development of land which is at risk from storm surge and stormwater flooding or erosion should contain

(a) sufficient technical information to demonstrate that the proposed development will be protected from flooding or erosion; and

(b) the design of any coastal protection measures which are to be included and an assessment of the effect of such measures on the beach and adjacent coast

(c) evidence, where appropriate, of financial guarantees or other arrangements to ensure that all future costs (including storm damage, future protection, environmental restoration and site restoration in the event of non-completion) will either be met by the developer or future owners, or have been accepted as a future committment by a local council or other appropriate agency.

Objective 7: Protect the physical and economic resources of the coast from inappropriate development.

The need for, and opportunities for, location-specific developments such as harbours, jetties and marinas, mining, the harvesting of salt and fish or shell-fish farming (aquaculture) which all have particular physical and/or biological requirements, should be assessed before introducing policies or zonings which would prevent or inhibit such development . There also may be unique features of particular attraction for tourists which require special consideration.

Objective 8: Locate all housing, including holiday houses, tourist accommodation, marinas and rural living located on land zoned for that purpose and for it to be environmentally acceptable and consistent with orderly and economic development.

It is important that the coastal policies for each council area clearly identify those areas where urban, rural living, tourist and marina developments could be located and that all dwellings, accommodation and land division for these purposes should be located within those identified areas.

The location and size of zones set aside for such development should be based upon the achievement of the environmental, conservation, amenity and hazard-risk objectives for coastal areas This means that generally the number of such zones should be limited, the shape of zones equidimensional, not linear, and the policies should ensure compact, orderly development

Many areas of the South Australian coast are remote from existing community services and infrastructure. A frequent problem is the provision of adequate water supplies for permanent settlements

Provision of an excessive number of zones or excessive area of zones would be likely to result in scattered development. To service them with public utilities and community facilities would be costly It would also detract from the achievement of the other objectives for the coast While adequate and appropriate land is zoned for development, remaining land even if considered environmentally suitable for development should be retained in its natural state or in commercial farming use (not rural living) until existing development zones are almost fully developed

Objective 9 To redevelop and redesign unsatisfactory coastal living areas which do not satisfy environmental, health or public access standards for coastal areas

There are numerous urban coastal settlements which have been developed without due regard given to flooding, erosion, public access or environmental requirements Such areas should only be developed further if they are within a zone of predominantly urban character and satisfy the coastal development policies Development in unsuitable locations, including holiday houses on public foreshores, may need to be moved to alternative sites in due course

ATTACHMENT "B"

Country Council-Wide Objectives

Coastal Development

The following objectives for coastal development are based on, and are in addition to the Regional Coastal Policies for the State as set out in the Regional Parts of The Development Plan. The Regional Part provides the background, the reasons and the framework for these council-wide objectives.

These broad objectives are for the control of any development which could affect coastal areas or could itself be affected by coastal processes and, as such, may be applicable to areas some distance from the shoreline. **Thus they are applicable beyond, as well as within, the boundaries of any coastal zones designated by a council.**

Objective 1: Manage development in coastal areas to sustain or enhance the natural coastal environment.

Objective 2: Protect the coast from development that will adversely affect the marine and onshore coastal environment whether by pollution, erosion, damage or depletion of physical or biological resources, interference with natural coastal processes or any other means.

Objective 3: Development which does not interfere with environmentally important features of coastal areas, including mangroves, wetlands, dune areas, stands of native vegetation, wildlife habitats and estuarine areas.

Objective 4: Development which does not detract from or reduce the value of sites of heritage, cultural, scientific, environmental or educational importance.

Objective 5: Preserve areas of high landscape and amenity value including stands of vegetation, exposed cliffs, headlands, islands and hill tops, and areas which form an attractive background to urban and tourist developments

Objective 6: Development which maintains or enhances public access to coastal areas in keeping with objectives for protection of the environment, heritage and amenity by provision of

(a) planned, appropriate easy to use public access to and along beaches

(b) coastal reserves and lookouts,

(c) convenient and safe public boating facilities at selected locations.

(d) convenient vehicular access to points near beaches and selected points of interest; and

(e) adequate car parking

Objective 7: Development only undertaken on land which is not subject to, or can be appropriately protected from, coastal hazards such as:

(a) inundation by storm tides or combined storm tides and stormwater,

(b) coastal erosion, or

(c) sand drift

Objective 8: Development located and designed to allow for changes in sea-level due to natural subsidence and probable climate change during the first 100 years of the development. This change to be based on the historic and currently observed rate of sea-level rise for South Australia with an allowance for the nationally agreed most-likely predicted additional rise due to global climate change.

Objective 9: Development which will not require, now or in the future, public expenditure on protection of the development or the environment.

Objective 10: The protection of the physical and economic resources of the coast from inappropriate development.

Objective 11: Development of coastal urban settlements, coastal rural living areas, tourist complexes and marinas only in environmentally acceptable areas.

Objective 12: Urban development including housing, holiday houses, tourist accommodation, and rural living, as well as land division for all such purposes, only in the zones specifically created for such developments.

