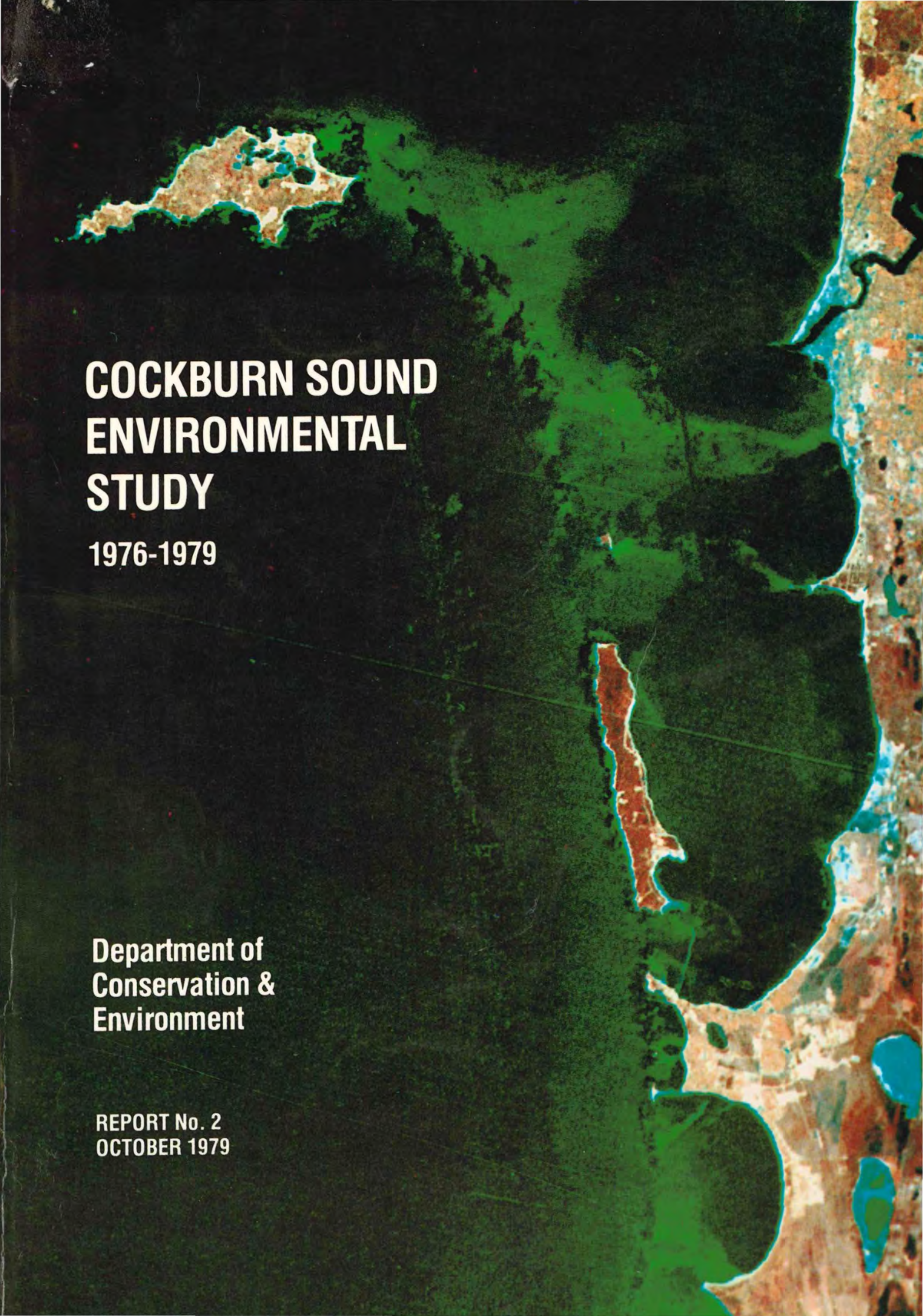

# COCKBURN SOUND ENVIRONMENTAL STUDY

## 1976-1979

**Department of Conservation & Environment**

REPORT No. 2
OCTOBER 1979

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and Environment

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Metropolitan Water Supply, Sewerage and Drainage Board
Murdoch University
Department of Health and Medical Services
Soil Conservation Service: Department of Agriculture
Western Australian Institute of Technology
Western Australian Museum

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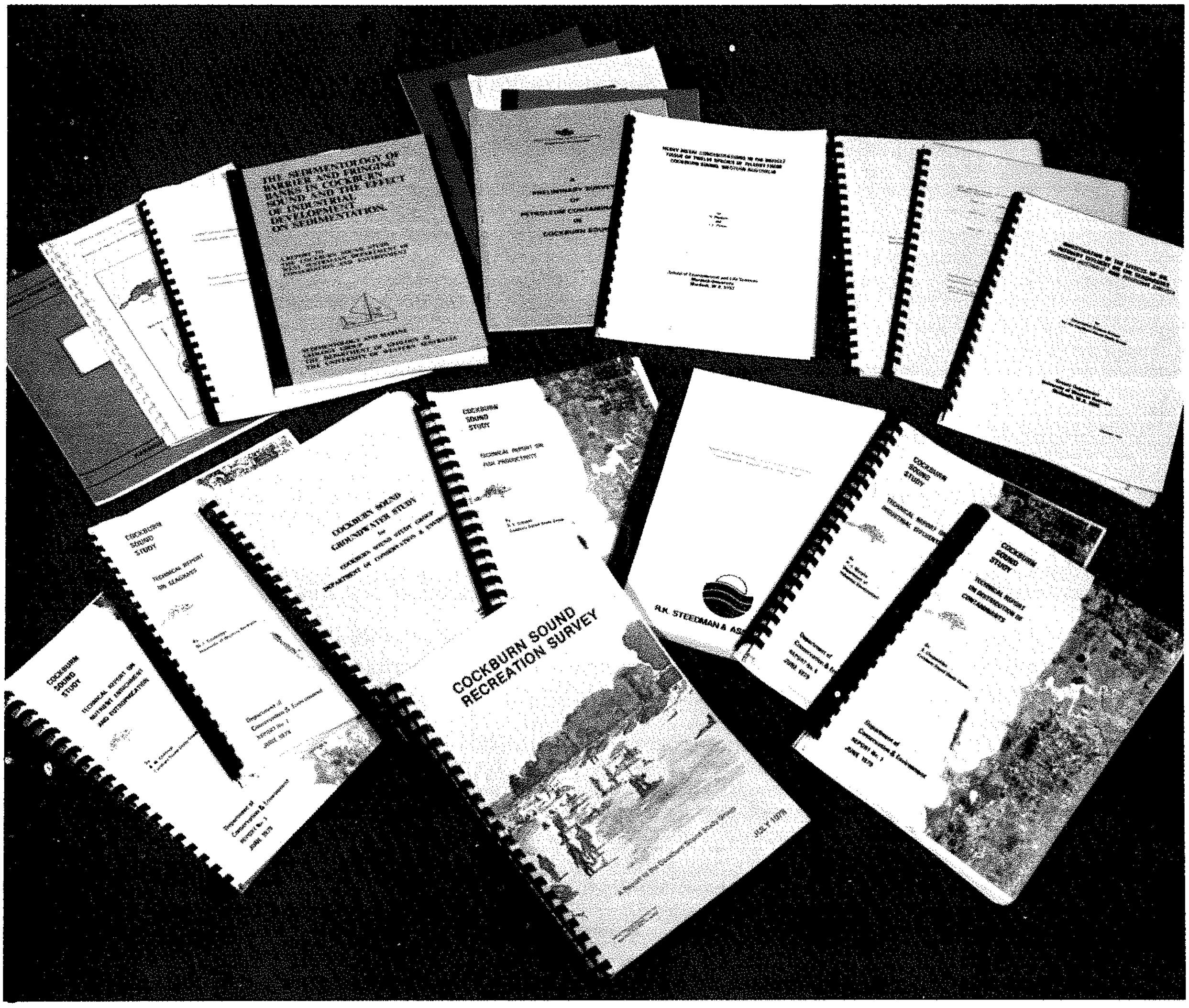



Reports to the Cockburn Sound Environmental Study containing scientific and technical data from which this report was prepared.
Photographed by Klaus Schmechtig of Graphic Image Photography.

# PREFACE

Development of Cockburn Sound as the outer harbour for the Perth-Fremantle area really began in the 1950s and gained momentum in the next 25 years. The first major unit of an industrial complex, which built up on the eastern margin of the Sound, was an oil refinery which opened in 1955. This was followed by the development of other major and ancillary industries. Wastewaters from several of these industries and from a wastewater treatment plant at Woodman Point started to be discharged directly into Cockburn Sound. In 1971 a cement manufacturing company was given the right to dredge lime sands from Success and Parmelia Banks for the next 40 years. The Commonwealth Government (in 1969) announced plans to build a naval establishment on Garden Island to be linked with the mainland by a solid fill causeway with two open bridge sections. Work was begun on the causeway in January 1971 and completed in April 1973.

By 1940 meatworks had been established on the foreshore of Owen Anchorage setting the pattern for the development of this area for meatworks, woolscourers, fellmongers, fish processors, etc., and in 1949 a power station was also built on these shores.

Throughout the period of industrial development around Cockburn Sound there has been a steady growth of urban population. In 1976 the total population in the hinterland of the Sound from Fremantle to Rockingham was about 145 000 and is expected to reach approximately 200 000 by 1990.

Prior to the passing of the Environmental Protection Act of 1971, no single authority was responsible for the environmental management of the Cockburn Sound area, although general responsibility for the waters, seabed, flora and fauna of the Sound itself was in the hands of the Fremantle Port Authority. Certain departments had specific roles, e.g., the Department of Fisheries and Wildlife managed the fish resources and the Department of Health and Medical Services was concerned with matters relating to public health. Zoning for land use has been controlled by the Metropolitan Region Planning Authority (MRPA). In 1961 an inter-departmental committee, known as the Cockburn Sound and Kwinana Development Committee, was formed to examine the Cockburn Sound area and to make recommendations as to zoning. The object of planning at that time was to utilise the area for industrial growth.

Concerned at the deterioration of the environment in the area, members of local government authorities, industry and the Fremantle Port Authority in 1969 formed the Cockburn Sound Conservation Committee. Having no statutory powers and being unable to carry out field studies, the role of this Committee in environmental management has been mainly as a forum for discussion.

In recognition of some of the adverse environmental changes taking place in Cockburn Sound and in view of the plans to build a causeway, the Fremantle Port Authority with the Commonwealth Department of Works (now the Department of Housing and Construction) financed a range of environmental studies in the early 1970s. These covered the ecology, hydrology and beach morphology of Cockburn Sound.

A comprehensive review of these studies carried out on behalf of the Environmental Protection Authority in 1975 proposed approaches to solutions and pointed out aspects requiring further research. After this review had been considered by the Environmental Protection Authority and the Conservation and Environmental Council, the Western Australian Government allocated $500 000 for a three-year (1976-79) environmental study.

As approved by Cabinet, the object of this environmental study of Cockburn Sound was to obtain the information necessary to manage the Sound for multipurpose use, accommodating recreational and fishing activities as well as use for port and industry.

The Cockburn Sound Study Group, a core group of professional and technical personnel, was established in November 1976 under the guidance of a Steering Committee. The major aspects requiring investigation were identified and designated as segments of the overall study. Work on the segments was carried out by members of the Study Group and by consultants, Government Departments and Universities. For the highly technically trained, detailed reports on all aspects of the study are being published separately and are listed at the end of this report. They constitute an invaluable fund of technical and scientific information about the Sound.

This report covers in general terms the detailed work of many scientists and technicians over three years. The main environmental problems have been identified and options presented for solving them. The report has been prepared not only for those responsible for making major management decisions but also for private individuals with an interest in the area. The conclusions and recommendations presented in this report have been reviewed and broadly endorsed by the Cockburn Sound Study Steering Committee.

# SUMMARY, KEY CONCLUSIONS AND RECOMMENDATIONS

The Cockburn Sound Environmental Study report is itself a summary of many separate reports covering up to three year's work by members of the Cockburn Sound Study Group, State Government and University Departments and private consultants. The summary which follows is drawn mainly from the segment reports described in Chapters 4 to 7 and the recommendations are taken largely from those contained in Chapter 9 which deals with development of solutions to environmental problems. Attention is drawn to detailed conclusions and recommendations on specific topics contained in appropriate chapters of this report.

## SUMMARY

The Cockburn Sound Study was initially divided into the seven segments listed below. Information about each topic is summarised in this section.

**Recreation**

The Sound is enjoyed for recreation by people from many parts of the metropolitan area. Complaints from visitors are more often concerned with facilities for recreation rather than directed against industry. There is some degree of tolerance of industry amongst users of the Sound, provided people have access to beaches. Facilities which are most sought include boat ramps, showers/toilets, picnic facilities, shade, parking, kiosk, etc. Particularly among community groups, however, there is a general fear of pollution and an uncertainty about the future availability and quality of beaches in the face of continued industrial growth.

**Fish Resources**

This baseline study has shown that significant catches are taken annually by professional and amateur fishermen. There is little competition between professional and amateur fishermen as they generally seek different species, although there are complaints from time to time of competition between net fishermen and anglers. Over the years some changes in species have resulted where the seagrass has receded, but they seem not to have adversely affected the habitat of species of importance to professional or amateur fishermen.

**Urban and Industrial Effluents**

Of the wide range of substances being discharged into the Sound, those having the most widespread effects are the nutrient compounds of nitrogen and phosphorus. These compounds stimulate the growth of algae, large and small. The major input of nitrogen to the Sound at present is the effluent from the Kwinana Nitrogen Company (KNC). That Company, however, proposes in-plant treatment to substantially reduce its ammonia and nitrate discharges. The second largest source of nitrogen compounds is the primary treated sewage discharged from the Woodman Point Wastewater Treatment Plant (WPTP). The volume of sewage discharged will continue to increase. Further treatment ashore or a discharge to ocean waters are being considered. The major source of phosphorus is the gypsum waste from the CSBP fertiliser works. This Company has plans for disposal of gypsum on land in the future.

Other constituents in effluents which are of concern include heavy metals (particularly cadmium, chromium, lead, copper and zinc which accumulate in shellfish) which are present in varying amounts in the effluents discharged from industries in the James Point area and the WPTP wastewater discharge. There is an input of soluble fluoride from CSBP of unknown but potential environmental concern and organic chemicals derived from the oil refining processes at the BP Refinery. In the Owen Anchorage waters there is visible discolouration and turbidity from the effluents discharged by the abattoirs and other industries that occasionally affect water quality at Coogee Beach.

Enteric bacteria including Salmonella serotypes are contained in discharges from WPTP and the abattoirs. On occasion, concentrations of these organisms in seawater and mussels from shore waters and recreational sites in the Woodman Point/Owen Anchorage area have exceeded generally accepted public health standards.

As part of its planned expansion, CSBP (the major contributor of cadmium) proposes land disposal of its waste gypsum. Since most constituents of concern in the CSBP discharge are associated with the gypsum, land disposal should significantly reduce inputs, although various materials may be released slowly from the sediments in the Sound for an extended time.

Localised contamination of groundwater has occurred beneath a number of industries owing, for example, to spillages and soaks.

**Seagrass**

Studies related to the general disappearance of seagrass along the eastern shore of the Sound appear to indicate that heavy growth of thick mats of filamentous algae or epiphytes on the seagrass are the principal cause and that, in addition, there is a reduction of light or "shading" in deeper waters due to dense phytoplankton growth. Both forms of algal growth are stimulated by a relatively high availability of nutrients. Localised loss of seagrass which has occurred in a number of places may be attributed to unidentified toxic substances in discharges and to physical activities such as dredging and construction of groynes.

**Nutrient Enrichment**

The input of nutrients (nitrogen and phosphorus) in wastewater discharges is an underlying cause of periodic blooms of phytoplankton in the Sound and of the loss of seagrass over large areas along the eastern shore. Nitrogen has been identified as the key nutrient, i.e. the one that is limiting for phytoplankton growth, and a reduction in nitrogen inputs from the major sources noted above will reduce phytoplankton growth and constitute an action of primary importance. Reduction of the other nutrient, phosphorus, may have little effect unless very substantial reductions can be achieved and it is most unlikely that phosphorus could be reduced sufficiently for it to become the limiting nutrient. Emphasis is placed on the reduction of nitrogen loads and not phosphorus as the growth requirements of phytoplankton are such that the availability of nitrogen rather than phosphorus is likely to be the limiting factor for growth.

**Seawater Movement**

The Study Group has come to the conclusion from all the evidence now available that exchange of water with the ocean is quite limited (irrespective of any minor effects the construction of the causeway has had). Much of the time the Sound behaves like a tidal "lake". Thus its ability to cope with pollutants, especially those which are not degradable, is limited. Because of a weak eddy holding water in Mangles Bay, algal blooms occur there more frequently than elsewhere in the Sound. Coincidentally, this is where the greatest number of beach users gather.

Currents in the Sound are wind-driven to a large degree. For example under southerly wind conditions, waters from the Sound move along the shore into Owen Anchorage, while northerly winds move waters into the Sound.

**Sand Movement**

The Success and Parmelia banks protect the Sound from storm waves, and, along with Garden Island, contribute to the comparatively calm water within the Sound. The seagrass cover stabilises the banks and prevents large scale erosion although some sand movement is required for continued growth of one of the two predominant seagrass species. Construction of groynes can retard longshore sand movement and leads to accretion and erosion of existing beaches where littoral sand movement occurs.

# KEY CONCLUSIONS AND RECOMMENDATIONS

The Study has shown the following:

- that the Sound behaves as a tidal "lake" for much of the time and thus effluents do not move out of the Sound readily;
- that seagrass dieback is related to the increase in nutrient input to Cockburn Sound;
- that water quality has deteriorated through the occurrence of undesirable blooms of free drifting algae, also attributable to nutrient input;
- that some of the biota, sediments and inshore waters are contaminated by heavy metals or bacteria;
- that the nutrients, heavy metals and bacteria originate from industrial or sewage effluents.

From these main conclusions flow the key recommendations. As a group, they provide the framework upon which to base a water quality management programme in Cockburn Sound.

1. Water quality objectives related to the various uses of the Sound and its flora and fauna should be established following the guidelines set out in Chapter 3. Recommendations for these have already been made by the working party set up by the Environmental Protection Authority.

2. All waste dischargers should proceed with such process changes, in-plant treatment, or removal of specific wastewater discharges from Cockburn Sound as necessary to achieve collectively these water quality objectives.

3. For the Woodman Point Wastewater Treatment Plant, it would appear less costly in terms of capital and operation costs to develop a new deep-water outfall to the ocean rather than provide facilities to remove nutrients, particularly nitrogen compounds. Since the plant is, or will become, the principal source of wastewater and nitrogen compounds which can be collected in a regional system, the Metropolitan Water Supply and Drainage Board should obtain oceanographic and other information necessary to evaluate the merits of disposal to ocean waters, in contrast to nearshore waters having restricted circulation.

4. Industries in the Cockburn Road Special Industrial Area should pretreat wastewaters to a degree compatible with connection to a regional wastewater treatment and disposal scheme.

5. Monitoring of the effectiveness of in-plant and other control measures should be carried out by periodic sampling of effluents, nearshore waters, biota and sediments in the vicinity of existing outlets. The Fremantle Port Authority in collaboration with the Environmental Protection Authority should organise and evaluate this monitoring.

6. Steps should be taken to prevent further pollution of groundwater, and recovery programmes in the more severely affected areas should be expanded as fully as possible.

7. Future plans for the mining of lime sands from Success and Parmelia Banks should be carefully examined to ensure that the banks maintain their protective function.

8. Recognising that competition between different users for the limited open foreshore remaining around the edges of the Sound must increase in the future, decisions regarding future use of foreshores should have regard to existing and potential uses.

# PART 1

## BACKGROUND INFORMATION

This part of the report consists of three chapters and presents background information about Cockburn Sound and the study. Chapter 1 briefly traces the environmental changes which prompted the study, and outlines the organisation and management arrangements under which it was carried out. Chapter 2 describes the Cockburn Sound Study Area as well as its resources and uses. Chapter 3 identifies beneficial uses of the Sound's waters and suggests objectives for water quality characteristics important in protection of these uses.


(a)
(b)
(c)
(d)

v) assessment of the fisheries production and potential for professional and amateur fishermen;

vi) appraisal of water movements to reassess flushing of effluents and to provide alternative options to treatment on land by discharge of effluents into well-flushed areas;

vii) beach movement studies to assess the role of seagrass naturally or the need for artificial devices to control beach erosion.

In line with these objectives, the study's main focus has been the environmental impact of natural and man-made pressures upon the aquatic environment. Consideration of land-associated aspects has been limited to the immediate vicinity of the Sound and has included aspects such as competing uses of the foreshore and impacts on coastal resources. There are no fresh water streams of significance discharging directly into the Sound, so it has not been necessary to study an extensive land drainage basin.

Air emissions were not included in the present study. Industrial emissions to the atmosphere are being examined by the Kwinana Air Modelling Study set up by the Department of Conservation and Environment in collaboration with the Clean Air Section, Department of Health and Medical Services. However, studies carried out elsewhere have shown that airborne pollutants are not major sources of inputs to coastal embayments.

## 1.3 DEFINITION OF STUDY AREA

The study area is bordered by Garden Island on the west, Cape Peron and the Shire of Rockingham on the south, and the coastal strip on the east of the Sound (Figure 2.1).

Physically, the northern boundary of the Sound extends seaward from Woodman Point and includes Parmelia Bank. However, under certain circulation patterns, waters from Owen Anchorage flow across Parmelia Bank into the northern part of Cockburn Sound and have an impact on water quality within the Sound. The opposite is the case at certain other times. Therefore, the nature of present and future inputs from land sources to Owen Anchorage and the general quality of the offshore waters were examined insofar as they may affect or may be affected by activities and conditions in Cockburn Sound. Warnbro Sound to the south, being free from industrial activities, was used as a control area for comparative purposes.

## 1.4 METHOD OF APPROACH

At the time of setting up the study seven major study segments were identified as requiring detailed investigation under the general supervision and co-ordination of the Project Leader seconded from CSIRO. As the study progressed some segments were modified or expanded according to needs identified after closer examination of particular environmental problems and of the data available. The nature of the segment studies as they finally evolved is described below. The detailed reports on each segment are being published separately and can be referred to by persons needing technical and scientific details. A number of accessory reports containing back-up data complementing the main technical reports were prepared by various departments and institutions. These and other segment reports are listed with other references cited in the body of this report.

### 1.4.1 Cockburn Sound Recreation Survey

Feilman Planning Consultants Pty. Ltd. of Perth were engaged to provide a report[1] on present and future recreational use of Cockburn Sound and to work closely with the Study Group in making assessments of the relative value of multiple uses of the Sound and its foreshores.

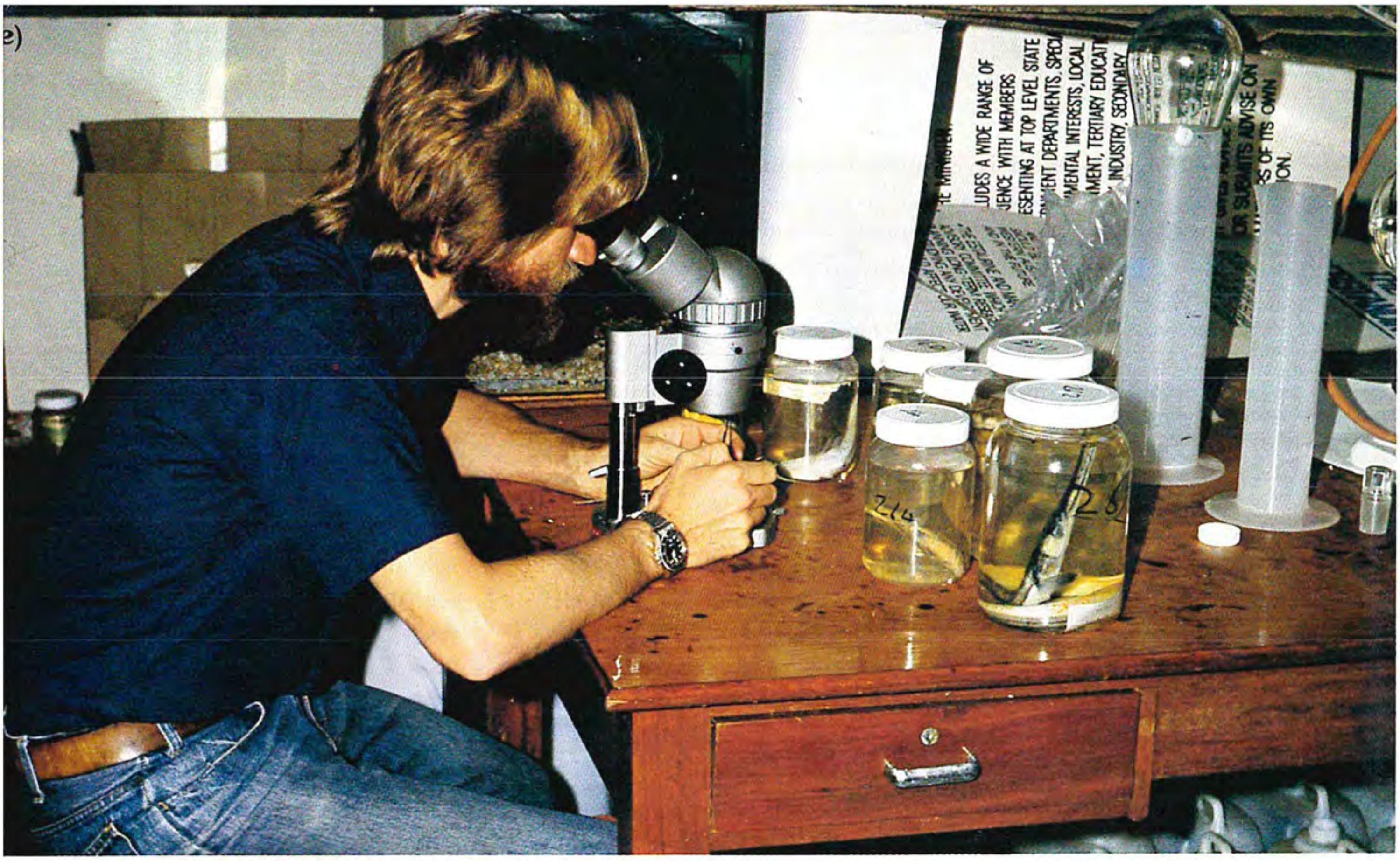
### 1.4.2 Fish Resources and Production

A fish ecologist was appointed to the Study Group to prepare a quantitative assessment[2] of the faunal resources of the Sound. Work was carried out in close conjunction with the research staff of the Department of Fisheries and Wildlife. Attention was given to species composition, seasonal changes in distribution and relative abundance, and habitat preferences. However, both the paucity of existing information on the fish fauna of the Sound, and the short term nature of the overall study meant that the fish programme had to be restricted in scope, being principally concerned with gathering baseline data.

In addition to the work by the fish ecologist, and as a step toward a better understanding of the structure of the fish community within the Sound, research staff of the Western Australian Museum

Plate 1. A and B. Aspects of the field and laboratory work carried out for the Study.
A (a): Study Group divers measure the growth of tagged seagrass leaves. (b): Study Group scientists filtering seawater samples for the study into nutrient enrichment and eutrophication. (c): Marine chemist analysing crab flesh on an atomic absorption spectrophotometer for the study on the distributions of contaminants. (d): Study Group diver collecting a core of sediment for heavy metal analysis.

e)



(h)

were given financial support and encouragement to report on earlier studies of the benthic community, and a grant was given to support a further quantitative sampling of benthic fauna. Reports on these tasks have been presented separately.[3–4–5]

### 1.4.3 Description and Distribution of Urban and Industrial Effluents

A research chemist from the Department of Industrial Development, with support from the Study Group, was responsible for (i) sampling and analysis of effluents in order to determine concentrations and quantities of substances discharged by major contributors; and (ii) presenting the results in a technical report on this segment.[6] In addition, an analytical chemist at the Western Australian Institute of Technology[20] extracted and analysed hydrocarbons in the refinery effluents, under the joint sponsorship of the Cockburn Sound Study and BP Refinery.

The distributions and concentrations of effluents after discharge to the Sound and in groundwater were studied and separate reports on these activities also have been submitted.

A marine chemist was appointed to the Study Group to study the distribution of waste substances (other than nutrients) once they have entered the Sound and an analyst at Murdoch University was granted an Environmental Fellowship to determine levels of heavy metals in fish from Cockburn Sound and the Swan River estuary.[21] The report by the marine chemist on these activities is of great value in documenting the concentrations and distributions in biota, sediments and water of waste inputs after they are discharged to the Sound.[7]

Layton Groundwater Consultants of Perth were engaged to report on the quality of groundwater along the eastern margin of the Sound.[8] Several industries discharge a portion of their wastewaters to land and spillages on plant sites have occurred over the years. Analyses of groundwater show that wastes have reached aquifers used by some industries for process water.

Finally, the Study Group co-operated with the State Health Laboratory Services in collecting samples of seawater and mussels for laboratory testing for enteric bacteria.[9]

### 1.4.4 Seagrass Studies

Historically, the gradual disappearance of seagrass from the eastern shores of the Sound has been a topic of considerable public and Governmental interest. As a part of the present study a grant was made to the Botany Department, University of Western Australia, for a post-graduate marine biologist to extend research on seagrass with field and some laboratory support by the Study Group.[10] In addition, another research student from the same Department carried out aquarium tests on the effects of pollutants on seagrass.[11]

### 1.4.5 Nutrient Enrichment Studies

Perhaps even more than seagrass disappearance, periods of high phytoplankton growth rates leading to algal blooms have attracted public attention. Accordingly, an ecologist was appointed to the Study Group to investigate nutrient enrichment of the Sound's waters by nitrogen and phosphorus compounds and, if possible, to correlate the results with the occurrence of algal blooms in the Sound.[12]

### 1.4.6 Seawater Circulation in the Sound

Circulation and related physical phenomena in the Sound are the mechanisms by which wastewater inputs are transported, dispersed and diluted. The consulting firm of R.K. Steedman & Associates was commissioned to develop a mathematical model of circulation in the Sound, to calibrate it using data collected from the Sound itself, and to use it to predict the distribution and concentration of various constituents of input wastewaters.[13] Other segment studies, particularly the seagrass and nutrient enrichment studies, have used the findings of this study of seawater circulation within the Sound, although the conclusions reached in the segments are not dependent on simulations made by the model.

### 1.4.7 Sand Movement

Three separate activities have been carried out within the general framework of this segment: (i) a grant was made to the Geology Department, University of Western Australia, to enable a post-graduate student to study and report upon selected aspects of sedimentology in the Sound;[14] (ii) the status of coastal dunes was examined and reported upon by a member of the Soil Conservation Service;[15] and (iii) recent changes in the eastern shoreline were examined and reported upon by the Harbours and Rivers Branch, Public Works Department.[16]

Plate 1.B (e): Fish ecologist identifying juvenile fish for the study on fish production. (f): Beach scene, Cockburn Sound; the numbers of beach users and boat owners were assessed during the survey on recreation. (g): Fishermen in Owen Anchorage; the numbers of amateur fishermen operating in the Study Area and their catches were assessed. (h): Automatic sampling equipment used to collect seawater samples for the study on industrial effluents.

## 1.5 STUDY ORGANISATION

The study was conducted by the Cockburn Sound Study Group, composed of scientists and supporting staff hired or seconded for the duration of the study. For convenience, the Study Group office was established in Fremantle, rather than in departmental offices in Perth. Co-ordination, liaison, general study direction and management activities were the responsibility of the Project Leader and a small, capable, supporting staff.

Study overview and guidance, particularly in matters of policy, was provided by a six-man Steering Committee, chaired by the Director of the Department of Conservation and Environment, and including the Co-ordinator of the Department of Industrial Development, the Chief Research Officer of the Department of Fisheries and Wildlife, the General Manager of the Fremantle Port Authority, the Director of the Commonwealth Department of Housing and Construction, and the Refinery Manager of BP Refinery (Kwinana) Pty. Ltd. representing industries on Cockburn Sound.

## 1.6 ACKNOWLEDGEMENTS

The Cockburn Sound Environmental Study could not have been carried out without the hard work and co-operation of all members of the Cockburn Sound Study Group, officers of the Department of Industrial Development and The University of Western Australia. In addition, three segments of the Study were researched by consultants and valuable support was given to the Core Group by the personnel of the Department of Conservation and Environment and the Department of Fisheries and Wildlife. Facilities for analysis and expert advice were also provided by Murdoch University and the Western Australian Institute of Technology. Assistance from representatives of industries, local shires and members of the general public was greatly appreciated. Guidance during the course of the study was given by all members of the Steering Committee. The names of persons and organisations who actively participated in the study are listed at the front of this report.

CHAPTER 2

# DESCRIPTION, RESOURCES AND USES OF THE COCKBURN SOUND STUDY AREA

This chapter contains brief descriptions of the Cockburn Sound Study Area and its resources and uses. The first section describes the general physical characteristics of the Sound and adjacent land; the second section presents information on land uses and related resources; and the third section outlines the water-oriented resources.

Plate 2. Aerial view of Cockburn Sound and Owen Anchorage (foreground) looking south from Fremantle

## 2.1 GENERAL PHYSICAL CHARACTERISTICS

Cockburn Sound is part of a depression between the Spearwood Ridge, rising to 66 m (metres) at Mt. Brown, and the Garden Island Ridge, rising to 54 m at Mt. Moke (Figure 2.1). The main basin of the Sound is 17 to 22 m in depth, affording a well-protected anchorage. The shallow sill of the Southern Flats (2 to 3 m water depth) almost closes the southern opening of the Sound. The water surface area of the Sound is about 10 050 ha (hectares). Erosion and accretion associated with changes of sea level during the last 10 000 years have resulted in a land link between these ridges at Rockingham on the south and in two shallow submerged sills, Parmelia and Success Banks, to the north. Along the eastern side of Cockburn Sound and Owen Anchorage a shelf about 3 km (kilometres) wide was cut into the Spearwood Ridge by wave action and now is submerged to a depth of 6 to 8 m.

Most of the Sound is lined by relatively narrow sandy beaches. With industrial development, sand dunes have been levelled along parts of the coastline, though the foredune has been left intact in a few localities. In certain areas, overuse of the dunes by the public has resulted in accelerated wind erosion.

Along the eastern foreshore, limestone cliffs occur at James Rocks in Owen Anchorage and also along 2.7 km of the coast northwards from the vicinity of Mt. Brown. On the south-western end of the Sound, there are cliffs at Cape Peron and on the western side there are occasional headlands along Garden Island and Carnac Island. Groynes have changed the beach line in some localities, notably at Woodman Point and in Owen Anchorage.

Land and marine sediments in the study area are relatively rich in calcium carbonate. Strata profiles usually show high levels in the dunes, lower levels in the wave zone, and high levels in the deep central basin of the Sound. The sediments of Parmelia and Success Banks are generally very high in carbonate material and low in siliceous fragments. As described later, lime sands are mined from these banks and used in making cement.

## 2.2 LAND USES AND RELATED RESOURCES

For convenience, this section is divided into segments covering land uses, coastal flora and fauna, scenic and aesthetic values, and freshwater resources. More detailed descriptions of recreational and industrial developments are given in Chapter 4.

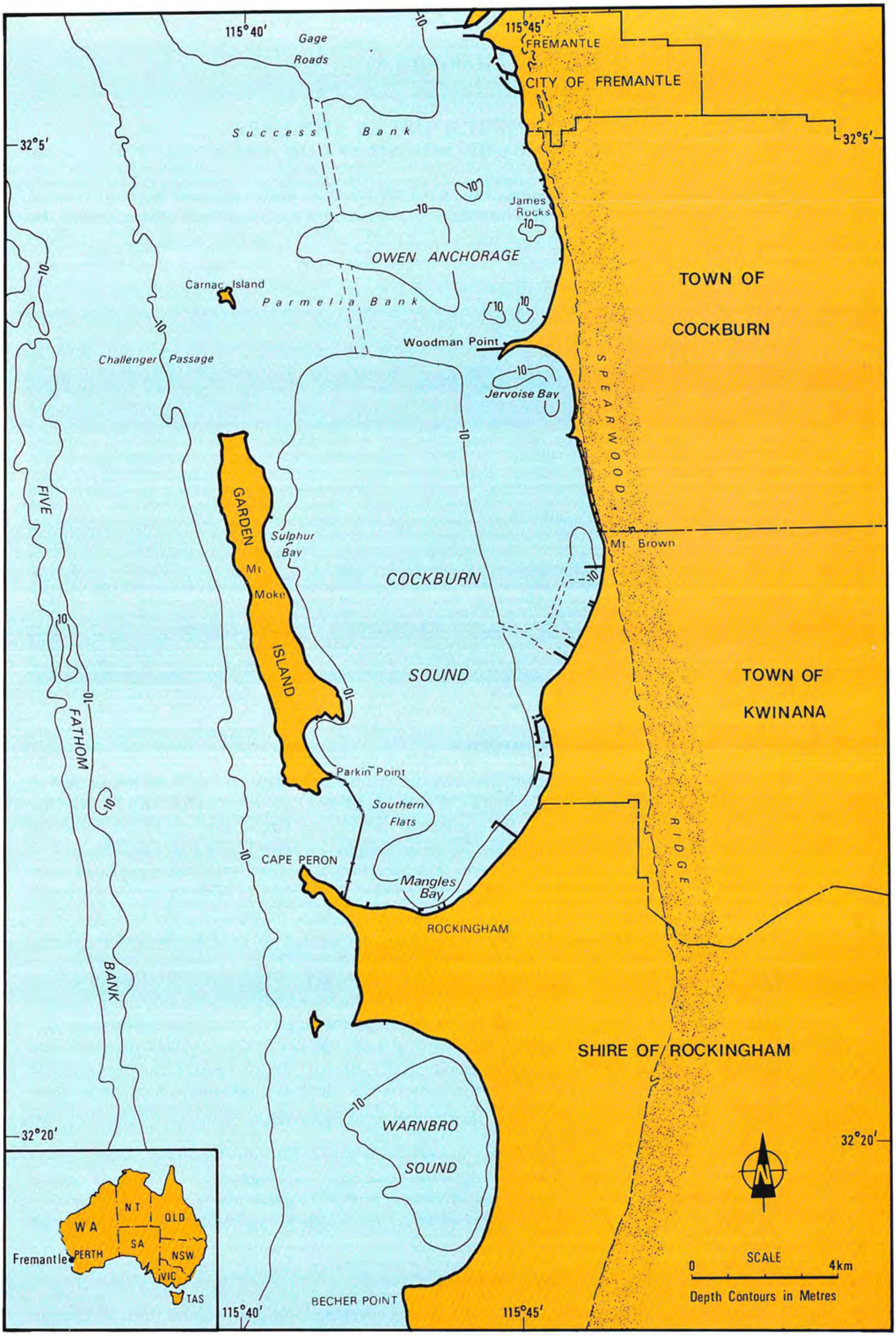



FIGURE 2.1. Cockburn Sound and adjacent areas.

### 2.2.1 Land Uses

Land uses within the study area are subject to control through the Metropolitan Region Planning Authority which covers the Perth metropolitan region. Figure 2.2 shows zoning and other features of the current Metropolitan Region Scheme within the study area.

Much of the foreshore is designated as reserved land vested either in local authorities such as the Fremantle City Council, the Towns of Cockburn and Kwinana, and the Shire of Rockingham, or in Government bodies such as the Ministries for Works, Lands, Mines, and Transport; the Metropolitan Water Supply, Sewerage and Drainage Board; the Fremantle Port Authority; and the Department of Youth, Sport and Recreation. The total length of mainland foreshore of Cockburn Sound and Owen Anchorage is about 30 km. About 12.5 km are available and suitable for intensive recreation at present. This will be increased to about 14.7 km, or nearly 50 per cent of the total length, when the Explosives Magazine and Quarantine Station are developed for recreational use. Other reserved lands are designated for railways, port installations and public purposes. A discussion of the main recreational reserves and factors affecting their continued suitability for use is contained in Chapter 4.

Figure 2.2 also shows the locations of the principal industries in the study area. Industry types along the shore of Cockburn Sound are varied and include oil refining; iron, steel, alumina, and nickel refining or processing; and chemical and fertiliser production. Abattoirs, and plants processing fish and hides are predominant in the Owen Anchorage area. As at August 1979, about 4500 persons were employed by industries in the Cockburn Sound area and about 2300 in the Owen Anchorage area. Chapter 4 contains brief descriptions of the industries included in the effluent sampling programmes carried out during the study.

Three local government authorities border Cockburn Sound and Owen Anchorage. As shown on Figure 2.1, these are, from south to north, the Shire of Rockingham, the Town of Kwinana and the Town of Cockburn. Populations of these were 22 000, 15 000, and 32 000, respectively, in 1978. Residential development is concentrated in the Township of Rockingham which had an estimated population of 7500 persons. A small segment of the northern part of Owen Anchorage is bordered by the City of Fremantle.

### 2.2.2 Coastal Flora and Fauna

Urban and industrial growth along the coast of the Sound has removed many of the original plant communities. In addition, burning, clearing, introduction of foreign species, and erosion hastened by overuse have greatly altered most of the remaining vegetation.

In the grounds of the Quarantine Station and the Explosives Magazine on Woodman Point, natural stands of the Rottnest pine, *Callitris preissii,* are possibly the last on the mainland still showing some regeneration. In the same locality there is an unusual overstorey of the tuart, *Eucalyptus gomphocephala,* and some good examples of *Acacia rostellifera* closed scrub.

Along the Spearwood Ridge immediately south of Woodman Point, is probably the only limestone heath complex remaining in the metropolitan area of Perth. This is a particularly interesting area as it is at this locality that two different limestone heath communities meet. However, botanists who have studied the area have concluded that it is highly unlikely that any of the areas of heath are of sufficient size and condition to maintain themselves as viable examples of limestone heathlands.[19]

The recreation reserve at Cape Peron retains some of the natural coastal vegetation but poorly co-ordinated development of holiday centres and rezoning of portions of the reserve for other uses are having their effects. On the point itself some erosion and sand drift problems are being tackled with revegetation.

Management of the flora and fauna of Garden Island is supervised by a joint Commonwealth-State committee. Much of the vegetation remains in a relatively undisturbed condition. The restricted range of species, single storey and closed canopy, distinguish this from any other plant community. Present development of the naval facility is considered not to have endangered the important plant communities nor the fauna dependent upon them.

The numbers of the tammar, *Macropus eugenii,* may have increased on Garden Island since 1973 when cereal rye was planted on cleared areas as a short-term measure to stabilise exposed sand. With the disappearance of this food source and the installation of security fencing within the naval facility, the tammars are expected to stabilise at a population of about 700-770 adult animals. Feral cats were introduced when some holiday cottages were established on Garden Island. The cats continue to represent a hazard to tammars and to the bird population. Although efforts are being made to reduce the number of cats, the causeway from the mainland affords a point of entry.

On the fauna reserve of Carnac Island eggs and young seabirds nesting on the cliffs and in burrows afford an important source of food for the tiger snake, *Notechis scutatus,* and the king skink, *Egernia kingii.* Both of these reptiles also occur on Garden Island but apparently at lower densities than on Carnac Island.