Objective 13: Development of coastal urban settlements, coastal rural living, tourist accommodation and marinas in an orderly and economic manner which provides for a range of sites while ensuring the number of locations and the size of the zones do not exceed that which is indicated as being required by an realistic assessment of future demand.

Objective 14 To redesign and redevelop coastal living areas which do not satisfy environmental, health or public access standards for coastal areas.

ATTACHMENT "C"

(Country Council-Wide Principles)

COASTAL AREAS

The following principles of development control are applicable to all development which could impact on coastal areas, affect coastal processes or be subject to effect or hazard from coastal processes now or in the future, whether or not the development is located in a designated coastal zone.

The area of Blanche Harbour defined by the Blanche Harbour Management Plan, that is Sections 16 and 18, Hundred of Gillan, is exempted from the Regional Coastal Areas Policy Supplementary Development Plan in relation to Principles 7, 15 and 23 of Attachment C of the SDP.

Environmental Protection

1 Development, including flood, erosion and wave protection measures, should not adversely affect the ecology of coastal areas, the seabed or coastal waters by pollution, significant loss of habitat, interference with coastal processes or any other means.

2 Development should not be located in delicate or environmentally-sensitive coastal features such as sand dunes, wetlands or important remnants of native vegetation.

3 Development should not, nor be likely in the future to, adversely affect the ecology and stability of environmentally sensitive coastal features

4 Development should not be undertaken where it will create or aggravate coastal erosion, or where it will require coast protection works which cause or aggravate coastal erosion.

5 Land should only be divided in such a way that:

(a) it or the subsequent development and use of the land will not adversely affect the management of the land, adjoining land or the coast;

(b) sand dunes, wetlands and remnant vegetation are maintained in single parcels;

(c) the number of allotments abutting directly onto the coast or onto a reserve for conservation purposes is minimised; and

(d) outside of urban, tourist-accommodation and rural living zones it will not result in allotments with frontages to the coast or coastal reserve shorter than the depth of the allotment (or less than the square root of the area for irregular shaped allotments);

6 Development should be designed for solid or fluid wastes and stormwater run-off to be disposed of so that it will not cause pollution or other detrimental impacts on the marine and on-shore environment of coastal areas.

7 Effluent disposal systems incorporating soakage trenches or a similar system should be located not less than 100 m or greater where it is necessary to avoid effluent migration onto the inter-tidal zone, the 100 m to be measured from:

(a) the mean high water mark at spring tide adjusted for any subsidence for the first 50 years of development plus a sea-level rise of 1.0 m; or

(b) the nearest boundary of any erosion buffer determined in accordance with Principle 27,

whichever is the greater. Except where health commission standards can be met by a lesser setback

8 Development should preserve natural drainage systems and should not **significantly** increase **or decrease** the volume of water flowing to the sea. Where necessary it should incorporate stormwater management schemes including:

(a) onsite harvesting of water and land based disposal systems;
(b) retention basins to facilitate settlement of pollutants and to regulate water flow; and
(c) infiltration.

9 Development should not cause deleterious effects on the quality or hydrology of groundwater

10 Development proposed to include or create confined, coastal waters (whether partially or wholly), including water subject to the ebb and flow of the tide, should ensure the quality of such waters is maintained at an acceptable level.

11 Development should not preclude the natural geomorphological and ecological adjustment to changing climate, sea level or other conditions. For example landward migration of coastal wetlands should not be prevented by embankments. Development should be designed to allow for new areas to be colonised by mangroves and wetland species and for removal of existing embankments where practical

Preservation of scenic, heritage and other values

12 Development should not result in the disturbance or the devaluation of sites of heritage, cultural, scientific or educational significance.

13 Development which is proposed to be located outside of urban and tourist zones should be sited and designed to not adversely affect:

- the natural, rural or heritage character of the area;
- areas of high visual or scenic value;
- views from the coast, near-shore waters, public reserves, tourist routes and walking trails; or
- the amenity of public beaches by intruding into undeveloped areas

14 Development within urban and tourist accommodation zones should be designed and sited in sympathy with the existing natural and built character of its locality. It should not be out of scale, of conflicting colour or materials or detract from any natural backdrop to the zone, nor project above the skyline visible from the coast.

Maintenance of public access

15 Development adjacent to the coast should not be undertaken unless it has or incorporates the provision of a public reserve, not including a road or erosion buffer provided in accordance with Principle 26, of at least 50 m width between such development and the toe of the primary dune or the top edge of the escarpment, unless the development relates to small scale infill development in a predominantly urban zone.

16 Development which abuts or includes a coastal reserve for scenic, conservation or recreational purposes should be located and designed in such a way as to have regard to the purpose, management and amenity of the reserve and to prevent illegal incorporation of reserve land into private land.

17 All development, including marinas and aquaculture development, should be located and designed for public access along the waterfront, to beaches and coastal reserves to be maintained, if not increased.

18 Access to beaches and reserves should be, by means of walkways and roads suitably designed and constructed to meet the environmental objectives and principles for coastal areas.