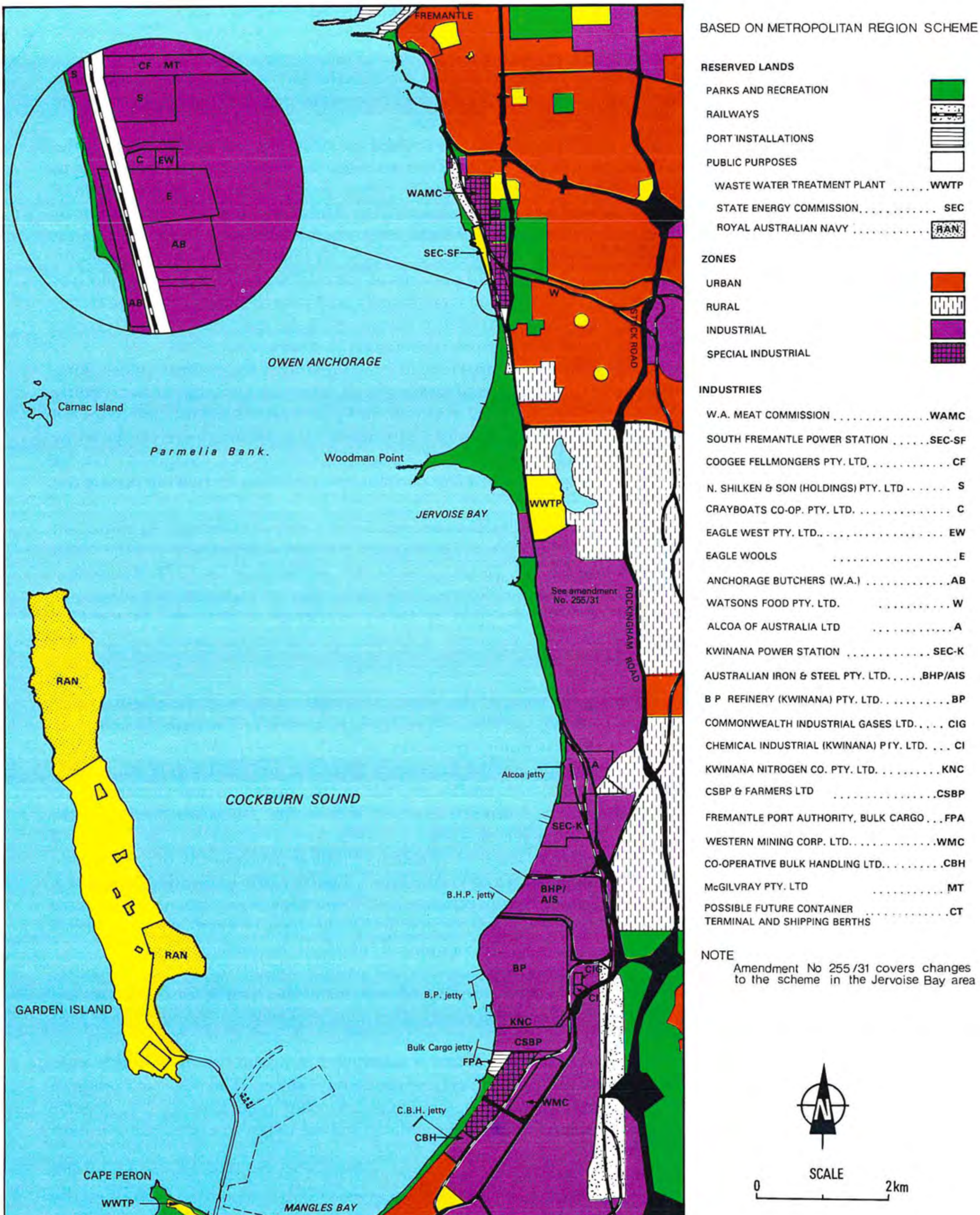



FIGURE 2.2. Details of the Metropolitan Region Scheme and the position of industries in the Cockburn Sound Study Area.

### 2.2.3 Scenic and Aesthetic Values

Any assessment of scenic and aesthetic values must involve subjective and personal factors. Nevertheless they rank high in importance with people concerned with maintenance of an area for recreation or residential purposes. Industry leaders, too, are aware of the advantages of maintaining scenic values. As a result, these aspects are not the sole province of residents of the Cockburn Sound area or of those coming to the Sound for recreation.

Since land along the shores of the Sound is not significantly elevated and vegetation is relatively low, natural landscapes are not highly scenic. Of greater value are the seascapes, the sandy beaches, calm waters and the Garden Island background. Somewhat more dramatic landscapes of cliffs and reefs can be seen from Cape Peron and Garden Island.

In addition, some parts of the Sound provide underwater vistas of seagrass and soft bottom communities, with some reef and coral outcrops. These underwater scenic values may not seem as significant as those off more exposed coastlines, but the relative calm and safe conditions in the Sound make it a starting point for enjoyment of underwater attractions.

### 2.2.4 Freshwater Resources

Since there are no natural streams flowing into Cockburn Sound, entry of freshwater is restricted to groundwater except for some stormwater from pipes discharging across beaches and a small channel cut from Lake Richmond to Mangles Bay.

In the more recent limestones and sands on this portion of the coastal plain, an unconfined aquifer known as the Jandakot Mound is a significant freshwater resource. Many of the industries along the shoreline of Cockburn Sound and Owen Anchorage draw upon the western edge of this aquifer.

Hydrogeologists of Geological Survey, Department of Mines, have calculated that the flow of groundwater through the unconfined aquifer entering the sea from South Fremantle to Cape Peron is in the order of 7.5 million $m^3$ per year. During the present study 110 bores were identified along the eastern margin of the Sound. Of these, 76 are production bores and all but one draw from the unconfined aquifer. At present, annual production of water from these totals at least 10.2 million $m^3$ per year. This exceeds the total available water estimated to be flowing westward from the Jandakot Mound.

Based on information from industries covered by questionnaires, industries adjacent to the Sound use about 6.7 million $m^3$ per year of metropolitan scheme water. Because of the rising costs of water supplied by the Metropolitan Water Supply, Sewerage and Drainage Board, industries increasingly are turning to groundwater. However, the data given indicate that the unconfined acquifer is already overused.

Little is known about artesian waters in the Cockburn Sound area and some may be too saline for industrial use. From time to time, there have been reports of "freshwater springs" coming to the surface of Cockburn Sound and Owen Anchorage. These may represent release of water from artesian sources. Only one of the production bores located near the eastern margin of the Sound penetrates to artesian waters. A bore at Cockburn Cement draws about 750 000 $m^3$ per year. At present, restrictions are imposed on the extraction of artesian water until a better understanding of the behaviour of this resource is obtained.

As noted in Chapter 1, the effects of industrial operations on groundwater quality in the study area are the subject of a report prepared by consultants specifically for the present study. Findings and other information are given in Chapter 5.

## 2.3 WATER-ORIENTED RESOURCES AND USES

The principal water-oriented resources and uses of the Sound include fish production, shipping and related activities, recreation, and water for industrial processes. Each of these is described briefly below.

### 2.3.1 Fish Production

This subject is one of the major aspects covered by the Cockburn Sound Study and, as noted in Chapter 1, is the subject of the Technical Report on Fish Productivity. A summary of the report is given in Part II of this overview report. Hence only a few general comments are presented here. In brief, the study showed that the Sound is an important area for fish production in terms of the numbers and value of fish caught by commercial and amateur fishermen. In addition, it is a protected embayment which provides shelter and sustenance for many marine species at some time during their life cycles.

Historically, the Sound has been a major commercial fishing area in which much of the fresh fish for the Perth metropolitan area has been caught. In the year 1977-78 the total catch of fish, crustacea, and molluscs was 760 910 kg as measured on a live weight basis. In terms of weight caught the five most important species were scaly mackerel, mussel, pilchard, Perth herring, and blue manna crab. The estimated value of the commercial catch in that fiscal year was approximately $487 000.

Facts and figures on the extent of amateur fishing in the Sound and on actual fish catches were obtained by creel surveys carried out monthly during the year 1978 as a part of the fish study. Based on a number of assumptions, information from the creel census indicated a total catch of over 2.5 million individuals for the year 1978. Of these the catch of blue manna crabs was estimated at about 885 000. This figure is about four times the commercial crab catch for the Sound and one and one half times the commercial crab catch for the whole of Western Australia.

In addition to the blue manna crab, the main species fished for in the Sound by amateurs are Australian herring, whiting and skipjack. Thus, the main species caught in the Sound by amateur fishermen are different from those caught by professionals except for the blue manna crab. As far as is known, however, the crab does not rank high in terms of income production for professional fishermen. With the substantial differences in species caught, it appears that there is little cause for conflict or competition between professional and amateur fishermen within the Sound.

Plate 3. Cargo ship at an industrial jetty in Cockburn Sound.

### 2.3.2 Shipping and Related Activities

Shipping access to Cockburn Sound is by a single channel through Success and Parmelia Banks. This has been dredged to about 14 m and has a navigable width of about 150 m. Lime sands presently are being mined from these two banks along the site of a future second shipping channel which is about 950 m to the east of the existing channel and about 300 m wide. Access to the steelworks and alumina refinery is by Stirling Channel which is about 11 m deep and 120 m wide. The approach to the alumina refinery itself is by Calista Channel, about 12 m deep and 150 m wide.

During 1977-78 a total of 467 ships having a gross registered tonnage of 9 147 000 tonnes entered Cockburn Sound. Total imports and exports by these ships are summarised in Table 2.1.

At present there are nine cargo berths on the eastern margin of the Sound. These consist of one at the alumina refinery, two at the steelworks, three at the oil refinery, two at the bulk cargo jetty and one at the grain terminal.

Long range plans for expansion of activities by the Fremantle Port Authority (FPA) in the Sound were prepared in 1966, approved by State Cabinet and incorporated in the Metropolitan Region Scheme along with amendments approved in 1972. Activities included development of (i) 17 new berths along with necessary shore support facilities by reclamation works in Mangles Bay and the Southern Flats area of the Sound as indicated in Figure 2.2; (ii) an additional berth for the grain terminal; and (iii) further offshore berths between the grain terminal and the bulk cargo jetty.

In the first stage, establishment of port facilities in Mangles Bay would involve reclamation and development of 65 ha of the waters between Hymus Street and the Garden Island Causeway for wharves backed by port storage areas and railway lines. Implementation of this plan would have substantial environmental and sociological impacts not only on the existing uses of this part of the Sound and its shores, but also on community lifestyles. In any case, implementation is dependent on increases in demand on the FPA for port and related services. For several years the general level of demand has remained relatively stable and the situation appears likely to continue into the foreseeable future. It appears appropriate, therefore, not to deal specifically with potential effects of reclamation and port development in Mangles Bay in this report.

In Jervoise Bay, proposals for improvements including breakwaters, a wharf for oil platform module construction, jetties and slipways for small ship building, jetties for the fishing industry, marinas, and a yacht club were prepared on behalf of the Metropolitan Region Planning Authority (MRPA).

An Environmental Review and Management Plan (ERMP) was submitted for comment by the public and relevant government departments and authorities. The proposal also includes development for public recreation of several segments along the north and south shores of Woodman Point, including the Explosives Magazine and the Quarantine Station.

Members of the Cockburn Sound Study Group held several discussions with officers of the Department of Conservation and Environment who were responsible for review of the ERMP. Potential effects on the waters of the Sound and on established beneficial uses were outlined and it was concluded that management plans proposed would be able to cope with these effects. The proposal for development of Jervoise Bay was adopted by the MRPA in August 1979 for incorporation in the Metropolitan Region Scheme.

### 2.3.3 Recreation

Opportunities exist for a wide diversity of recreational pursuits in the Cockburn Sound area. As shown by recreational use data, the Sound is at least as important a recreational resource of the Metropolitan Region as the Swan River estuary. The Cockburn Sound Recreation Survey was one of the major segments covered by the Cockburn Sound Study and the report on the survey is summarised in Chapter 4 of this overview report. Hence only a few general comments need to be presented here.

Plate 4. Sunbathers, swimmers and sailing enthusiasts relax in the shadow of industry.

There are three main recreational beaches along the shoreline of the Sound: Palm Beach, Rockingham Beach and Kwinana Beach; and two along the shoreline of Owen Anchorage: Coogee and South Beach. Improvements include car parks, picnic facilities and children's playgrounds as well as showers and toilets along with shops or kiosks. In general, sufficient facilities presently are available to meet the demand but on peak days at popular locations facilities are approaching their limits.

Based on counts in December 1978 and January 1979, a maximum of about 7000 people are on Cockburn Sound and Owen Anchorage beaches at peak times on a typical hot summer weekend day. Beach users tend to concentrate at the five main beaches because they are more accessible, have a variety of facilities, and are least affected by non-recreational uses. Rockingham Beach accounts for over half of all beach users and nearly all of them live outside the Shire of Rockingham. At other beaches, the sources of visitors also were widespread but more people were from the immediate localities than at Rockingham.

Family groups represent a high proportion of the beach users along the shores of the Sound. Swimming and picnics are the main activities. This usage pattern is a direct reflection of the comparative shelter and safety offered by the Sound's beaches.

Along the shore of Cockburn Sound, there are three main public boat launching ramps. These have a total capacity of eight lanes. Cockburn and Kwinana each have one two-lane ramp and Palm Beach has two two-lane ramps. Use of the small and difficult ramp at the Naval Base is minimal. No launching facilities exist in Owen Anchorage. There are two private boat clubs operating on Cockburn Sound. One, the Cockburn Power Boat Association (CPBA) is located in Jervoise Bay and has a membership of about 1000 persons drawn from throughout the metropolitan region and lists approximately 950 power boats. Two ramps are available for club members. The second, the Cruising Yacht Club, is located at Rockingham Beach and has a membership of 874 persons and 96 registered yachts.

Observations during the recreation survey showed that more than 600 boats carrying over 2000 people used the area on a typical hot summer weekend day. Fishing and general pleasure boating were the main activities with concentrations of boats on Southern Flats, Garden Island west, Jervoise Bay and Mangles Bay. At peak times, the three public launching ramps and the CPBA ramps were used to capacity. Data supplied by the CPBA showed that more than 130 boats are launched from the club ramp each weekend throughout the autumn, winter and spring periods. Although the Cruising Yacht Club operates from a restricted site, about 50 yachts are involved in races throughout a day during the main sailing season.

There are six holiday camps of various types and two educational camps on or near the foreshores of Cockburn Sound and Owen Anchorage. The caravan and cabin parks, rented cottages and camps are used intensively, particularly during the summer school holidays. The educational camps are heavily booked throughout the year. The State Education Department makes considerable use of the Sound and Owen Anchorage for vacation swimming classes, sailing and canoeing instruction, and for scuba diving courses.

Four beaches are regularly used for horse training. These are South Fremantle Power Station, South Woodman Point to the Boat Yards, Barter Road south of the Kwinana Power Station and Kwinana south to the CBH jetty. Except for South Woodman Point, beach work is limited by local authorities to the early hours of the morning to avoid conflict with swimmers and other beach users.

### 2.3.4 Industry

In addition to its use by industry for shipping, the waters of Cockburn Sound provide process cooling water for many industries along its shores and sand dredged from Parmelia and Success Banks provides a source of lime for use in cement manufacture.

Based on information developed in the study segment dealing with inputs to the Sound the total volume of fresh and salt water discharged into the Sound is about 1600 ML/d (megalitres per day). The Kwinana Power Station accounts for nearly two-thirds of the total.

Under a long-term agreement extending until the year 2011, Cockburn Cement Ltd. is dredging lime sands from Parmelia and Success Banks. Dredging at present is along the line of the proposed second shipping channel through the banks. Dredged sand is barged to a jetty on the north side of Woodman Point. The sand is washed at the jetty and then pumped through a pipeline to the cement plant which is located east of Cockburn Road. The turbidity in the Sound waters caused by the fine material washed from the sand is readily visible. Recently, the discharge has been relocated to a position where the water is deeper to improve dilution and mixing and to prevent accumulation of discoloured sand on adjacent beaches.

**Table 2.1** **IMPORTS AND EXPORTS: COCKBURN SOUND 1977-78**

| Type of Cargo | Total weight tonnes |
|---|---|
| **Imports** | |
| Petroleum | 5 669 338 |
| Caustic soda | 573 482 |
| Coke | 445 088 |
| Fertiliser | 400 934 |
| Iron and steel | 209 810 |
| Limestone, sands | 104 100 |
| Manganese ore | 17 334 |
| Total imports | 7 420 086 |

| Type of Cargo | Total weight tonnes |
|---|---|
| **Exports** | |
| Alumina | 2 224 272 |
| Grain | 1 890 624 |
| Petroleum | 1 475 085 |
| Iron and steel | 534 965 |
| Iron ore | 235 829 |
| Bunkers | 170 533 |
| Bauxite | 19 307 |
| Total exports | 6 550 615 |

## CHAPTER 3

# BENEFICIAL USES AND WATER QUALITY CRITERIA

Wastewater disposal practices must not alter receiving water conditions to the extent that recognised beneficial uses, such as recreation, fishing and boating, are impaired. The development of appropriate water quality criteria for Cockburn Sound has been undertaken by a working group representing various Government departments established for that purpose by the Environmental Protection Authority. An interim report was submitted by the working group on 30 September 1979 and this chapter draws upon some of its contents in describing beneficial uses of the Sound and criteria for specific water quality parameters.

Many of the terms, phrases and philosophies relating to beneficial uses and water quality criteria need to be defined at the outset to avoid misunderstanding. Section 3.1, therefore, gives definitions for the principal terms used in this chapter and in discussions of water quality management elsewhere in this report. Section 3.2 describes existing water pollution control practices in the Cockburn Sound area and, for purposes of illustration, cites relevant portions of agreements which govern some of the present discharges to the Sound. Section 3.3 describes the beneficial uses of the Sound as contained in the working group's interim report and Section 3.4 outlines the relationship between beneficial uses and various water quality parameters. Finally Section 3.5 summarises the numerical and other criteria for water quality parameters and beneficial uses.

## 3.1 DEFINITIONS

It is useful at this stage to define the term *beneficial uses* and to distinguish between water quality *parameters, criteria, objectives* and *standards*.

### 3.1.1 Beneficial Uses

A beneficial use is any use of the environment or any segment or element of the environment that is conducive to public benefit, welfare, safety or health. A beneficial use will require protection from the detrimental effects of any direct or indirect alteration of the environment. Where conflicting uses exist consideration of social, economic and scientific factors may be required to determine the uses to be protected.

### 3.1.2 Parameters

Parameters are specific physical, chemical or biological characteristics of wastewater or of receiving waters, for example, clarity, temperature, biological oxygen demand, and individual chemical elements.

### 3.1.3 Criteria

Criteria are the scientific yardsticks upon which a decision or judgement may be made concerning the ability of water of a given quality to support a designated beneficial use. Where a given use does not exist or is not intended to exist, then criteria for some parameters would not apply. Some constituents of discharges to Cockburn Sound have only local effects and others have regional effects. In applying water quality criteria to the constituent of a given discharge, therefore, it would be necessary to consider beneficial uses affected or likely to be affected by the discharge and to consider the relevance of allowing a local mixing zone within which various parameters could dilute or otherwise be reduced to concentrations consistent with the criteria.

### 3.1.4 Objectives

Objectives represent the desirable and possibly long-term aims or goals of a water quality management programme. Such objectives are often derived after consideration of water quality criteria in the light of economic, social or political factors.

### 3.1.5 Standards

Standards are current legally enforceable levels established by an authority. Standards are based upon the most relevant scientific knowledge currently available and will reflect both the beneficial use to be protected and a reasonable safety margin. Frequent changes in standards are inappropriate since they control the nature and type of wastewater treatment and disposal facilities provided. However, as additional knowledge is gained about the response of receiving waters to specific inputs of parameters, new criteria can be adopted and standards modified accordingly.

## 3.2 EXISTING WATER POLLUTION CONTROL PRACTICES

Before citing some of the requirements for existing discharges, it is appropriate to review the present situation regarding authority for control of wastewater discharges to groundwater and to the waters of the Sound.

### 3.2.1 Background Information

The unconfined groundwater aquifer around the Sound is drawn on for urban, industrial, and market garden use. The Rights in Water and Irrigation Act, 1974-76, requires persons proposing to dispose of effluent which will reach the groundwater to apply for a licence specifying the volume and content of effluent permitted to be discharged. However, to date only one licence has been issued in the Cockburn Sound and Owen Anchorage area, although there are discharges to groundwater, as described elsewhere in Chapter 5.

The Fremantle Port Authority Act, 1902-1976, classifies the areas below high water mark in Cockburn Sound, Owen Anchorage and Gage Roads as the Outer Harbour of the Port of Fremantle. Thus the Fremantle Port Authority (FPA) has general responsibility for management of the waters, seabed, flora and fauna of the Sound. Other departments have specific roles, e.g. the Department of Fisheries and Wildlife managing fish resources and the Department of Health and Medical Services concerned with matters relating to public health. Most regulations under the FPA Act relate to port development and management. However, there are regulations concerning discharges or spillages which might affect water quality or "be injurious to marine plant or animal life" and Section 262(2)(c) of the Act enables the FPA to set standards for bacterial, physical and chemical content of discharges.

The Environmental Protection Act, 1971, authorises the control of pollution arising from discharge of wastes. Under its Act, the Environmental Protection Authority (EPA) may take action if a person or body holding a statutory permit under any Act is causing pollution by discharging waste, and also against anyone causing pollution by discharging waste without a permit. The EPA may also require those discharging wastes to carry out monitoring, both of the waste and also of the receiving environment, in such manner as the EPA specifies.

What appears to be lacking at present is a set of guidelines to water quality objectives, properly developed and adopted, which define concentrations, loads, or other characteristics for water quality parameters relevant to the protection of beneficial uses of the Sound. It is expected that these matters will be resolved when the working group has submitted its final report and a formal policy has been adopted.

Table 3.3 shows Western Australian standards and National Health and Medical Research Council (NH & MRC) values for metals in seafood.

### 3.2.2 Requirements for Existing Discharges

In establishing some of the major industries adjacent to the Sound, the Western Australian Government drew up agreements with particular companies which became Acts of Parliament. These agreements set out in broad terms the way in which the companies were permitted to operate and include in several cases permission to use the waters of the Sound for cooling or effluent disposal purposes. Three examples are given below.

The BP Refinery at Kwinana was established under the Oil Refinery Industry (Anglo-Iranian Oil Company Limited) Act, 1952. Mention is made in the Act of using seawater for cooling but there is no specific reference to the discharge of pollutants, to oil spillage, or to any other impact upon the environment.

In the Industrial Lands (Kwinana) Agreement Act, 1964, Section 27 allows CSBP to discharge up to 350 tons of gypsum per day into the Sound at not less than 8 fathoms below low water. Section 15 appears to be even more flexible concerning effluents and states that CSBP may draw seawater for cooling purposes in its operations from the Sound, and may return it to the Sound mixed with effluent from manufacturing operations provided that the discharge is not dangerous or injurious to public health.

The Cement Works (Cockburn Cement Limited) Agreement Act, 1971, has a number of sections dealing with the removal of lime sands but none authorising the discharge of wastes. Under this Agreement the Company has a 40-year permit to dredge lime sands from Success and Parmelia Banks and dredging must be planned to prevent conditions detrimental to the navigable channels or port installations or to efficient working of the port. The importance of maintaining banks to protect the Sound from high wave energy during storm conditions places a heavy responsibility upon those planning long term dredging operations.

Waste discharges to Cockburn Sound fall within the ambit of existing pollution control legislation, including that administered by the Fremantle Port Authority and the Environmental Protection Authority, except where permission to discharge wastes is specifically given in the Private Agreement Act.

### 3.3 BENEFICIAL USES

Cockburn Sound is a beautiful natural harbour which provides a haven from the often rough ocean waters. The beneficial uses are classified broadly into eight categories, each of which is briefly described in this section. At a later date in development of the water quality management programme for the Sound specific areas may be designated where specific uses apply. This has not been attempted as part of the Cockburn Sound Study.

#### 3.3.1 Aesthetic Enjoyment

Since most of the shore and shore waters of the Sound can be seen from highways running near the shore aesthetic conditions (appearance, colour, odour) are of importance to residents and tourists. These conditions, of course, are of even greater importance to beach and boat users. Correction of undesirable conditions and their avoidance in the future is extremely important in maintaining the multiple use concept for the Sound.

#### 3.3.2 Seafood Processing

Waters required by seafood processing industries may have either short or long term contact with seafoods. The short term exposure occurs in washing procedures, whereas longer exposures occur when, for example, live crustacea are kept in holding tanks. Various water quality criteria are important to this use; most of them relate to health aspects, either of the seafood where stored live or of the consumer.

#### 3.3.3 Industrial Cooling Water

Many of the industries as well as the power generation plants on the shores of the Sound and Owen Anchorage use saltwater for cooling processes. A degree of water quality needs to be maintained which will not damage or otherwise affect the operation of equipment or damage materials.

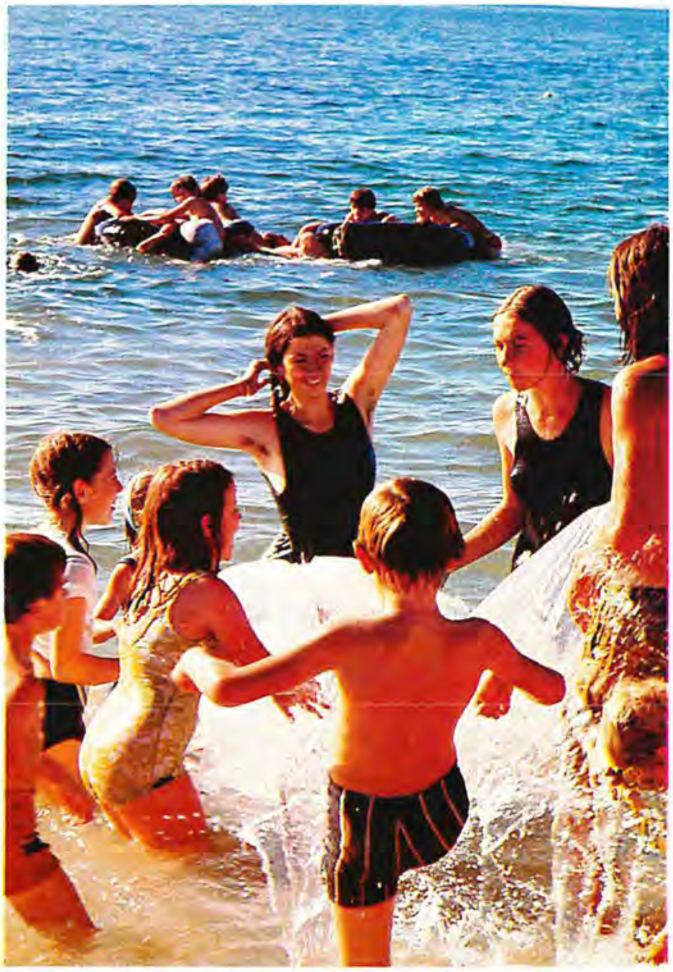


Plate 5. Good water quality is important if the Sound is to be used for recreation.

### 3.3.4 Shipping

As described in Chapter 2, shipping is a major use of the Sound. Many industries are dependent on shipping to bring in raw materials and carry out finished products. A lower degree of water quality generally is acceptable in waters used exclusively for shipping than for most other beneficial uses.

### 3.3.5 Water Contact Recreation

Swimming and boating activities are among the most important beneficial uses in many parts of the Sound and along its foreshores. Because these activities can involve complete immersion in seawater, water quality relating to public health is of primary importance.

### 3.3.6 Fish Passage

This beneficial use is concerned with waters used by fish in their normal movements and migratory patterns.

### 3.3.7 Crustacea, Fish and Molluscs for Food

The waters of the Sound are used by amateur and professional fishermen. The composition and relative numbers of various species of fish and shellfish were covered by the baseline study of fish resources summarised in Chapter 4 of this report. The study reveals that the Sound is a highly productive body of water and, with proper management of inputs and other activities affecting growth and development of fish and shellfish, that it offers long term opportunities for amateur and professional fishermen. The intensity of recreational fishing can be expected to increase in the future. Human health as well as the health of the various sea animals is of principal concern in considering applicable water quality parameters.

### 3.3.8 Aquatic Ecosystem Maintenance

An ecosystem comprises a physical and chemical environment interacting with a more or less stable community of organisms. The stability of a particular ecosystem depends on many inter-related factors some of which are sunlight, temperature, pH and inorganic nutrients.

It is considered that the waters in most parts of Cockburn Sound and Owen Anchorage are important in terms of ecosystem maintenance. On this basis, a sufficiently high level of protection should be provided so that any waste discharges or man-made changes which do occur may be assimilated readily or tolerated by the system without any detectable effects on the biota or the structure of the ecosystem to which they belong.

### 3.3.9 Summary

In summary, Cockburn Sound supports a wide range of beneficial uses. It is expected that there will be a steady increase with time in recreational activities, including swimming, fishing, beach walking and picnicking along the shores of the Sound and Owen Anchorage. This increase also will be accompanied by a continuing high degree of concern by the public for the aesthetic condition of the waters and shoreline and the well-being of marine ecosystems. Although water quality criteria should be designed to maintain and protect these beneficial uses recognition must also be given to other uses including those related to industry and to shipping.

## 3.4 RECEIVING WATER QUALITY PARAMETERS

In developing water quality criteria, it is necessary to consider the relationship between various water quality parameters and beneficial uses. The working group's interim report lists 23 water quality parameters or sets of parameters which are applicable to one or more of the beneficial uses described above. The inter-relationships between water quality criteria and beneficial uses are indicated by the open circles in the matrix shown in Table 3.1. It should be noted, however, that identification of the relationship between beneficial uses and water quality parameters does not imply that the same level of control for a given parameter is needed to adequately protect all beneficial uses. The inter-relation which requires the highest degree of control is shown by the boxed-in circles in Table 3.1.

## 3.5 RECEIVING WATER QUALITY CRITERIA

Water quality criteria are numerical, quantitative, or qualitative limits on water quality parameters which should not be exceeded in the receiving waters. The interim report referred to earlier contains suggested criteria for all parameters and beneficial uses shown in Table 3.1. For purposes of this report, however, it is considered sufficient to list in Table 3.2 the criteria associated with the highest degree of control (the boxed-circles in Table 3.1). It must be emphasised that these criteria apply only to receiving waters and not to concentrations in discharged effluents.

It is noted that many of the criteria give only a median value or, in other cases, a single value which is not to be exceeded.

It is expected that the water quality criteria developed after consideration of the working group's interim report will express limits for many water quality criteria in a probabilistic form, i.e. a mean or a median and a second value which is to be met a high percentage of the time. The use of probabilistic criteria is a more rational approach than to require waste management systems to be designed to meet the 'once-in-a-lifetime' event.

**TABLE 3.1 RELATIONSHIPS BETWEEN WATER QUALITY PARAMETERS AND BENEFICIAL USES**

| Water quality parameter / Beneficial use | Aesthetic enjoyment | Seafood processing | Industrial cooling water | Shipping | Water contact recreation | Fish passage | Crustacea, fish and molluscs for food | Aquatic ecosystem maintenance |
|---|---|---|---|---|---|---|---|---|
| Grease, oil, floatables | [O] | o | o | o | o | o | o | o |
| Suspended & settleable solids | [O] | | | | o | | | [O] |
| Colour, odour & turbidity | o | | | | [O] | o | | o |
| Fine solids | | o | o | | | o | [O] | o |
| Light penetration | o | | | | [O] | | | |
| Barriers* | | | | | | [O] | [O] | o |
| Temperature | | o | o | | | o | [O] | o |
| pH | | o | o | o | o | o | [O] | [O] |
| Hydrocarbons | | o | | | | o | [O] | o |
| Salinity | | o | | | | o | o | [O] |
| Dissolved oxygen | | o | | | | o | [O] | o |
| Arsenic and heavy metals | | o | | | | o | [O] | o |
| Pesticides, PCBs | | o | | | | o | o | o |
| Phenolic compounds | | o | | | | o | [O] | o |
| Surfactants | o | [O] | o | o | o | [O] | [O] | o |
| Cyanide | | o | | | | o | [O] | o |
| Fluoride | | o | | | | o | [O] | o |
| Total chlorine residual | | o | | | | o | [O] | o |
| Hydrogen sulphide | | o | | | | o | [O] | o |
| Ammonia | | o | | | | o | [O] | o |
| Nutrients (N & P) | [O] | | o | o | | o | o | [O] |
| Faecal coliforms | | o | | | o | | [O] | |
| Radionuclides | | o | | o | o | | [O] | |

o Indicates beneficial uses upon which water quality parameter has an impact

[O] Indicates the use which controls the nature of the water quality criteria given in Table 3.2

* Barriers to flushing and fish passage

## TABLE 3.2 SUGGESTED WATER QUALITY CRITERIA FOR COCKBURN SOUND

These criteria are based on the 30 September 1979 interim report of the working group established by the Environmental Protection Authority to develop suggested water quality criteria for marine and estuary waters of Western Australia.

As indicated in the text only the level which covers the most sensitive beneficial use is given.

| PARAMETERS | CRITERIA |
|---|---|
| Grease, oil, floatables | No visible evidences of wastewater origin |
| Suspended & settleable solids | No visible evidences of wastewater origin, no deposition |
| Colour, odour, turbidity | No noticeable or objectionable change in natural conditions |
| Fine solids | Less than 80 mg/L |
| Light penetration | Secchi disc visible for 2 m depth |
| Barriers | No construction or chemical barriers |
| Temperature | No change greater than ±1°C from normal |
| pH | Within 6.5–8.5 range; no change greater than 0.2 units |
| Hydrocarbons | Soluble aromatics 1 μg/L, fuel oil 3 μg/L, kero 5 μg/L, crude oil 10μg/L |
| Salinity | No long term change greater than ±2% of normal |
| Dissolved oxygen | No reduction below 6 mg/L or decrease greater than 10% of normal |
| Arsenic and heavy metals | Values in seawater depend upon individual metals<br>Concentrations in seafood not to exceed values given in Table 3.3 |
| Pesticides | Values depend upon individual pesticide |
| Polychlorinated Biphenyls | Maximum concentration 0.001 μg/L |
| Phenolic compounds | Median less than 300 μg/L |
| Surfactants | Maximum concentration less than 1% of 96h $LC_{50}$* |
| Cyanide | Median less than 5 μg/L |
| Fluoride | Median less than 2 mg/L |
| Total chlorine residual | Median less than 2 μg/L |
| Hydrogen sulphide (undissociated) | Maximum less than 2 μg/L |
| Ammonia (expressed as N) | Median 0.6 mg/L |
| Nutrients (N & P) | Reduce total nitrogen inputs to the Sound ** |
| Faecal coliforms | Median less than 15 org/100 mL for mussel areas;<br>150 org/100 mL for recreation uses |
| Radionuclides | Maximum 10 pCi/L |

For some parameters or some discharges, the criteria should be applicable at the edge of an initial mixing zone rather than at the point of discharge itself.

* The concentration found lethal to 50% of test organisms as a result of 96 hour exposure; varies depending on specific pollutant and test organism.

** As described in Chapter 8, data collected during the Cockburn Sound Study have been used to determine two levels of control of nutrient discharges to the Sound: (i) reduce inputs of total nitrogen to levels estimated to have existed in the early 1970s (2000 kg/d) and (ii) reduce inputs of total nitrogen to levels estimated to have existed in the late 1960s (1000 kg/d).

**TABLE 3.3 WESTERN AUSTRALIAN STANDARDS AND N.H. & M.R.C. VALUES FOR METALS IN SEAFOOD**

| Element | W.A. Standard* | N.H. & M.R.C. 1973** | N.H. & M.R.C. 1978*** |
|---|---|---|---|
| Cadmium | 5.5* | 2.0 | 1.0 |
| Zinc | 40.0 | 1000.0 | 100.0 |
| Copper | 30.0 | 30.0 | 50.0 |
| Lead | 2.0 | 2.0 | 2.5 |
| Nickel | 5.5* | NA | 1.0 |
| Chromium | 5.5* | NA | 1.0 |
| Cobalt | 5.5* | NA | 1.0 |
| Mercury | 0.5 | 0.5 | 0.5 |
| Arsenic | 1.5 | 1.5 | NA |

NA Not available

Concentrations are expressed as μg of the element per g of wet body weight (except for arsenic which is $As_2 0_3$).

* Adopted for use in Western Australia under Food and Drug Regulations, 1961, as amended, made under the Health Act, 1911-1978. Values apply to fresh seafoods except * which apply to processed seafoods in containers but these values are accepted for fresh seafoods also.

** Proposed for adoption for seafood by the National Health and Medical Research Council.

*** Under consideration only; for shellfish.

# PART II

# SUMMARY OF THE STUDIES

This part of the report consists of four chapters and presents brief overviews of the findings from specific technical and scientific investigations carried out during the study. Chapter 4 describes recreational resources and activities, major industries located along the shoreline, and fish resources and production in the Cockburn Sound area. Chapter 5 summarises results of detailed studies carried out to identify and quantify chemical and other inputs to the Sound and summarises results of a study of groundwater quality in relation to industrial effluent disposal. Chapter 6 presents data on physical characteristics including water circulation and sand movement studies. Chapter 7 gives principal results from studies of chemical and biological characteristics.

# CHAPTER 4

# RECREATIONAL AND INDUSTRIAL DEVELOPMENTS, FISH RESOURCES AND PRODUCTION

Chapter 2 presented broad descriptions of recreational and industrial resources in the study area and included brief comments about professional and amateur fishing activities. This chapter describes each of these three important aspects in more detail. Much of the information is based on findings and other data from the technical reports dealing with recreation, industrial effluents, and fish resources and production.

Figure 4.1 shows the locations of foreshore reserves designated for recreational purposes and other uses and shows the location of major industries and discharges.

## 4.1 RECREATIONAL DEVELOPMENT

Much of the information presented in this section has been taken from the report on the Cockburn Sound Recreation Survey by Feilman Planning Consultants Pty. Ltd. and this report can be referred to for more detailed information.[1]

This section is divided into seven parts. These describe (1) the objectives and terms of reference of the recreation survey; (2) the extent and type of use; (3) public attitudes with respect to recreation derived from interviews during the survey; (4) expected growth in demand for recreational facilities; (5) the characteristics of recreational areas along the shore; (6) areas outside the Cockburn Sound area which could be developed to accommodate greater usage; and (7) existing interactions between recreation and other development on or near the shoreline.

As stated in Section 1.3, Owen Anchorage has been considered in the Cockburn Sound Study only to the extent that the activities there affect the Sound or vice versa. Recreation reserves are a case in point, so a few comments are appropriate about those along the shore of Owen Anchorage as well as those along the shore of the Sound.

### 4.1.1 Objectives and Terms of Reference of Recreation Survey

The overall objective of the Recreation Survey was to provide sufficient data on the recreational use of Cockburn Sound, both present and future, to assist the study team and others in making assessments on the relative values of the multiple uses of the Sound and its foreshores.

The terms of reference included the following elements:

1. Identify the natural resources for various forms of recreation and the extent of these (a) presently available, and (b) likely to be available in the next 10 to 15 years.
2. Document the facilities necessary to utilise these recreational resources, and the extent to which the facilities are (a) supplied at present, and (b) required in the future.
3. Carry out surveys to quantify present density and frequency of various types of recreational usage.
4. From public submissions, meetings or interviews, assess attitudes to the natural resources and facilities.
5. Consider whether particular forms of usage have been affected by other uses or developments.
6. From data on population pressures and attitudes, together with projections of resources and facilities available, forecast pressures for recreational needs in the next 10 to 15 years.
7. Identify any factor likely to inhibit such growth.
8. Consider alternative locations and their capability to absorb some of these pressures for recreational activities.

### 4.1.2 Extent and Type of Recreational Usage

Peak recreational usage occurs during the summer on hot weekends. Hence beach and water use counts and interviews were made in December 1978 and January 1979. At a given time during such days, a maximum of about 7000 people were on the Cockburn Sound and Owen Anchorage beaches and about 600 boats containing about 2200 people were on the offshore waters. Considering arrivals and departures of part-day users, it is reasonable to conclude that recreational facilities attracted over 10 000 people on peak days in the summer of 1978-79. Based on the interviews, over 80 per cent of the people lived within the Perth metropolitan region.

It is interesting to compare these figures with those for the Swan River estuary. The Swan and Canning Rivers Activity Study, completed in November 1977 for the Department of Conservation and Environment, found that at peak time on a summer Saturday afternoon the waters and foreshores were being used by a total of about 5300 people. Of this total, about 2400 were using the foreshores and 2900 were on various types of boats.

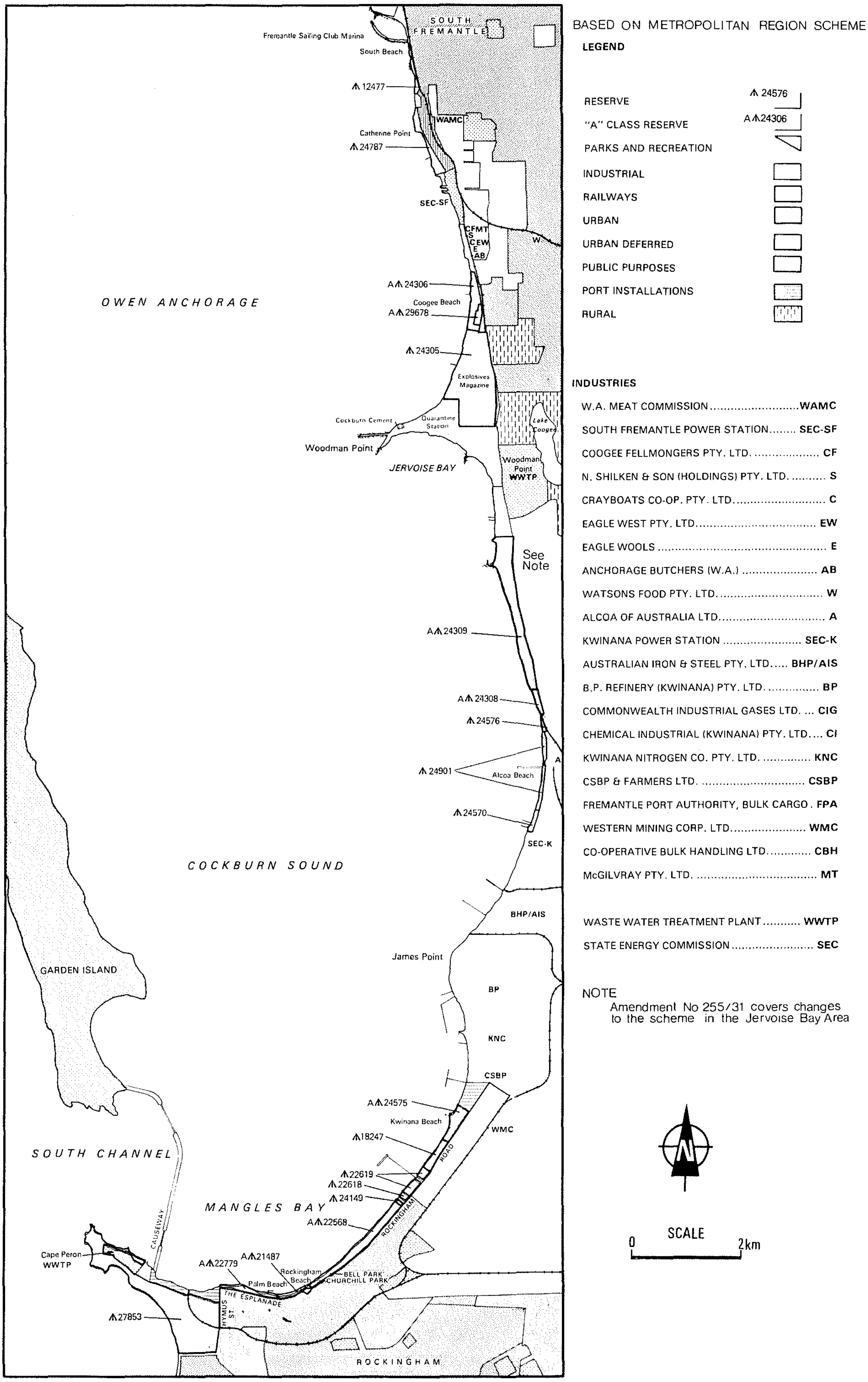



Figure 4.1 Location of recreation and other reserves and major industries.

Plate 6. Mangles Bay is a popular area for yachtsmen.

Nearly all of the users of the main Cockburn Sound and Owen Anchorage beaches are in family groups. This reflects the value attached to the beaches being safe and sheltered as well as equipped with picnic areas and other amenities. Half or full day family swimming and picnic outings account for a high proportion of beach use. Most beach users concentrate at the five main developed beaches–Palm Beach, Rockingham Beach, Kwinana Beach, Coogee Beach and South Beach. Rockingham Beach, comprising Churchill and Bell Parks, accommodates over half of the beach users (Figure 4.2). Interviews indicated that over half of the beach users come to the beach at least once a month.

Fishing is the main activity in boats launched from the three main public ramps in the Sound and general pleasure boating is second in importance. Boating activity spreads across the Sound and Owen Anchorage with concentrations at Southern Flats, Garden Island, Jervoise Bay and Mangles Bay. Very few boats launched in the Sound appear to venture north of Woodman Point. Nearly half of the boat operators interviewed come to the area at least once a week.

Interviews with beach users and pleasure boat operators during the recreation survey showed that, except for the beaches at Rockingham, the beach users come from nearby locations. Rockingham beaches draw from a wide variety of localities within the metropolitan region (Figure 4.2). Users of public launching ramps also come from throughout the metropolitan region, although proportionally more people come from nearby localities.

### 4.1.3 Public Attitudes

During the recreational survey, interviews were held with (i) local community groups; (ii) beach users; and (iii) pleasure boat operators in an attempt to assess public attitudes and concerns regarding uses of beaches and adjacent waters. Each type of interviewee showed different attitudes and concerns.

Local community groups indicated concern about additional port and industrial developments. They recognised the need for industry on economic grounds, but also felt that the recreational potential of the Sound has been disregarded in the past. The majority of groups required that industry be controlled by (i) location off the foreshore; (ii) limitations of effluents; or (iii) restrictions on growth.

Beach users indicated concern over a variety of matters including insufficient shade and shelters, presence of industry and government installations, beach litter and parking. From the responses, there did not appear to be a strong concern about the non-recreational uses of the Sound. Nearly 90 per cent of the first-time visitors to the area indicated a desire to return again.

Boat users were more concerned with facilities such as launching ramps and car parks, than with the effects of industry on their activity.