19 Access roads to the coast and lookouts should preferably be spur roads. Tourist routes may be loop roads but should be located back from the coast and only where the road will not detract from the amenity of the area or lead to management problems.

Hazard risk minimisation

20 Development should not occur on land where the risk of flooding is unacceptable having regard to personal and public safety and to property damage.

21 For the purposes of assessing coastal developments **the standard sea-flood risk level** for a development site is defined as the 100 year average return interval extreme sea level (tide, stormwater and associated wave effects combined), plus an allowance for land subsidence for 50 years at that site.

22 Land should not be divided for commercial, industrial or residential purposes unless a layout can be achieved whereby roads, parking areas and adequate development sites on each allotment are at least 0.3 m above the standard sea-flood risk level, unless the land is or can be protected in accordance with Principle 25

23 Commercial, industrial or residential development should only be undertaken where

(a) building floor-levels are at least 0.25 m above the minimum site level of Principle 21 (ie 0.55 m above the standard sea-flood risk level), unless the development is or can be protected in accordance with Principle 25 and

(b) there are practical measures in accordance with Principle 25 available to the developer, or subsequent owners, to protect the development against a further sea-level rise of 0.7 m above the minimum site level determined by Principle 22

24 Buildings to be located over tidal water or which are not capable of being raised or protected by flood protection measures in future, should have a floor level of at least 1.25 m above the standard sea-flood risk level.

25 Development which requires protection measures against coastal erosion, sea or stormwater flooding, sand drift or the management of other coastal processes at the time of development, or which may require protection or management measures in the future, should only be undertaken if:

(a) the measures themselves will not have an adverse effect on coastal ecology, processes, conservation, public access and amenity;

(b) the measures do not now, or in the future require community resources, including land.

(c) the risk of failure of measures such as sand management, levee banks, flood gates, valves or stormwater pumping, is appropriate to the degree of the potential impact of a failure; and

(d) adequate financial guarantees are in place to cover future construction, operation, maintenance and management of the protection measures.

26 Development should be set-back a sufficient distance from the coast to provide an erosion buffer which will allow for at least 100 years of coastal retreat for single buildings or small scale developments, or 200 years of retreat for large scale developments such as new towns, unless:

(a) the development incorporates private coastal works to protect the development and public reserve from the anticipated erosion, and the private coastal works comply with Principle 25; or

(b) the council is committed to protecting the public reserve and development from the anticipated coastal erosion.

27 Where a coastal reserve exists, or is to be provided in accordance with Principle 15, it should be increased in width by the amount of buffer required.

28 The width of an erosion buffer should be based on:

(a) the susceptibility of the coast to erosion;
(b) local coastal processes;
(c) the effect of severe storm events;
(d) the effect of a 0.3 m sea-level over the next 50 years on coastal processes and storms; and
(e) the availability of practical measures to protect the development from erosion caused by a further sea level rise of 0.7 m per 50 years thereafter.

29 Where there is inadequate area to provide the necessary erosion buffer to development on land at risk from long-term coastal erosion (for example small-scale infill development including land division), such development should not occur unless:

(a) the council has committed itself to erosion protection measures which may be necessary along this section of the coast; **or**
(b) a legally binding agreement is included on the freehold title(s) that protection measures will not be built and that any building will be transportable and will be removed when threatened by erosion or storm surge flooding; **or**
(c) a legally binding agreement is included on the freehold title(s) that protection measures that comply with Principle 25 for coastal development will be built by the land owner(s) when required.

30 Development should not occur where essential services cannot be economically provided and maintained having regard to flood risk and sea-level rise or where emergency vehicle access would be prevented by a 100 year average return interval extreme sea-level event, adjusted for 100 years of sea-level rise.

<u>Protection of physical and economic resources</u>

31 Development outside of urban zones should not take place if there is the potential for significant conflict with likely development which benefits the wider community based on any of the special economic or physical resources of coastal areas such as:
tourist attractions,
harbour and jetty sites,

aquaculture sites,
marina sites, and
mineral deposits of State or national importance.

Settlement, tourist facilities and marinas in appropriate zones

32 Urban development including holiday house settlements and tourist developments, marinas, rural living, country living and other development of a non-commercial farming nature, including land division for all such development, should only be undertaken in zones designated for such development.

33 Tourist development outside of zones designated for such development should be confined to small-scale, short-stay accommodation within or adjacent to an existing inhabited farmhouse and operated as a minor adjunct to normal commercial farming.

34 Outside of urban and tourist-accommodation zones no more than one dwelling should be constructed on an allotment.

No premature development.

35 Development, including land division, urban, holiday settlement, tourist development and other urban-type developments should be:

(a) compact not linear development;
(b) contiguous with any existing built-up areas;
(c) developed in a staged and orderly manner which facilitates the economic provision of services and infrastructure, and
(d) in particular no such development should occur without provision of an adequate reticulated domestic-quality mains water-supply and a common effluent drainage scheme.

Redevelopment of unsatisfactory areas

36 Existing development which is contrary to the objectives for coastal areas should not be redeveloped unless the redevelopment significantly rectifies the unsatisfactory aspects