### 4.1.4 Expected Growth of Demand

Population projections made by various governmental authorities envisage that the 1990 population of the Perth metropolitan region will be in the range of 1.15 to 1.5 million persons. This compares with a 1976 census population of 0.8 million. Assuming present proportions of beach users from various population units, the numbers of persons that will use the beaches on peak summer days in 1990 is forecast to be between 13 000 and 15 500.

These forecasts are considered reasonable; however, recreational patterns change and a number of factors can operate to increase the estimates. These factors include:

(i) increased leisure time,
(ii) reduction of the suspected effects of non-recreational development,
(iii) provision of additional facilities.

At present, the three main public boat launching ramps in Cockburn Sound have a total of eight lanes. Based on the conclusion that these ramps are currently being used at or near capacity and allowing for population and boat ownership factors, the need for an additional four to eight lanes of public boat ramps by 1990 has been forecast. It is noted that power boat usage may not increase at the present rate because of increased cost and possible scarcity of fuels.

The shoreline of Cockburn Sound and Owen Anchorage has the capacity to accommodate the projected demands provided (i) improvements are undertaken on a planned basis; (ii) action is taken to reduce actual and perceived concerns about water pollution; and (iii) decisions on future uses of foreshore take account of present and potential uses. In particular, development of the northern shoreline of Woodman Point and of the Quarantine Station and Explosives Magazine will accommodate a substantial proportion of the increased demand.

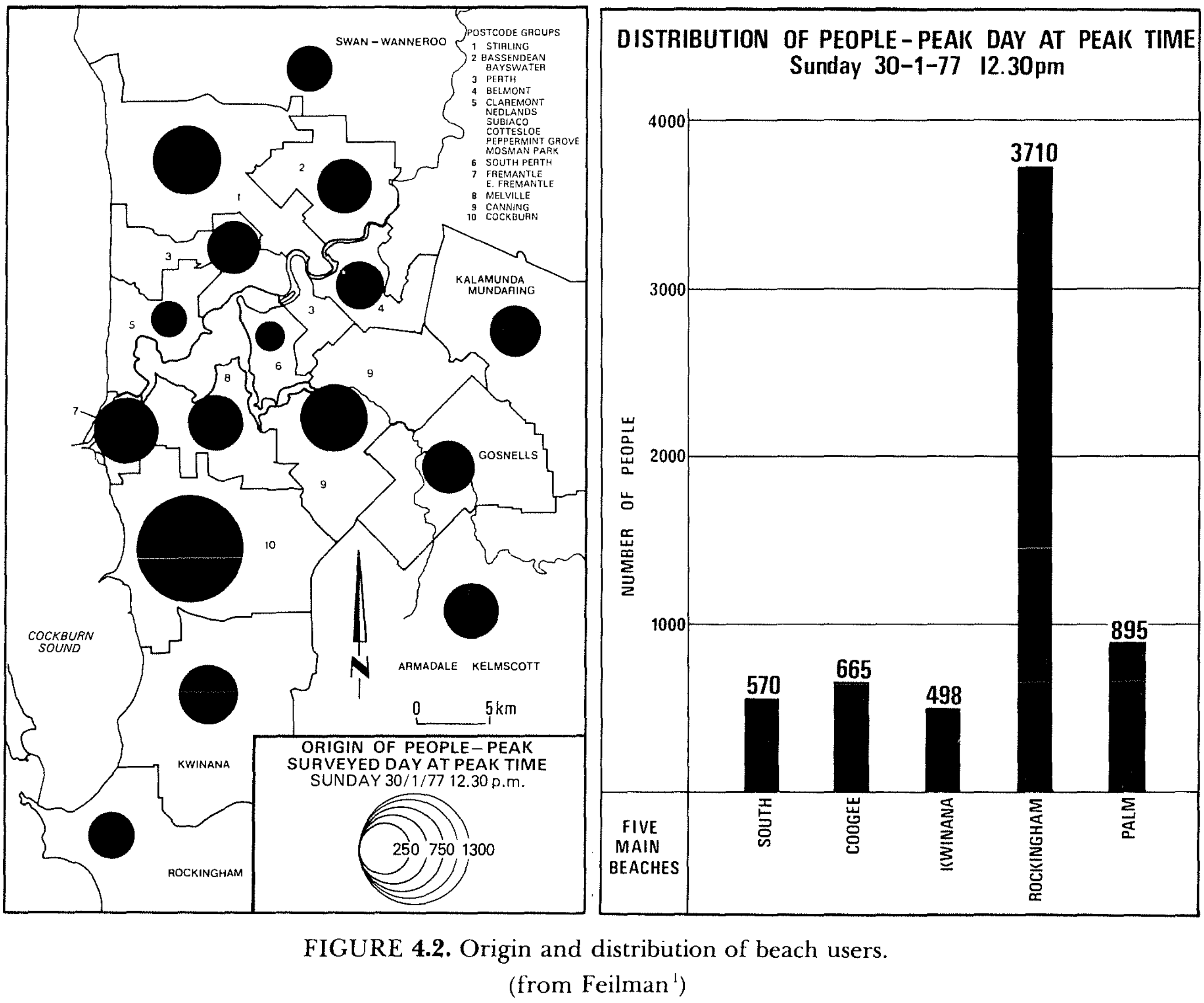



FIGURE 4.2. Origin and distribution of beach users.
(from Feilman[1])

### 4.1.5 Characteristics of Recreational Areas

The main recreational reserves shown on Figure 4.1 have been grouped into areas and discussed below. Where appropriate, comments are included about the condition of specific reserves and factors affecting their suitability for recreational use.

**Fishing Boat Harbour to Coogee Beach.** At South Beach reserve (12477) the dunes have been levelled, grassed and paved to provide facilities for beachgoers. The northern section of this reserve has been excised for buildings associated with the new marina which will be available only to members of the Fremantle Sailing Club.

Reserve 24787 extends from South Beach to the groyne just north of the power station. Substantial sand accretion has occurred at Catherine Point. At present access is by foot from South Beach, but use of this reserve for recreation could be greatly increased if better access were provided, preferably without further levelling of dunes. The proximity of a foundry and railway yards backing the dunes adds to the generally degraded appearance of this part of the reserve. Rubble from the foundry site appears to have encroached onto the dunes.

South of Catherine Point foreshore development includes a wide variety of industries. In a number of cases, the construction of protective breakwaters and walls was combined with natural rock headlands to make access difficult. In addition, most existing industries discharge tradewastes at the shore of Owen Anchorage or a short distance offshore.

Recreational reserves 12477 and 24787 are the closest to urban centres and therefore represent valuable resources which should attract large numbers of people. However, they are little used because of real or "perceived" deterrents such as polluted water, odours, restricted access and the industrialised landscape.

**Coogee Beach to Woodman Point.** Two A class reserves (A24306 and A29678) are used for recreation in this area. Bordering these to the south is the Explosives Magazine (reserve 24305) which, with the Quarantine Station, is to be closed and the land made available for parks and recreation. A redevelopment and recreation complex has been proposed for an area of 260 ha including Coogee Beach, Woodman Point and the shores of Jervoise Bay, and has been incorporated into the Metropolitan Region Scheme. Development of the complex covers enlargement and improvement of beaches and recreational shoreline activities including an extensive marina facility and breakwater system in Jervoise Bay south of Woodman Point. In addition, space has been designated for small shipbuilding activities and for construction of oil platform modules.

At the existing Coogee Beach reserve (A24306), the beach is 15 to 25 m wide and is backed by high dunes, partly levelled for a beach park and caravan park (A class reserve 29678). The frontal dunes are degenerating seriously due to wind action and trampling of the vegetation by visitors. On the other hand, the foreshore and dunes contained within the Quarantine Station and Explosives Magazine areas have not been subjected to human pressure since virtually the whole of this section of foreshore has been closed to public access for most of this century.

The opening of this section of foreshore will add about 2 km of protected beach to the Cockburn Sound foreshore and could provide an alternative for family groups presently using the foreshore at Rockingham. However, the value of this additional stretch of foreshore as a recreational resource is lowered by (i) water contamination arising from tradewastes discharged to the shore waters by industries north of Coogee, and (ii) discolouration of the nearby beach by washings from the Cockburn Cement dredged sand processing plant. The latter problem has been reduced by a new system whereby sand washings are discharged into the sea east of the jetty, 80 m offshore in 7 m depth of water.

**Jervoise Bay to James Point.** Two A class reserves, A24309 and A24308, extend from the shipbuilding yards to the northern end of the Alcoa alumina refinery, and are bounded on the east by the Cockburn Road. As potential resources for beach recreation, these reserves have little to offer because of existing uses and the proximity of industry and because the remaining shoreline consists of low rocky limestone cliffs.

The northern section of reserve A24309 is used by a go-kart club. This section will become part of the reconstruction site for offshore oil platform modules in the new Jervoise Bay complex. The natural flora and topography has been disturbed by the quarrying of limestone by the Town of Cockburn, by frequent burning and by trail bikes. Close to the alumina refinery, reserve A24308 has been developed as a caravan site.

The narrow strip of beach, 10 to 20 m wide, running south from the caravan site is reserved for Parks and Recreation (reserves 24576 and 24901). This use seems inappropriate due to the proximity of the alumina refinery and power station. In addition the beach has very limited access, and water, aerial and visual pollution is severe, noise levels are high and the beach often is coated with alumina dust.

**Kwinana Beach to Mangles Bay.** This length of shoreline is the most valuable recreation resource in the study area. The north-facing beaches are well protected from prevailing winds, and thus are well suited for swimming in calm water and for boat launching without protective groynes.

The entire beach from Kwinana Beach to Hymus Street in Rockingham is reserved for Parks and Recreation (Figure 4.1) although not all portions have the protection of A classification. The reserves form a narrow strip extending from the beach through the foredunes to the Rockingham Road and The Esplanade. Inland, the northern area is zoned industrial, while the major portion to the south is residential. Four of these reserves are A class, Kwinana Beach (A24575) and Rockingham and Palm Beaches (A22568, A21487 and A22779).

The Kwinana Beach reserve is of some historical interest as the wreck of the ship 'Kwinana' was washed ashore in 1922. Sand has accreted out to the wreck from which a jetty and launching ramp have been built. The potential of this reserve for recreation could be limited depending on the uses which may be made of the Fremantle Port Authority land immediately to the north and of the industrial zoned land east of Rockingham Road (Figure 4.1).

Part of the foredunes at Kwinana Beach has been modified to form a car park. The dunes adjacent to Rockingham Beach have been levelled, grassed and planted with trees to form Churchill and Bell Parks (reserves A22568 and A21487).

As mentioned in Chapter 2, conversion of recreational waters in Mangles Bay to harbour use and the addition of port services close to urban development would have substantial environmental and sociological impacts. Beneficial uses and water quality objectives for the southern section of Cockburn Sound would have to be reassessed.

**Cape Peron.** The Cape Peron area (reserve 27853) has high scenic value. Those parts still held for recreation retain some of the original vegetation but the area is under considerable pressure. The land was handed over to the State in 1966 by the Commonwealth on the condition that the whole area (180 ha) should be used solely for recreation purposes. At the request of the W.A. Government, however, this condition was later rescinded. Subsequently, various portions of this recreation reserve have been excised for a sewage treatment site, for port ancillary services, and for public works, roads and railways. The plan for this reserve, as shown in the 1972 report of the inter-departmental Committee for the Development of Cockburn Sound and Kwinana, retains only 104 ha (about 58 per cent of the original reserve) for recreation.

**Garden Island.** Garden Island is freehold Commonwealth territory. As noted in Chapter 2, its environmental management is supervised by a joint Commonwealth-State Committee. Portions of the Island are accessible to the public including an area around Cliff Head. This is the locality at which Captain Stirling in 1829 made his first settlement. The area was established as a reserve site in 1972.

### 4.1.6 Recreational Areas beyond the Study Area

There are a number of beach areas south of the study area on the shoreline of Shoalwater Bay and Warnbro Sound which can accommodate considerably greater numbers of people than presently use them. The shoreline of Shoalwater Bay and Warnbro Sound is 17 km in length, and almost all of this is suited to intensive beach recreational use except when seaweed is washed up on the beaches. This is 1.3 times the length of shoreline of Owen Anchorage and Cockburn Sound which is considered suitable for family beach use.

The Shoalwater-Warnbro shoreline is relatively sheltered and could provide further beach development. The northern half of Warnbro Sound is susceptible to wind waves from sea breezes and the seagrass grows to within 10 to 20 m of the beach. These conditions could limit the use of the shoreline for swimming. The more sheltered southern portions of Warnbro Sound are at present largely inaccessible and more than 19 km further from the main source of beach users than the Rockingham-Palm Beach shoreline which is the main family beach in the metropolitan region.

During the survey period, about 1200 people were on the Shoalwater-Warnbro shoreline at peak times on peak summer days. These people were predominantly from the immediate urban areas and presumably were avoiding the crowded Rockingham shoreline. It is considered that the Shoalwater Bay-Warnbro Sound shoreline will be increasingly used by local residents as the population of the Rockingham-Warnbro urban area grows. Additionally, as the Mangles Bay shoreline becomes increasingly crowded, the Shoalwater-Warnbro beaches will be used by regional visitors who are prepared to forego the near-perfect family beach conditions available in Mangles Bay to avoid the crowds.

### 4.1.7 Interactions between Recreational Uses and Other Developments

Historically, developments associated with port and industrial activity on or adjacent to the shoreline have reduced the length of shoreline of Owen Anchorage and Cockburn Sound available for recreation. These developments include buildings, railways, groynes, effluent outfalls and private ownership of the foreshore. Inspections during the recreation survey indicated that these developments occupy about 12.3 km of the total mainland shoreline length of about 30.3 km. It is recognised that even before these developments, all of the 12.3 km were not necessarily suitable for intensive recreational use.

The survey also identified the locations and length of beaches available and suitable for intensive recreational use. These have a total length of 13.4 km as summarised in Table 4.1. "Available and suitable" implies public ownership, reasonable access, sandy beach, calm and clear water, no fallout of airborne particulate matter, and a shoreward landscape not dominated by industrial structures. "Intensive recreational use" is defined as part or all day family group swimming and picnicking use. During the survey, over 90 per cent of the beach users along the shores of Cockburn Sound and Owen Anchorage were found to be engaged in this type of activity.

At some beaches, particularly those in the Coogee area, access roads pass through relatively unattractive industrialised landscapes. This situation tends to discourage beach use. In addition, reports of real or "perceived" pollution of shore waters in Owen Anchorage and Cockburn Sound have the same effect on a region-wide basis.

## 4.2 INDUSTRIAL DEVELOPMENT

This section contains background and historical data about industrial development in the study area and about the specific industries and wastewater treatment plants (WWTP) shown in Figure 4.1 and included in the sampling and analysis of industrial effluents described in Chapter 5. Table 4.2 lists the industries and other installations and indicates the principal activities in which they are engaged. The following pages describe them with particular emphasis on operations which produce the major wastewater outputs. Information has been taken from the Cockburn Sound Study Technical Report on Industrial Effluents[6] and that report can be referred to for more detail. Objectives and terms of reference are given in Chapter 5 which discusses the sampling and analyses programme and its results.

For convenience, this section is divided into five parts. These describe (1) the general development of industry in the study area, (2) specific industries in the Kwinana Industrial Area (including those discharging to Cockburn Sound), (3) specific industries in the Cockburn Road Special Industrial Area (including those discharging to Owen Anchorage), (4) the two wastewater treatment plants discharging into the Sound or adjacent waters, and (5) the two power stations located in the study area.

### 4.2.1 History of Industrial Development

The brief history of industrial development is presented as a preface to the descriptions of specific industries.

Meatworks were established on the foreshore of Owen Anchorage prior to 1940, and set the pattern for development of meatworks, woolscourers, fellmongers, fish processors, and similar operations in the Cockburn Road Special Industrial Area. Nearly all of those operations discharge industrial wastewaters at or close to the shoreline of Owen Anchorage. The building of the South Fremantle power station on the shore of Owen Anchorage in 1949 included the erection of groynes across the beach to protect the seawater cooling system. These groynes arrested the southward movement of beach sands in Owen Anchorage, as discussed in Chapter 6.

Development of Cockburn Sound as the outer harbour for the Perth-Fremantle area began in the 1950s and gained momentum in the next 25 years. The first major unit of the Kwinana Industrial Area, the industrial complex which has built up on the eastern margin of the Sound, was an oil refinery (opened in 1955), followed by a steel rolling mill (1956), an alumina refinery (1964), a blast furnace (1968), a fertiliser plant (1968), a power station (1970), a nickel refinery (1973), and a bulk grain terminal (1976). Many ancillary industries developed in association with the major industries in this area. Wastewater treatment plants were constructed by the Metropolitan Water Supply, Sewerage and Drainage Board (MWSS&DB) at Woodman Point (1966) and at Cape Peron (1975).

With the development of this industrial complex, wharves and groynes have been built and channels excavated for shipping access. The shipping channel through Success and Parmelia Banks, dredged to a depth of 8 m from 1919 to 1929, was widened to 91 m during the period 1940 to 1945, was dredged again during the period 1951 to 1955 to 152 m wide and 11.6 m deep, and in 1967 the channel was deepened to 13.7 m, remaining at 152 m wide. Lime sand mining is being carried out so as to provide an alignment for a second channel which may be required in the future.

### 4.2.2 Kwinana Industrial Area

Six major industries are located within the Kwinana Industrial Area (Figure 4.1). Four discharge their wastewaters to Cockburn Sound and two utilise land disposal for their wastewater.

**Alcoa of Australia Ltd. (Alcoa).** The Alcoa alumina refinery at Kwinana was established under a ratified Agreement between State and Company (Alumina Refinery Agreement Act, 1961-1967). The agreement called for the establishment of an alumina refinery at Kwinana with a capacity of not less than 0.12 million ton/y* by 31 March 1967.

Construction of the first unit of 0.2 million ton/y capacity was commenced in December 1961, and

*The unit "ton" is used to be consistent with agreements or quoted capacities; in other cases, the abbreviated "t" stands for tonnes; 1 ton = 1.016 tonnes and 1 tonne = 0.985 ton.


(a)
(b)
(c)

the first shipment of alumina was in February 1964. A further five units were added to the refinery over the next six years with capacity reaching 1.25 million ton/y in December 1970. Because of site limitations, this is the effective maximum capacity possible at this location. Since 1970, the Pinjarra alumina refinery has been established and plans are well advanced for a third refinery at Wagerup.

The residue from the bauxite is pumped to special mud lakes which are sealed to prevent contamination of the groundwater. Since July 1978, the only flow of water to the Sound from the Alcoa worksite is rainfall runoff from three non-process areas of the refinery. Although air pollution is beyond the scope of the Cockburn Sound Study, it should be noted that airborne alumina dust often falls onto nearby recreation reserves and is a substantial deterrent to public use. On occasion, the sealed bottoms of the mud lakes have failed and wastewater has seeped into the groundwater in the unconfined upper aquifer.

**Australian Iron and Steel Pty. Ltd. (AIS).** The Broken Hill Proprietary Company (BHP) operates two separate plants on its Kwinana site. One is a steel rolling mill producing steel shapes for local demand. The other is a sinter plant/blast furnace complex producing pig iron primarily for export. The Kwinana operations are managed by Australian Iron and Steel Pty. Ltd. (AIS), a BHP subsidiary.

In 1952 the BHP Company entered into a ratified Agreement with the Western Australian Government (Broken Hill Proprietary Steel Industry Agreement Act, 1952). The Company agreed to install a steel rolling mill of not less than 50 000 ton/y capacity. In return, the State made certain undertakings with respect to mineral leases held by BHP at Yampi Sound, temporary reserves at Koolyanobbing (both for iron), and a mining reserve (for coal) at Collie.

The rolling mill was commissioned in July 1955 and has been in operation since then rolling steel imported from BHP's eastern states operations. The present capacity of the mill is 200 000 t/y (dependent to a certain extent on products). In recent years, the mill has operated below capacity. Only four to five shifts are being worked each week at present compared to a potential 20. Actual production for the year 1978 was about 75 000 t of rolled steel products.

Fresh water from bores is used in the rolling mill and there is no use of seawater. A high degree of recirculation is practised and discharge to the Sound only occurs when settling ponds are filled with solids.

In 1960 BHP entered into another ratified Agreement with the State (Broken Hill Proprietary Company's Integrated Steel Works Agreement Act, 1960). The Company agreed to construct a blast furnace of a capacity not less than 450 000 ton/y by 31 December 1968. In addition the Company was committed to the installation of 330 000 ton/y capacity of finished products from steelmaking and associated rolling mill facilities by 31 December 1978.

The blast furnace was commissioned in May 1968 and has operated since that time. The steelmaking obligation has been changed to 500 000 t/y capacity and the operation date altered to 31 December 1980. The present capacity of the blast furnace is approximately 18 000 t of hot metal per week or a potential annual output of 900 000 t. Output has been restricted by market demand and full production potential has not been achieved for long periods because of lack of demand. The pig iron is almost totally exported with production generally around 500 000 to 600 000 t/y with a maximum of 850 000 t in 1973-74.

Facilities associated with the plant include a sinter plant, a power station and raw material handling equipment. From the blast furnace, the hot metal is tapped into 200 t torpedo cars and transferred to a pig mill for casting into pig iron. In a non-integrated works there are no alternatives to production of pig iron. The plant does not have the capability to produce coke and the necessary supplies are imported from BHP's Port Kembla works.

The blast furnace was relined in November 1974 and a further reline in 1980 was recently announced. The reline will be accompanied by furnace modifications to lift capacity by around 200 000 t/y. The total cost of all planned works is estimated at about $24 million.

Seawater for cooling purposes is the major water use in the blast furnace complex. A constant flow of 175 ML/d is used in the power station. Some of the seawater from the power station is used in the blast furnace area for gas washing, cooling pig iron, and slag granulation. All seawater flows are discharged to the Sound.

**BP Refinery (BP).** The BP Refinery was the first major industry established in the Kwinana Industrial Area. An Agreement between the Company and the State was ratified by Parliament in 1952 as the Oil Refinery Industry (Anglo-Iranian Oil Company Limited) Act, 1952. Construction work was begun in 1953 and first production took place in February 1955. The refinery has been steadily expanded and new processing units installed since its inception. Present crude oil use is between 4 to 4.5 million t/y compared to a maximum capacity of 5.2 million t/y (giving a potential increase of approximately 150 000 t/y). In April 1978 plans were announced for the installation of an alkylation unit of capacity

Plate 7. The Kwinana Industrial Complex. (a): The BP Refinery at James Point (foreground), the Kwinana Nitrogen Company, the CSBP fertiliser works and the Co-operative Bulk Handling grain terminal. (b): The Australian Iron and Steel works. (c): The Alcoa alumina refinery (foreground) and the SEC Kwinana power station.

105 000 t/y in motor spirit production through blending with some existing streams presently used for other purposes.

The refinery uses saltwater for cooling purposes and a mixture of scheme and bore water for process purposes. In the initial stage of development this water was returned to the Sound after use through two outfalls situated on the beach. When the lubricating oil plant was established in 1962, a third outfall handling its used saltwater was established at the same site. In 1968 more saltwater was taken in by the refinery to supply the KNC and CSBP developments. There was also an increase in scheme water use associated with KNC. The catalytic cracker expansion at the refinery in late 1978 has lead to a further increase in saltwater intake and a new outfall to the Sound. During the wastewater sampling programme, the saltwater volume for all purposes was about 425 ML/d (excluding an additional 45 ML/d now provided to the catalytic cracker).

In addition to seawater, the refinery uses about 8 ML/d of fresh water. In the past, this has been drawn mainly from scheme water. In more recent times, this has been partly replaced with bore water drawn from within the refinery property. Some of the fresh water comes into contact with process streams and can be contaminated with hydrocarbon and other organic compounds.

The water component of oil held in storage tanks in the tank farm on the refinery site is drained periodically from the bases of the tanks and allowed to flow into the unsealed safety basins surrounding the tanks. The drain valve is closed when oil starts to flow out with the water. Over the years, the basins around the crude oil tanks have tended to develop an impervious seal. Earlier, however, seepage from the basins entered the unconfined aquifer and is responsible for much of the groundwater contamination presently found under the refinery grounds.

Some wastewater from KNC is returned to the refinery but most wastewaters which are passed from the refinery to KNC and CSBP are discharged to the Sound in a pipeline from the CSBP plant. The discharge from the BP refinery directly to the Sound totals about 330 ML/d.

**Kwinana Nitrogen Company Pty. Ltd. (KNC).** Construction of the KNC works was begun in late 1966 and the first production was in 1968. The works are a joint venture between the British Petroleum Company of Australia Limited (BPCA) and CSBP & Farmers Ltd. (BPCA 80 per cent, CSBP 20 per cent). It is located on a 2 ha site on the southern boundary of the BP Refinery land. The present capacity is 100 000 t/y of ammonia ($NH_3$), 83 000 t/h of nitric acid ($HNO_3$) and 1400 000 t/y of ammonium nitrate ($NH_4NO_3$).

The basic feedstocks are refinery gas from BP, steam and air. The ammonia produced from the reaction of hydrogen manufactured from the refinery gas and nitrogen from air is partly used in making nitric acid. The remainder is reacted with the nitric acid to form ammonium nitrate. The ammonium nitrate is then sent as a hot liquid to CSBP for granulation to a form suitable for use in explosives or as a fertiliser.

KNC uses seawater for cooling and condensing purposes. As noted above, this seawater is passed along from the BP Refinery. After its use by KNC, a small quantity is returned to the refinery and the balance is sent on to CSBP. Some is used at CSBP and the total volume is disposed to sea. About 65 ML/d of seawater passes from the KNC works to CSBP.

**CSBP & Farmers Ltd. (CSBP).** In 1964, following the discussions between CSBP, BPCA and the State Government which resulted in formation of KNC, an agreement between the parties, ratified as the Industrial Lands (Kwinana) Agreement Act, 1964, provided for CSBP to construct a new concentrated fertiliser manufacturing complex at Kwinana instead of proceeding with extensions at its North Fremantle site. The agreement provided for CSBP to discharge up to 350 tons/d of gypsum to the Sound waters.

The works is now the largest superphosphate works in Australia. At present, manufacturing is at a rate of 500 000 t/y with the capacity to produce 1 000 000 t/y of single superphosphate. Four interconnected basic processes are carried out at the CSBP Kwinana works: (i) sulphuric acid is manufactured from imported sulphur; (ii) phosphoric acid is manufactured from sulphuric acid and imported phosphate rock; (iii) single and double superphosphate is manufactured by the reaction of sulphuric acid and phosphoric acid with imported phosphate rock; and (iv) compound fertiliser is manufactured from ammonium nitrate and ammonia (both from KNC) and ammonia sulphate (from Western Mining Corporation's Kwinana Nickel Refinery).

In addition, ammonium nitrate from KNC is prilled for industrial use as a blasting agent mainly in the Pilbara iron ore mines. There is also a nitric acid plant on-site which is run when needed for additional ammonium nitrate production.

As noted above, CSBP uses saltwater drawn from BP (direct and via KNC) for cooling and gypsum dissolving purposes. Bore water drawn from on-site bores is used primarily for coolers in the sulphuric acid plant, and dust and fume scrubbing in the phosphoric acid plant. Scheme water is used to react with the sulphur trioxide generated by burning sulphur in the sulphuric acid plant and also for general boiler make-up water in the works. The CSBP discharge from all sources totals about 80 ML/d.

**Western Mining Corporation (WMC).** The WMC nickel refinery at Kwinana was established under the Nickel Refinery (Western Mining Corporation Limited Agreement) Act, 1968, and operations were started in 1973. The refinery produces nickel (21 000 t in 1978-1979), ammonium sulphate (98 500 t in 1978-1979) and mixed sulphides (3500 t in 1978-1979). The ammonium sulphate is sold to CSBP at Kwinana. The nickel concentrate feed is supplied from Kambalda and the nickel matte by the Kalgoorlie smelter.

Effluent is not dischaged to Cockburn Sound. All effluent streams, including the tailings slurry, go to a sealed tailings pond at Baldivis. Storm water from within the plant goes either into the process or with the effluent stream. Storm water from outside the process area is disposed of by ground seepage.

### 4.2.3 Cockburn Road Special Industrial Area

Nine major industries are located within the Cockburn Road Special Industrial Area (Figure 4.1). Wastewaters from eight industries are discharged to Owen Anchorage close to shore. The other industry utilises land disposal for its wastewater.

**Western Australian Meat Export Commission, Robb Jetty Division (WAME).** This abattoir complex is operated by the Western Australian Meat Commission and primarily is involved in cattle and sheep slaughtering for the export market. A range of by-products such as fertilisers, tallow, sausages etc., are also produced. The normal slaughtering period is eight hours per day, five days per week with the capacity to handle 500 cattle and 6300 sheep per shift. However, there are plans to enlarge the capacity to the point where the total kill now divided between this abattoir and the Midland abattoir will be undertaken here.

The wastewater generated within the complex flows to a centralised treatment area. Except for paunch wastes, all flow passes through a rotary screen and is introduced into a dissolved air flotation unit for removal of floatable solids which are recovered for further processing. The water from the unit is then directed to two saveall screens. The paunch wastes are directed without pre-treatment to a third saveall screen. The overflow from the three savealls flows through rotary screens before flowing to the pipeline for disposal a few metres off the beach. The average daily discharge is 2.2 ML/d, with a maximum of 4.6 ML/d. The settled and screened material from the main wastewater stream is returned to the by-products section. The settled and screened paunch solids are buried on-site. Blood recovery facilities precede the air flotation units.

**Anchorage Butchers Pty. Ltd. (Anchorage).** This abattoir complex is basically similar to the WAME operation, i.e. slaughtering of cattle and sheep. The capacity is around 200 cattle and 3000 sheep per day in a single eight-hour shift working a five-day week. There are plans to enlarge the capacity of the works in the near future and existing wastewater treatment facilities are under review as part of the planning process.

The wastewater generated from the sheep and cattle areas flows in separate streams to two separate rotary screens before flowing as a combined stream to a series of savealls. Blood recovery facilities and some coarse screening precedes the savealls. The screened material either is sent back for reprocessing or is trucked to a local tip, depending on its origin. Paunch wastes also go to the tip. The fat that separates in the pits is recovered for tallow production and the settled solids are sold as organic fertiliser or trucked to the tip. The screened and settled wastewater is then disposed of to Owen Anchorage through a pipeline discharging 290 metres offshore (average 1.0 ML/d).

**Watson Foods Pty. Ltd. (Watsons).** This industry is engaged in the slaughtering, butchering and packaging of pigs and pig by-products. An average of 450 pigs is processed daily on an eight-hour day shift, five days per week.

Blood is almost totally recovered from the killing area for use in by-products. The wastewater is screened, passed through a dissolved air flotation unit for removal of floatables and then run to two saveall screens operating in series. The screened and floatable solids are returned to the by-products section. The wastewater is pumped to the ocean outfall. An overflow from the savealls goes to a divided lagoon east of the works. This unsealed lagoon acts as an equalisation basin at times of peak flow. The wastewater flowing to the lagoon is pumped to the second section and oxygen is injected during the pumping. Also an enzyme, actizyme, is added to the water to encourage breakdown of the organics in the water. Overflow from the second section returns to the first via a gravity drain. Late in the day, when fresh wastewater flow ceases, wastewater from the first lagoon is picked up by a pump, returned to the savealls, and then pumped to sea (average 0.8 ML/d).

**N. Shilkin and Son Pty. Ltd. (Shilkin).** This firm conducts two separate operations. On the west side of Cockburn Road, there is a chrome tanning and dyeing operation based on treating cattle hides at the rate of 300 hides per day on a single ten-hour shift, five days per week. The east side operation takes the tanned hides and prepares them to the stage where they can be used for a variety of leathergoods.

The wastewaters from the west side are collected by a system of floor drains into a pit adjacent to the building. The wastewaters are then pumped to a screening area for removal of gross solids and then are drained back to a settling pit. From this pit, the wastewater is pumped to a holding tank equipped with a siphon so that the entire contents can be discharged at one time. The tank discharges about once per day to a pipeline terminating 300 m offshore in Owen Anchorage. Any overflow flows by gravity to a pipeline discharging 50 m offshore. There are plans to shift the dyeing operation from the west side to the east side of Cockburn Road. It is expected that this will enable recovery of chromium and lime from the tanning wastewaters and improve the wastewater quality. The present arrangements prevent this recovery.

**Eagle West Pty. Ltd. (E. West).** This industry prepares sheepskins for export to Japan for tanning. Some chrome tanning also is carried out for the local market. Maximum weekly production is about 1200 hides (1000 for export, 200 tanned for sale) on an eight-hour shift five days per week.

The wastewaters discharge to six settling pits arranged in series to allow for some solids settlement. The wastewater then is either pumped to the Watson's outfall for discharge to the sea or allowed to flow into an apparently large underground cavern. This cavern shows no signs of filling with wastewater and it would appear that the water escapes to the groundwater as fast as it flows to the cavern. In practice, almost all flow goes to the cavern and only intermittently to the sea via Watson's outfall.

**Eagle Wools Pty. Ltd. (E. Wools).** Two related companies operate on this site. The Eagle Wools Company tans sheepskins for the local market and is the major source of wastewater being discharged to the sea. The other company, Colyer-Wilcox Pty. Ltd., salts cattle and sheep hides prior to export for further processing. There is a minor flow of blood and brine from this operation.

At Eagle Wools, about 600 sheepskins are chrome tanned per week on a five-day, eight-hour single shift basis. Wastewaters are generated during transfer of skins from tank to tank and during dumping of tank contents from time to time. The wastewater flows down floor drains to a canal equipped with coarse screens and then into a holding pit. From these the wastewater is pumped to one of two lagoons for disposal by land soakage. While one lagoon is being used, the other is drained and is ready to be used when the other lagoon fills to the point where overflow occurs. Overflow is discharged to the sea at the shore about 50 m to the south of Watson's groyne. In normal operation, very little flow occurs to the sea as the two lagoons can handle all of the present flow on an alternate basis. Wastewater from Colyer-Wilcox flows to floor drains and then to the holding pit mentioned above, where it mixes with the E. Wools wastewater. The total volume of wastewater is about 0.025 ML/d. Proportions ranging from 0 to 100 per cent are discharged to the sea depending on conditions in the lagoons.

**Coogee Fellmongers Pty. Ltd. (C. Fell).** This company recovers wool from scrap pieces of sheepskins obtained from other companies. The scrap wool is first washed in detergent and hot water. The washed scrap wool is drained and placed in tanks. The tanks are then filled with a weak solution of sodium ethylene diamine tetracetic acid (NaEDTA) and aerated. This digests and dissolves skin and tissue fragments associated with the wool. The NaEDTA complexes any iron present preventing staining of the wool by iron. The wool is then washed again, dried and baled for export.

The company works a five-day week with wastewater generated between 0700 to 0900 h and 1450 to 1530 h. Wastewaters flow through floor drains to a small pit. Coarse solids are screened out at the pit inflow point and the wastewater is then pumped to a pipeline discharging some 290 m into the sea. Once a week the solids in the pit are removed and dumped on-site to dry. The grease arising from the process floats on top of the water in the pit in the morning but the hot water dumped in the afternoon emulsifies the grease. It is then pumped to the sea as an emulsion with the hot water.

**Crayboats Co-operative Pty. Ltd. (Crayboats).** There are two distinct operations at this site. In the early part of the day (between 0800 and 1600 h), part of the premises is used for sorting and packaging prawns. This occurs for about 11 months of the year on a five-day week basis. The other operation involves rock lobster processing for export on a seven-day week basis (between 1500 and 2300 h) during the rock lobster season, November to June.

The wastewaters flow down floor drains to two settling pits in series. A coarse screen is available at the end of the floor drains to remove coarse material. From the second pit the wastewater is pumped to Watson's pipeline for sea disposal. The screening and any settled solids are sent to the local tip. Wastewater volume totals about 0.2 ML/d.

**McGilvrays Tannery (McGilvray).** This company tans and dyes an average of 80 cattle hides per day on an eight-hour, five-day week basis. The hides are washed and dyed at the rate of 80 per day with chrome tanning of 130 per day during the last three days of the week.

The wastewater generated by the tannery flows along open floor drains to a small holding pit immediately behind the works. From here the wastewater is pumped to a soakage lagoon about 100 m east. The rate of flow is such that no standing water is present. Apparently the solids in the wastewater do not tend to block soakage and the lagoon has not needed removal of the solids to restore soakage for several years. Wastewater volume totals about 0.025 ML/d.

### 4.2.4 Wastewater Treatment Plants

The Metropolitan Water Supply, Sewerage and Drainage Board (MWSS&DB) operates two wastewater treatment plants which discharge to Cockburn Sound or nearby waters.

**Woodman Point Treatment Plant (WPTP).** The plant was commissioned in 1966 to serve the southern and eastern sections of the Perth region. It was designed for expansions to serve an ultimate population of 180 000 people generating 41 ML/d of wastewater. Since the initial contributory population was significantly lower, facilities were not built immediately to this capacity. The treatment given to the wastewater is commonly known as primary treatment. The incoming water is passed through a disintegrator and a grit tank before flowing into clarifiers. Effluent from the clarifiers is screened and then discharged to the Sound waters without any further treatment. The sludge is digested anaerobically and the digested sludge is placed on sand beds and allowed to dry before being carted away by market gardeners for use as soil conditioner. Treated wastewater presently is discharged to Cockburn Sound from a pipeline terminating 1800 m south-west of Woodman Point in 16 m depth of water.

In 1979, the plant was serving a contributory population estimated at about 130 000 people plus industries permitted to discharge to the sewerage system. Flows averaged about 30 ML/d. The MWSS&DB estimates that the existing plant will reach its full capacity in 1981-1982. Planning is well advanced for the construction of a new plant on the Woodman Point land. It will have an ultimate capacity of 125 ML/d and is intended to serve 415 000 people. The plant will provide primary treatment although preliminary studies have been made into feasibility and costs for added secondary treatment in the future. When the new plant is in operation, the existing plant will become redundant, except for the sludge digestion facilities which will be enlarged and continued in service.

With enlargement of the plant to handle higher rates of wastewater flow, the hydraulic capacity of the existing outfall to the Sound will be reached and an additional outfall will be needed. Selection of its capacity and discharge point will involve consideration of (i) the range of treatment processes and outfall options available to the MWSS&DB, and (ii) their environmental and financial implications.

**Point Peron Treatment Plant (PPTP).** The plant, located on Cape Peron just west of the Garden Island Causeway (Figure 4.1), has an estimated contributory population of about 5500 persons and an average daily flow of about 1 ML/d at present. Its design capacity is reported to be 1.4 ML/d from a contributory population of 7000 persons. The plant uses a form of biological treatment known as extended aeration. Effluent is discharged from a pipeline extending about 500 m seaward from Cape Peron.

Present plans for the MWSS&DB call for replacing the existing plant in 1982-83 with one providing conventional activated sludge treatment. The initial design capacity would be 5.5 ML/d capable of enlargement to an ultimate capacity of 20 ML/d from a contributory population of 120 000 persons.

### 4.2.5 State Energy Commission Power Stations (SEC).

The State Energy Commission operates three power stations in the metropolitan area: South Fremantle, Kwinana, and East Perth. The two of interest to the Cockburn Sound Study are South Fremantle which is south of WAME on the foreshore of Owen Anchorage, and Kwinana which is located just south of the Alcoa alumina refinery.

The South Fremantle Power Station was commissioned in 1951 and presently has a capacity (based on coal firing) of 100 MW. It was designed to burn coal but was converted to oil firing for some years prior to oil price rises in October 1973. Following this it was converted back to coal firing. The station presently generates on an immediate demand basis and in 1977-78 generated at an average of 60 MW which is consistent with immediate load operation.

The Kwinana Power Station was intended to be a major base load station operating on oil. The initial capacity of four 120 MW oil fired units was installed during the 1970 to 1973 period. These were to be followed by two 200 MW oil fired units. The first of the 200 MW units was installed as an oil fired unit and came into operation in April 1976. However, because of the changes in oil prices after October 1973 it was evident that oil firing was not an economic means of providing base load capacity. The Commission obtained Government approval in October 1975 to convert both 200 MW units to coal firing which was an economic means of providing base load. The actual generating capacity on coal is limited to 120 MW for each unit but 200 MW is available on oil firing and these two units still have the capacity to use oil. The station has an overall capacity of 720 MW on a coal/oil mixture or 880 MW on oil alone. There are no present plans to convert the first four units to coal firing.

Since completion of the conversion to coal firing at the Kwinana station, both power stations are similar in terms of water use and disposal. At maximum load, about 1000 ML/d of seawater is used for cooling purposes at Kwinana but a lower volume at South Fremantle would be consistent with its lower electricity output. Temperature rises between influent and effluent up to a maximum of about 11.5°C occur at peak loads at Kwinana, but the average is lower. This represents a substantial thermal input to the Sound the effect of which is localised. A comparatively minor amount of bore water is used at both stations to transport ash off-site. Furnace ash is transported for on-site disposal by bore water at Kwinana and by seawater at South Fremantle.

### 4.3 FISH RESOURCES AND PRODUCTION

Cockburn Sound has long been thought to be an important area of fish production near to metropolitan Perth not only in terms of the fish caught by commercial and recreational interests, but also as a protected embayment that many marine species depended upon at some time during their life cycles. However, the value of the Cockburn Sound ecosystem in contributing directly or indirectly to harvestable resources from the sea has never been well quantified. The fisheries segment of the Study, therefore, was directed towards making an assessment of the present and potential production for professional and amateur fishermen.

Much of the information presented below has been taken from the Technical Report[2] which may be referred to for detailed data.

#### 4.3.1 Objectives of the Study

Briefly, the objectives of the study were as follows:

1. To document present production in terms of catches taken by both commercial fishermen and those fishing for recreation;
2. To assess potential production, including resources not yet utilised;
3. To investigate Cockburn Sound's role as a breeding and nursery area for species fished either in the Sound or taken in adjacent waters;
4. To advise on the effects of changing habitats in the Sound.

The results of the study with respect to each of these four objectives are given in the following sections.

#### 4.3.2 Present Production

Commercial catch return statistics compiled by the Australian Bureau of Statistics provided the main source of information on the utilisation of the Sound's resources by professional fishermen. A creel survey of amateur fishermen interviewed as they returned to boat ramps within the Sound was carried out and an estimate was made of their total fish catch.

Historically, Cockburn Sound has been a major commercial fishing area from which much of the fresh fish for the metropolitan area has been caught. During the last financial year (1977-78) the Bureau of Statistics listed 28 full-time commercial fishermen as having operated in the Sound; 20 of these were principally concerned with catching bait fish (for angling and the rock lobster fishery), while most of the catches of the remaining eight contributed to the fresh food fish market of the metropolitan area.

Techniques most commonly used at present include beach seine or haul net (species such as mullet, Perth herring, sandy sprat), purse seine (pilchards, scaly mackerel), mesh net (crabs, shark, Australian herring, tailor, etc.) and line (snapper, mulloway). Dredging is also permitted for the capture of scallops. In the past some trawling was practised. However, this has been banned since 1970. Since the professional fishery catch within the Sound has not been documented prior to this study, comparisons cannot be made with the present catch figures.

A total of 29 species, having a total live weight of over 760 t, was caught commercially in Cockburn Sound during the year 1977-78. The five principal species, in order of weight caught, were scaly mackerel, mussels, pilchards, Perth herring and blue manna crabs. These accounted for 95 per cent of the total estimated income earnings of about $500 000 by professional fishermen from Cockburn Sound during the year 1977-78.

Other species which are caught in relatively small numbers, are still important because the professional fishery in Cockburn Sound is predominantly a multispecies and multimethod fishery. The reason for this is economic. In order to make a reasonable living, fishermen have to use a variety of fishing methods directed at a variety of species. Thus, some of the species, for example snapper, mullet, mulloway and sharks, are important in terms of the yearly operations of some fishermen, for they provide income when other species such as bait fish are unavailable.

Information from the creel survey and interviews at boat ramps was summarised using a computer programme to give monthly totals of both weekday and weekend fish catches. The six most important fish species to amateur fishermen were found to be blue manna crab, Australian herring, whiting spp., skipjack, garfish and yellowtail scad. The projected weight of crabs and fish caught during 1978 by amateur fishermen amounted to nearly 120 t and 210 t, respectively. The professional fishermen's catch of these species during the same period totalled only about 3 t or 1.5 per cent of the amateur fishermen's catch. This clearly illustrates that the species caught by amateurs differ considerably from those sought by professional fishermen.

### 4.3.3 Potential Production

At the present time when many of Australia's fisheries are being exploited at near optimum sustainable yields, and as the human population continues to expand, methods of increasing fish production need to be developed. Increases in production have traditionally come from areas or species that previously have been under-exploited. Historically, Cockburn Sound has been fished since the start of the colony leaving no unexploited areas. Thus the best approach today may be directed toward species presently under-utilised.

Plate 8. The blue manna crab, the species caught in greatest numbers by amateur fishermen in Cockburn Sound.

The Development Research Section of the Department of Fisheries and Wildlife currently is investigating the future potential of several species in Cockburn Sound which are not yet being fished or are being lightly exploited at present. A number of species are being considered for increased production or "aquaculture". Of these, the edible mussel *(Mytilus edulis)* is one of the most promising since it normally is found in seagrass beds within the Sound and as many as six spawnings per year have been recorded. However, as noted later in sections 7.1.4 and 7.3.2, mussels accumulate high body tissue levels of contaminants including heavy metals and bacteria, and this may threaten present and future utilisation. Scallops and prawns may also have a potential for increased production.

In summary, it would appear that improvements in water quality, particularly of constituents such as heavy metals, petroleum-derived hydrocarbons, and micro-organisms, need to be made, or at least assured before specific actions can be taken to increase production of the above species.

### 4.3.4 Marine Faunal Resources

An inventory of marine faunal reserves was carried out to assess the Sound's role as a breeding and nursery area.

Since 1971, the deep waters of the northern portion of the Cockburn Sound basin have been used by the Fisheries Research Branch of the Department of Fisheries and Wildlife for king prawn research. Significant catches of crabs, prawns and fish taken from this research area during night trawling operations have indicated that this area is a more important fish and crab habitat than was previously thought.

During the present study a number of conventional fishing techniques were used to collect specimens for identification and measurement. Techniques included (i) a large trawl net, (ii) a small trawl net, (iii) a beach seine, and (iv) four 50 m long set nets. A professional fisherman was employed to use a larger set net.

Sampling with these methods was carried out on a bi-monthly basis during the year 1977.

A total of just over 200 000 individuals representing 144 different species was counted and identified during the survey. A check list of these species and their common names is given in Appendix 3 of the Technical Report. Of the 144 species, 73 fish species and 8 invertebrate species of commercial and recreational fishing interest were collected.

A given species may utilise the Sound (i) as a permanent breeding and nursery habitat, (ii) as a nursery habitat for juveniles, or (iii) as an occasional feeding area for maturing and mature adults. During the faunal survey, species representing each of these categories were collected.

### 4.3.5 Effects of Changing Habitat

Of the many human activities which are likely to change habitats and affect the shellfish populations in Cockburn Sound, the most important ones are (i) dredging and filling, (ii) the process of building structures such as jetties, shipping berths and the causeway, and (iii) the continuation of present wastewater practices which, as discussed earlier in this chapter, have lead to increased evidence of degradation such as contamination, eutrophication, and loss of seagrass meadows.

The dependence upon specific habitats by the different life cycle stages of many species means that disturbances to any of these habitats will probably affect the population parameters of the species. As far as is known, however, no detailed study in the past has documented fish species characteristic of specific habitats within Cockburn Sound, thereby making it impossible to compare them with the present species composition or to draw conclusions concerning the effects of habitat changes during the intervening period.

However, during the 12-month survey, comparisons of species found in seagrass and sandy substrate habitats have shown that the species which prefer the seagrass habitat are of limited direct benefit to commercial and recreational fishing interests.

### 4.3.6 Recommendations

The principal recommendations emerging from the fish production study are as follows:

1. The commercial fishery should continue to be monitored, so that any significant changes in catch rates of different species can be detected. In addition, the amateur fishery which services most of the metropolitan area should be monitored at three to five-year intervals.
2. The effects of changing habitats should be examined again in about five years' time to obtain data for comparison with that collected during this study and to draw conclusions concerning effects of habitat changes during the period.
3. The management programme for Cockburn Sound should be directed towards eradication of contamination of mussels *(Mytilus edulis)* by bacteria and heavy metals so that this presently underutilised resource may be exploited. There is some evidence that petroleum-derived hydrocarbons may be finding their way into fish and mussels, but this may be a localised problem. This requires further investigation.

**TABLE 4.1 SHORELINE CHARACTERISTICS**

| Area | Shore length, kilometres | | | |
|---|---|---|---|---|
| | Beach | | Other[b] | Total |
| | Rec. use[a] | Total | | |
| Owen Anchorage | 2.7 | 6.2 | 3.2 | 9.4 |
| Cockburn Sound (mainland) | 10.7 | 15.5 | 5.4 | 20.9 |
| Mainland Shore | 13.4 | 21.7 | 8.6 | 30.3 |
| Garden Island | 0 | 19.5 | 5.6 | 25.1 |
| Grand Total | 13.4 | 41.2 | 14.2 | 55.4 |

[a]Available and suitable for intensive recreational use; see text for definitions.

[b]Includes Government and private property as well as rocky foreshores not suitable or accessible for intensive recreational use.

**TABLE 4.2 MAJOR INDUSTRIES AND OTHER WASTEWATER PRODUCING INSTALLATIONS IN THE STUDY AREA**

| Name | Principal activity |
|---|---|
| **Kwinana Industrial Area** | |
| Alcoa of Australia (W.A.) Ltd. | Alumina refining |
| Australian Iron and Steel Pty. Ltd. | Steel rolling mill and blast furnace |
| BP Refinery (Kwinana) Pty. Ltd. | Oil refining |
| Kwinana Nitrogen Company Pty. Ltd. | Nitrogenous fertiliser manufacturing |
| CSBP & Farmers Ltd. | Phosphatic fertiliser manufacturing |
| Western Mining Corporation Ltd. | Nickel and other metal refining |
| **Cockburn Road Special Industrial Area** | |
| Western Australian Meat Export Commission | Cattle and sheep slaughtering |
| Anchorage Butchers Pty. Ltd. | Cattle and sheep slaughtering |
| Watsons Foods Pty. Ltd. | Pig slaughtering |
| N. Shilkin and Son Pty. Ltd. | Hide tanning and dyeing |
| Eagle West Pty. Ltd. | Preparing sheepskins for export |
| Eagle Wools Pty. Ltd. | Sheepskin tanning |
| Coogee Fellmongers Pty. Ltd. | Recovering wool from sheepskins |
| Crayboats Pty. Ltd. | Prawn and lobster processing |
| McGilvrays Tannery | Hide tanning and dyeing |
| **Wastewater Treatment Plants** | |
| Woodman Point | Wastewater treatment |
| Point Peron | Wastewater treatment |
| **Power Stations** | |
| Kwinana | Electric power generation |
| South Fremantle | Electric power generation |

# CHAPTER 5

# URBAN AND INDUSTRIAL EFFLUENTS

Urban and industrial effluents can reach the Sound either by direct discharge or with groundwater which ultimately flows into the Sound. Section 5.1 summarises the activities of the effluent segment[6] of the study which dealt primarily with direct discharges to the Sound. Section 5.2 is drawn from the report[8] of consultants commissioned to study aspects of groundwater which were of particular relevance to the Cockburn Sound Study. Technical reports on each subject can be referred to for details and other information not given herein.

## 5.1 EFFLUENT SEGMENT

As described in Chapter 1, the responsibility for this segment was assigned to the Department of Industrial Development. The technical report[6] presents comprehensive coverage of wastewater flows and characteristics of urban and industrial effluents along with detailed descriptions of the industrial processes, wastewater treatment facilities, and possible in-plant actions which could reduce the amount of specific pollutants being discharged to the Sound. Since completion of the field and laboratory work in 1978, various process changes and variations in production rates have occurred. Although major process and treatment changes are noted in the text, the values given for loadings of various constituents must be regarded as indicative of present conditions (late 1979) rather than as precise measurements.

### 5.1.1 Objectives

The broad objectives for the effluent segment were:

1. To identify sources of man-made inputs to the Sound by direct discharge, spillage or groundwater contamination;
2. To plot the various effluent streams within industrial plants, the cross linkages of these streams, both within and between different plants, and to locate all discharge points in and around the Sound;
3. To record quantities, physical characteristics, and chemical composition of inputs including variability of rates of discharge;
4. To recommend means of reducing or eliminating discharges of effluent components causing or likely to cause environmental changes.

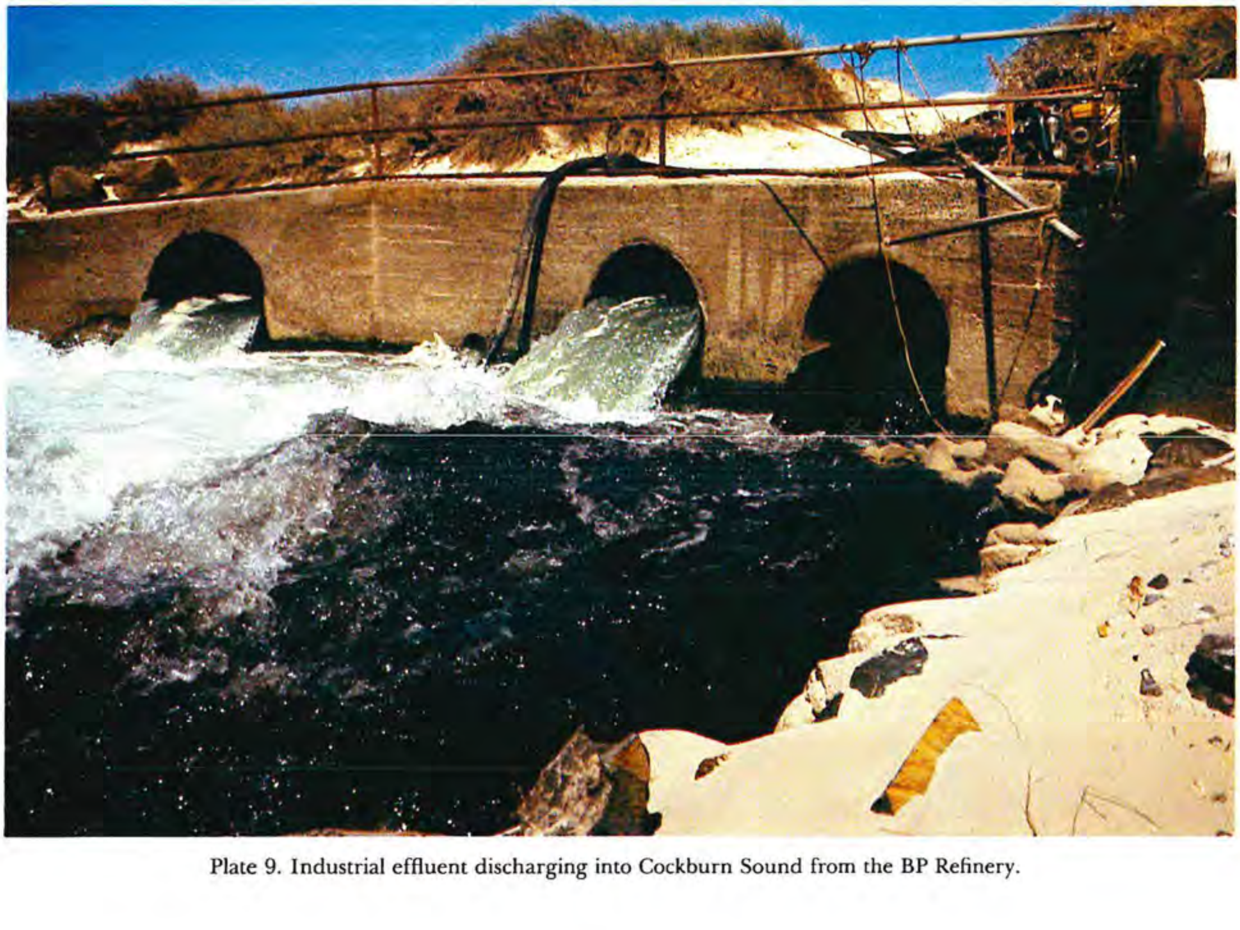


Plate 9. Industrial effluent discharging into Cockburn Sound from the BP Refinery.

### 5.1.2 Study Programme

Industries and government utilities discharging wastewater to Cockburn Sound and Owen Anchorage were identified through the distribution of questionnaires to industries in the Kwinana Industrial Area and the Cockburn Road Special Industrial Area. The location of these areas is shown in Figure 5.1. Intensive wastewater sampling programmes were undertaken at the industries identified as having direct discharges to the Sound or Anchorage. A wide range of analyses and physical measurements was made, average figures were derived for each industry and total loads for various components entering the Sound in the discharges were calculated. The major wastewater sources for each component were identified and, where possible, the source or sources within the industry determined. Some consideration was given to means of removing or reducing the individual inputs of components to the wastewater and this is referred to at appropriate places elsewhere in this report.

**Collection of Basic Information.** Following a Ministerial letter and officer level visits to industries in the Kwinana Industrial Area, a questionnaire was drawn up and sent to all of the industries. This was designed to obtain information regarding plant practices with respect to wastewater generation and treatment. The industry replies were studied and those with direct wastewater discharges to the Sound identified. A second questionnaire aimed at supplementing information obtained in the first regarding land disposal of wastewaters and groundwater use by industry was sent to the same industries, and a summary was prepared on the ground disposal situation based on the industry questionnaire responses, site inspections and the further information supplied by industries. This information was used in the study of effects of effluents on groundwater.[8]

Information obtained in the Cockburn Road Special Industrial Area in a 1971 questionnaire survey was updated by a new questionnaire. Industry replies were studied and industries with direct discharges to Owen Anchorage were identified. At the same time information on land disposal and groundwater use was obtained in Owen Anchorage.

Information on the Woodman Point and Point Peron Wastewater Treatment Plants was provided by the Metropolitan Water Supply, Sewerage and Drainage Board (MWSS&DB), and that for the Kwinana and South Fremantle power stations was obtained from the State Energy Commission (SEC).

**Sampling Locations.** Sampling locations at each industry discharging directly to the Sound and Owen Anchorage were selected during site visits to locate all discharge points. The outfall and water intake locations are shown in Figures 5.2 and 5.3.

**Sampling Programme.** Several types of sampling were carried out during the study. During periods of intensive grab sampling, carried out in June, July and October of 1977, and in January-February and July of 1978, each industry in the Kwinana Industrial Area was sampled on at least three separate occasions totalling at least 21 days of grab sampling at each industry.

Continuous sampling with an automatic sampler was carried out during the January-February 1978 period at the Woodman Point Wastewater Treatment Plant (WPTP) and at CSBP.

Effluent at WPTP and the Kwinana power station intake and outfall were sampled during only one of the periods since the water quality was expected to be reasonably constant.

In addition to the intensive sampling programme, a restricted programme of grab sampling was undertaken to provide information on levels of certain components outside these periods. The results from these samples provide a guide to the reliability of extrapolating intensive period levels and loads outside those particular periods. To a certain extent they also provide a guide to the variability of the particular wastewater, a result not available from the intensive sampling periods.

After the July 1978 sampling period, the BP Refinery carried out an expansion programme that included a new outfall (BP No. 1) and extra treatment facilities. To provide information on these changes wastewater samples were taken in March 1979 and analysed for selected components.

On some occasions it was convenient to make use of samples collected by industry on its own behalf and on request by the Study Group. Bulk samples of phosphate rock, gypsum, sulphuric acid and phosphoric acid were made available from the routine samples collected by CSBP. The SEC arranged for sample collection from the SEC Kwinana power station seawater intake and outfall during the July 1978 sampling programme. BP Refinery and AIS collected grab samples for the Study Group in March 1978.

No sampling was undertaken at the Point Peron Wastewater Treatment Plant (PPTP) as sufficient information was available from MWSS&DB analysis of the wastewater. The South Fremantle Power Station wastewater was not sampled because information supplied by the SEC indicated very close similarities in operation of the two stations. The assumption was made, therefore, that the water quality would be similar to that discharged by the SEC Kwinana station.

Since most industries in the Cockburn Road Special Industrial Area discharge to ocean outfalls, samples were collected as close to the entry point of the particular pipeline as possible and always at a point downstream of any treatment facilities. Wastewaters were sampled over a four-week period in February-March 1978 and each wastewater was sampled over at least four working days.

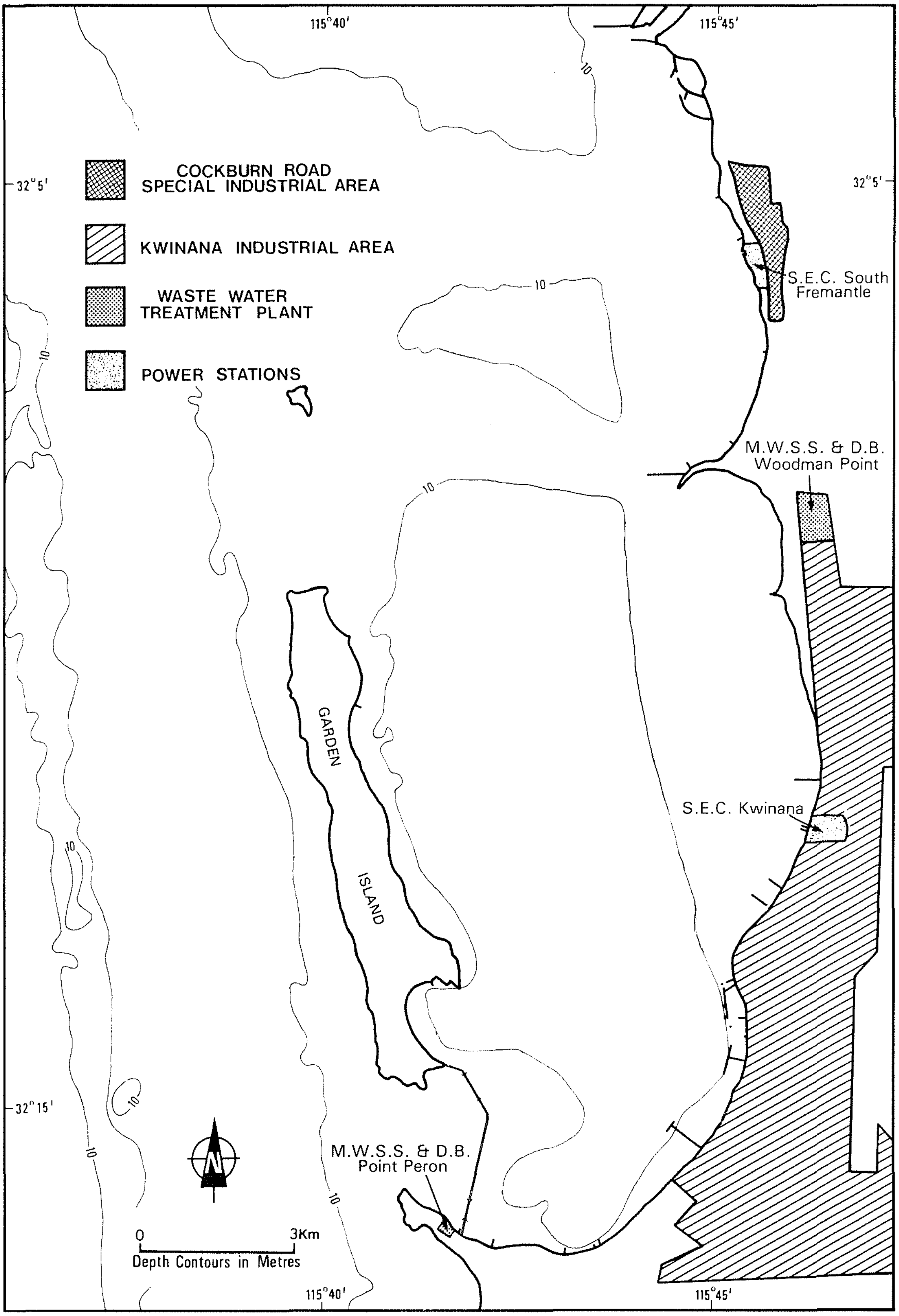



FIGURE 5.1. Location of Cockburn Road and Kwinana Industrial Areas.

**Sample Storage Preservation and Methods of Analysis.** In the planning stages of the study, techniques of storage and preservation were developed and used during the sampling programmes. Effective techniques are important because most substances being analysed are present in minute traces and results could be grossly in error without proper care in collection, storage and analysis. Analytical techniques were checked frequently between participating laboratories, including those operated by several industries, to ensure accuracy, reliability and reproducibility. Details of these activities are contained in the technical report.

### 5.1.3 Major Findings

This section presents the major findings of the effluent segment. Loadings were calculated for various substances using concentrations and wastewater flows recorded during the relevant sampling periods. Table 5.1 lists the flows and loadings from major industries in the Kwinana Industrial Area and from groups of industries in the Cockburn Road Special Industrial Area. At the top of each column, references are given to tables in the technical report so that they can be referred to if more detailed information is desired.

Findings for the following substances or groups of substances discharged to the Sound are discussed below: (i) metals, (ii) nitrogen and phosphorus, (iii) other chemicals, and (iv) pH and temperature. A brief discussion of results from industries discharging to Owen Anchorage from the Cockburn Road Special Industrial Area concludes this section.

Except where noted, inputs are expressed as "incremental" loads. These loads were calculated by subtracting the concentration of a given constituent in the incoming source of water (seawater, bore water, scheme water) from the analysed concentration of the wastewater.

It should be emphasised that the results are based on work during the period June 1977 to July 1978 and, therefore, can provide only a guide to wastewater quality outside that period. Sufficient grab samples were analysed to indicate that the results were reasonably representative of the wastewaters discharged over the period March 1977 to May 1979. Major process or treatment changes are noted in the text where they have a substantial bearing on the nature of loadings to the Sound.

The BP total wastewater results were calculated from the BP North, Centre and South outfall wastewaters results, and were properly weighed to allow for the differing volumes. This combined wastewater represents the field situation where these three streams have ample opportunity to mix before discharging to the Sound waters.

The contributions from the BP Refinery wastewater treatment units that provide the flow to the three outfalls were obtained by calculation. This was necessary to determine the sources of observed outfall wastewater concentrations and loads.

The CSBP outlet pipe wastewater results from the mixing of (i) CSBP wastewaters and waste gypsum (from phosphoric acid manufacture), (ii) saltwater used for cooling and condensing purposes at the Kwinana Nitrogen Company (KNC), and (iii) process wastewater flows from KNC. The designation of "CSBP pipe" indicates only the discharge situation. The concentrations and loads of components in the wastewater may be from a number of sources not all of which are within the CSBP works.

**Metals.** It is evident from Table 5.1 that the CSBP outlet (discharging materials from CSBP and KNC) is the major source of cadmium (4.3 kg/d), a substantial source of cobalt, chromium, iron, zinc and mercury, and a lesser source of copper, nickel, lead and arsenic. The wastewater discharged to the Sound waters is made up of four major sources:

- general CSBP plant water usage
- gypsum produced by the phosphoric acid plant
- process water from KNC
- seawater used for cooling from KNC

The waste gypsum is the major source for all metals except zinc which comes from the rest of the CSBP plant and the used seawater from KNC. The zinc in the KNC used seawater is from zinc anodes used for the protection of the cooling system against corrosion and the copper is probably background. There is no substantial contribution to the metal load from the KNC process waters despite the comparatively high concentrations for some metals in the wastewater discharged to the CSBP pipeline.

The BP Refinery discharges also contain substantial inputs of metals. Wastewater from the circular separators handling saltwater used for general refinery cooling water purposes, is the major contributor of most metals in the final discharges from the refinery. Sources within the refinery are believed to be as follows:

- Chromium—no obvious source.
- Copper—the major source of this metal appears to be the sweetening units where copper chloride is used to react with mercaptans in the lower boiling point crude oil fractions. The copper chloride is adsorbed onto a clay substrate of which a small amount is carried over with the sweetened product.

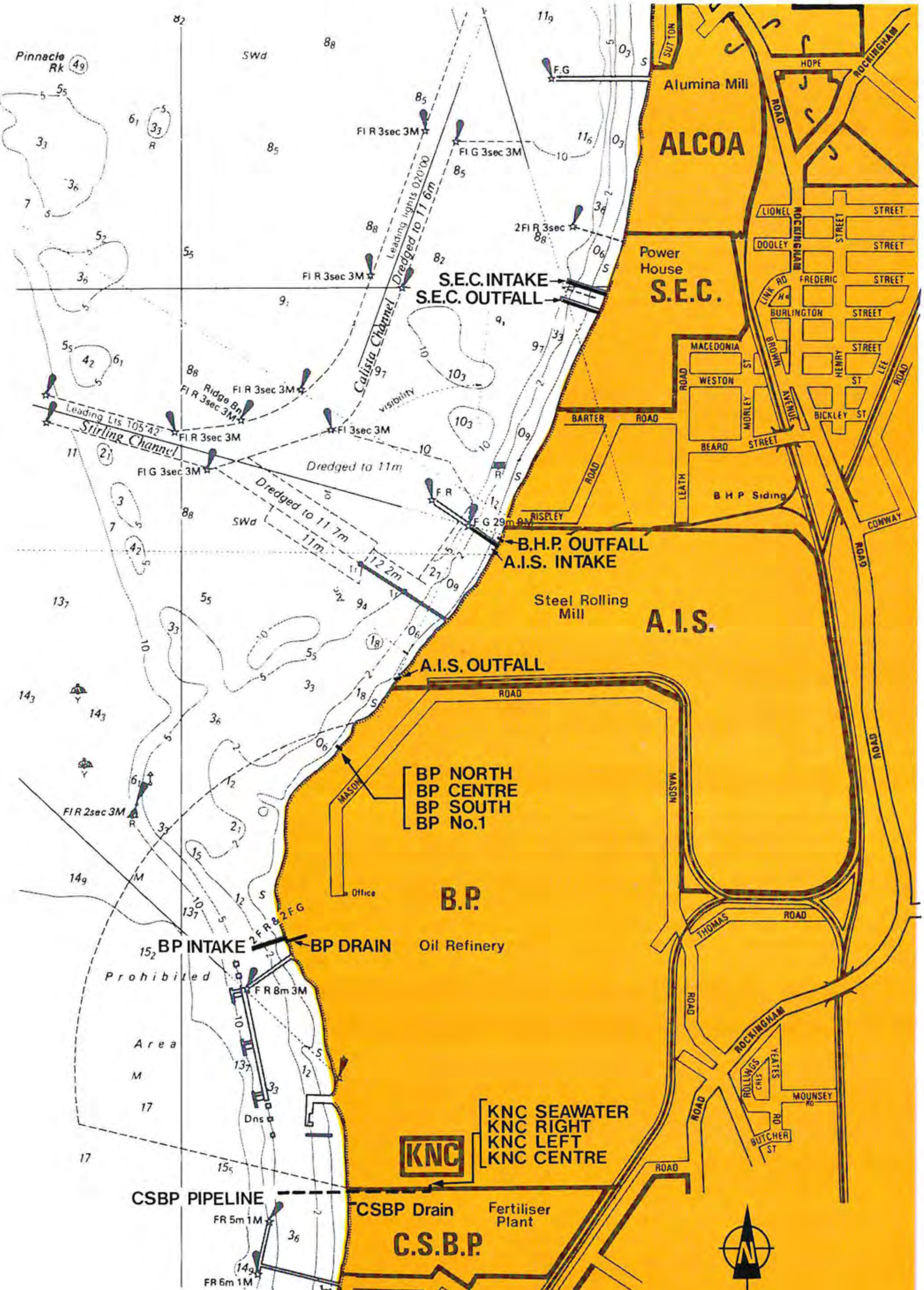



**FIGURE 5.2.** Seawater intake and wastewater discharge points for industries in the Kwinana Industrial Area.

The product is water washed and traces of copper appear in the particulate fraction from the API No. 1 overflow.

- Iron—the major source appears to be tankship ballast water that is bled from onshore reception tanks into the circular separators.
- Nickel—there is no obvious process source but it may be due to some corrosion products or to traces associated with crude oil.
- Lead—there is no obvious process source, but it may be due to leaded motor spirit washings coming ashore with tankship ballast.
- Zinc—the refinery uses zinc anodes to protect the cooling circuits from corrosion and it appears that the zinc in the wastewater discharge is from the zinc anodes.
- Arsenic—there is no obvious process source for this metal, but it may be from the crude oil.
- Vanadium—there is no obvious process source but vanadium is also present in crude oil and becomes concentrated in the heavy residual oil fractions.

The WPTP is a major contributor of cobalt, chromium, copper, lead and mercury. The sewage flow to the treatment plant is made up of domestic (88 per cent by volume) and industrial (12 per cent) wastewaters. From a comparison of the wastewater quality arriving at the WPTP and PPTP (with no industrial input) it is evident that industrial wastewater is the major source of chromium, copper, lead and mercury.

The primary treatment at WPTP apparently reduces the metal concentrations by about 30 to 40 per cent compared to the incoming sewage concentrations. The "lost" material probably is separated with the sludge, although no sludge analyses were made for metals.

**Nitrogen and Phosphorus.** Table 5.1 shows that nitrogen compounds discharged to the Sound total about 5000 kg/d as nitrogen. Total nitrogen and ammonia discharges are mainly from the following sources: CSBP pipeline (about 3100 kg/d and 2400 kg/d), WPTP (about 1400 kg/d and 1100 kg/d) and the BP Refinery (about 320 kg/d and 270 kg/d). The CSBP pipeline input is mainly (90 per cent plus) from process water from KNC with a minor input from CSBP (350 kg/d and 250 kg/d).

Phosphorus loads to the Sound total about 3800 kg/d. The two principal sources are CSBP (about 3300 kg/d) and WPTP (about 260 kg/d.) The SEC Kwinana loading is attributable to the fact that although differences in concentrations between influent and effluent are small, but within the accuracy of the analyses, the discharge volume is large (1000 ML/d).

Since completion of the intensive sampling programme, the BP Refinery has installed a "sour water" stripper as part of a major expansion to its catalytic cracker facility. This is designed to remove ammonia and hydrogen sulphide (90 per cent and 99 per cent, respectively). Some removal of phenols (30 per cent) is also achieved in the stripper. Wastewater samples were taken to establish the effect of the "sour water" stripper on ammonia levels in the BP Centre and BP South outfall wastewaters. The BP North wastewater was not affected as none of the water flowing to that outfall was treated in the stripper. The results of the analyses show that the ammonia concentration in the BP Centre wastewater is reduced by the stripper from 3.6 mg/L to 0.04 mg/L, a removal efficiency of 99 per cent. In terms of actual loads to the Sound, the stripper removes about 260 kg/d of ammonia as nitrogen, and the total nitrogen load for the BP Refinery in Table 5.1 would be reduced to about 60 kg/d, assuming no change in other factors which affected loadings during the intensive sampling period and adjustments made to obtain loadings during "normal" operation.

**Other Chemical Substances.** Table 5.1 lists the calculated loadings for a number of other substances found in discharges from various industries. Substances of principal concern are petroleum hydrocarbons from the BP Refinery, sulphides from WPTP and BP Refinery, and soluble fluoride from CSBP. The term "petroleum hydrocarbons" includes organic compounds from oil refining including aromatic and phenolic compounds. As noted above the "sour water" stripper at BP removes hydrogen sulphide.

Analyses of samples from waste streams in the refinery showed that wastewater from the API No. 2 unit and from the circular separator contribute about two-thirds of the petroleum hydrocarbons loading of 1000 kg/d as measured by the BP Refinery using an infra-red method of analysis. The gas chromatographic work carried out by the segment analysts revealed the presence of aromatic compounds in petroleum hydrocarbons in the flow from the API No. 1 wastewater flow. The load of these compounds accounted for only about 45 kg/d of the estimated 230 kg/d of petroleum hydrocarbons. Despite this small amount any input of aromatics is of concern because of their known detrimental effects at low concentrations as recorded in the literature.

Sulphide loadings* to the Sound total about 900 kg/d and are discharged from the BP refinery (about 600 kg/d) and from WPTP (300 kg/d estimated annual average). Sulphides are rapidly oxidised in seawater, and unless sufficient mixing with seawater takes place, depletions can occur in dissolved oxygen concentrations. This situation produces a local, rather than regional, effect.

The soluble fluoride load of about 6000 kg/d in the CSBP discharge with a concentration of 75 mg/L

* As determined by methylene blue method for water and wastewater.

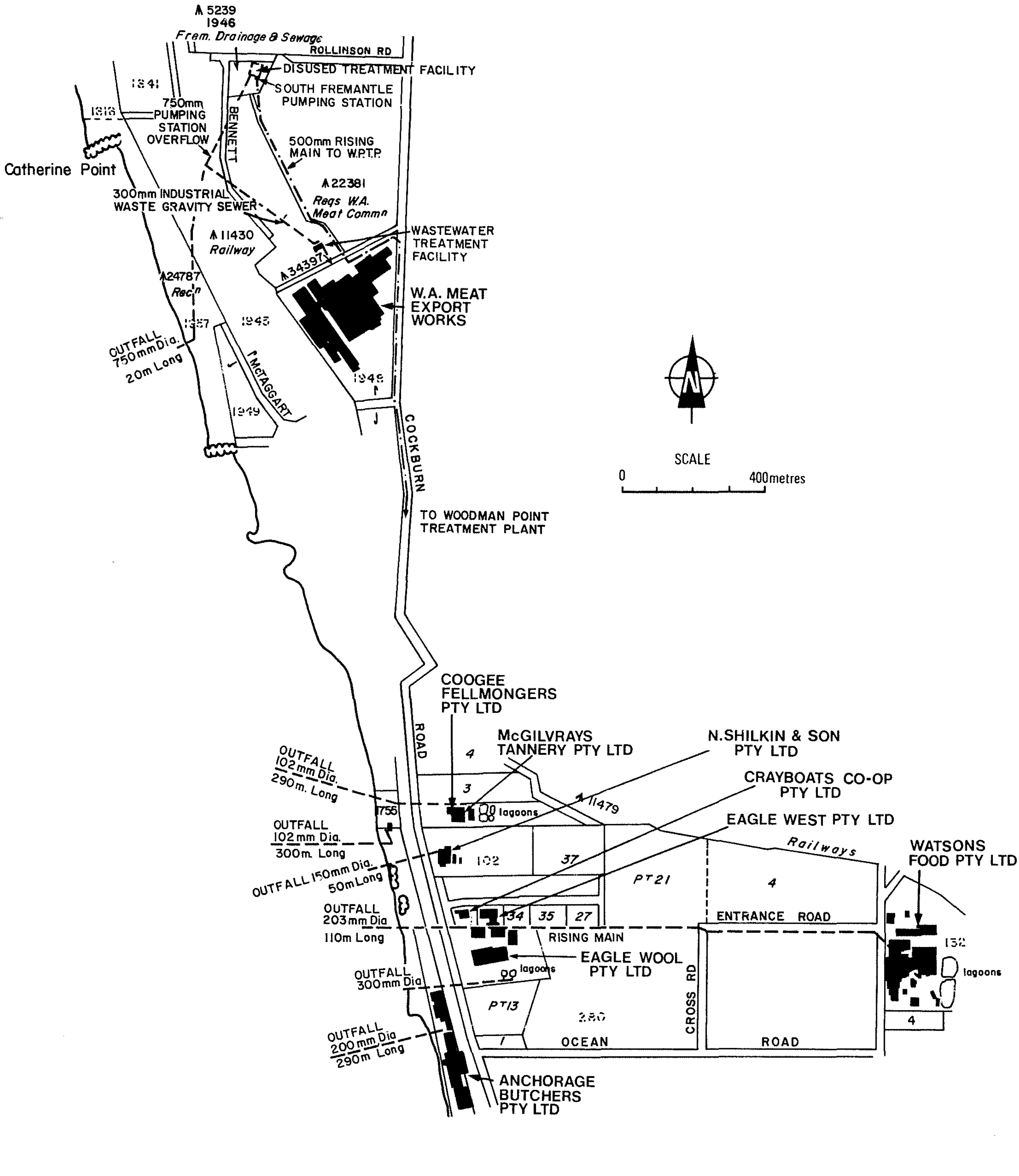



FIGURE 5.3. Wastewater discharge points for industries in the Cockburn Road Special Industrial Area.

is derived from the phosphate rock used at the plant. There may also be some insoluble fluoride load in the form of calcium fluoride but this was not covered by the analyses. Fluoride is of concern because of its toxic effects on biota.

**pH and Temperature.** The only discharge to the Sound whose pH is of concern from a water quality standpoint came from CSBP. The wastewater pH ranged between 2.5 and 3.5 because of the presence of acids, particularly phosphoric acid and sulphuric acid.

Temperatures of discharges to the Sound were found to vary from 17.9°C for SEC to 32.0°C for CSBP. In terms of thermal input, the discharges to the Sound contribute a total of 530 MW/h coming mostly from SEC (43 per cent) and BP Refinery (30 per cent).

**Cockburn Road Special Industrial Area.** Table 5.1 shows that industries in this area discharge wastewaters having a total volume of 4.0 ML/d. The Western Australian Meat Export Commission (WAME) abattoir is the principal discharger in terms of volume (2.2 ML/d), $BOD_5$ (5450 kg/d), COD (7700 kg/d), suspended solids (3600 kg/d), grease and oil (1120 kg/d), nitrogen (310 kg/d) and phosphorus (71 kg/d). The group of hide processing plants accounts for inputs of chromium (21.7 kg/d) and of copper, zinc and arsenic.

It is interesting to note that the total $BOD_5$ (8950 kg/d) is similar to the loading contained in the primary effluent discharged by the Woodman Point plant (8900 kg/d). For suspended solids and for oil and grease, the industrial input is substantially in excess of that from the treatment plant.

### 5.1.4 Principal Conclusions

The report on this segment of the Cockburn Sound Study[6] contains a number of conclusions and comments developed during the course of the study of effluent inputs. The more important are summarised below.

- Although coverage of some components is incomplete, it is considered that the major sources are identified adequately by the results. Thus any further analytical work should be directed toward components known or suspected of having adverse environmental effects.
- Data developed in the study of effluent inputs represent a limited period in the activities of the industries sampled. It must be recognised that process and production changes can substantially alter loadings.

For example, the BP Refinery has commissioned a "sour water" stripper which has reduced the ammonia load to the Sound. In addition, KNC anticipates implementing process improvements to prevent valuable nitrogen compounds from being lost. These will involve attention to the process dynamics of ammonia and nitric acid reaction, the use of less free ammonia in the ammonium nitrate product and the use of water containing ammonium nitrate in the nitric acid manufacturing process. Looking ahead, CSBP plans to construct a new phosphoric acid plant which will have significantly lower inputs of phosphorus and cadmium than those from the present plant; CSBP also has proposed a doubling and eventual tripling of plant capacity along with land disposal of waste gypsum with the resulting elimination of phosphorus, cadmium, fluoride and other direct inputs to the Sound from this source.

The effects of some of these actions on loads to the Sound are indicated by footnotes in Table 5.1 and they are discussed in detail in Chapter 9 of this report.

- The influence of rainfall runoff on competition and total loadings was not covered during the study. At AIS, BP Refinery and CSBP, runoff from sealed areas is directed to the Sound. Only at BP Refinery is there any treatment of this flow. Because the summers are usually dry, the first heavy winter rainfall runoff could carry significant loads of constituents having adverse effects on the Sound. A special purpose sampling programme such as this would be valuable in extending knowledge of inputs.

## 5.2 GROUNDWATER STUDY

Indirect effluent inputs to Cockburn Sound may result from accidental discharge or spillage of effluents, process liquors or chemicals onto the land surrounding the Sound. If this occurs in an unsealed area, contaminants infiltrate into the subsurface and enter the shallow groundwater system. Thus industry, and possibly many market gardeners and private landholders, may be contributing a diverse and complex variety of contaminants to the shallow groundwater which ultimately discharges into Cockburn Sound. Layton Groundwater Consultants were commissioned to study and report upon the aspects of particular relevance to the Cockburn Sound Study. This section has drawn extensively from the consultant's report.[8]

### 5.2.1 Objectives

The groundwater study had the following objectives:

1. To define the groundwater system into which the effluents, process liquors and/or chemicals migrate;
2. To describe the nature of groundwater recharge, discharge, occurrence and movement within this groundwater flow system;
3. To evaluate the chemical quality of the groundwater.

### 5.2.2 Conduct of the Study

In September 1977 a groundwater questionnaire was circulated to industries and Shire Councils within the study area covering the coastal strip of land lying between the shoreline of Cockburn Sound and Rockingham Road (1 to 2 km inland) and extending from South Fremantle to Cape Peron. Thirty industries (including several situated to the east of the study area) and all the Shire and Town Councils (Cockburn, Kwinana and Rockingham) completed and returned the questionnaire. Additional well data was obtained from the Geological Survey of W.A. data files, and a total of 110 wells was catalogued at this time.

Some groundwater contamination was indicated in chemical analyses returned with the groundwater questionnaire. However, chemical analyses of production bore water were inevitably designed to check the suitability of the water for industrial use rather than to detect groundwater contaminants. As about 70 per cent of the wells catalogued were production bores, it was concluded that a groundwater sampling programme was necessary, during which additional information on the location, size and contents of unsealed effluent disposal sites and product stockpiles would be gathered.

A number of fully penetrating groundwater observation bores were drilled between 25 April and 29 October 1978. Where bore sites were situated on industrial land, the industry involved agreed to cover the drilling and construction costs. BP, AIS, CSBP and Western Mining Corporation each covered the costs of these bores on their land. In addition, monitoring bores put down by Alcoa and SEC also were sampled. The Cockburn Sound Study Group was responsible for the drilling and construction costs of the other three bores.

The groundwater sampling programme commenced on 30 May and was completed by December 1978. 67 groundwater production and observation bores were sampled and eight samples of industrial effluent were collected. 213 water samples were submitted for chemical analysis. As many as ten water samples were collected from any one groundwater observation bore in order that variations in water quality with depth might be investigated.

### 5.2.3 Results of the Study

The results of the study are summarised below in terms of the groundwater flow system and groundwater quality.

**Groundwater Flow System.** Groundwater occurs at relatively shallow depths adjacent to Cockburn Sound. Consequently, effluent, process liquors and chemicals which are accidentally spilled onto the ground surface, discharged into ponds or in some instances injected directly to the sub-surface, can readily migrate down into the shallow groundwater system. The base of the shallow groundwater system is marked by older relatively impermeable siltstone and shale at a depth of 25 to 30 metres below sea level, through which contaminants do not pass.

In the northern part of the study area (Owen Anchorage and Jervoise Bay) the aquifer material is cavernous calcareous sandstone and limestone of the Coastal Limestone.

In the southern part (Kwinana and Rockingham) three units are present: (i) the Safety Bay Sand, consisting of fine grained calcareous material and up to 15 m thick; (ii) the Coastal Limestone (10 to 15 m thick); and (iii) the Rockingham Sand, consisting of coarse grained clayey, quartz sand generally less than 10 m thick. There is a marked permeability contrast between the Safety Bay Sand and the Coastal Limestone, also a low permeability silty shell bed (up to 1 m thick) is often present at the base of the Safety Bay Sand.

In the Owen Anchorage-Jervoise Bay area, intentionally discharged or accidentally spilled process liquors, chemicals and effluents tend to accumulate in and migrate through the Coastal Limestone aquifer. At Kwinana they tend to accumulate in and migrate through the Safety Bay Sand aquifer. Downward migration of groundwater and contaminants into the underlying Coastal Limestone is retarded by the clay and shell bed at the base of the Safety Bay Sand. This does not preclude contamination of the Coastal Limestone aquifer as the shell bed is very thin to absent in some areas, but it often results in the levels of contamination being substantially higher in the Safety Bay Sand.

The natural direction of groundwater flow is toward and ultimately into Cockburn Sound. Any contaminants contained in the groundwater will therefore discharge into the Sound along with the groundwater unless first intercepted or immobilised. In the industrial areas, groundwater is withdrawn for a variety of uses. Depending on the rate of use, the withdrawal may represent a substantial fraction of the groundwater available in a particular location.

Where intensive groundwater development is practised, as in parts of Kwinana, the abstraction rate exceeds the natural flow with the result that groundwater flow directions are reversed. Not only are the contaminated groundwaters drawn back to production bores but seawater intrusion is also promoted.

**Groundwater Quality.** Results of the extensive sampling analysis programme showed a wide variety and range of contaminated concentrations in the unconfined aquifer. Hence it is not possible to make meaningful general statements on the overall groundwater quality. In most cases, however, contaminants are highly localised and in most cases the source of the contamination is easily identified.

In the Owen Anchorage and Jervoise Bay areas, most of the industries use or produce relatively small quantities of process liquors, chemicals and effluent. As discussed in Chapter 4, many of the industries have fairly simple wastewater treatment facilities and outfalls through which effluents are piped directly into Cockburn Sound. The industries in these areas are small when compared to some of the industries present in the Kwinana Industrial Area.

Groundwater and effluent flow paths within the Coastal Limestone aquifer may be devious and confined to narrow zones of cavernous relatively porous 'limestone'. This has a significant bearing on the probabaility of production or exploratory bores intersecting contaminated groundwater flow paths. Also most of the industrial and urban groundwater production bores in the northern half of the study area draw water from the shallow zone immediately below the water table. Thus very few data are available on the groundwater quality in the lower half of the Coastal Limestone aquifer in the Owen Anchorage-Jervoise Bay area.

Bacteria, organic nitrogen, chloride and metals, such as chromium, zinc and copper, are the most common contaminants found in the unconfined Coastal Limestone aquifer. These are thought to originate from soak wells, pits (commonly used for the disposal of washdown water) and septic tanks; and from inadvertent seepage from unsealed effluent storage lagoons.

In the Kwinana Industrial Area, groundwater in the Safety Bay Sand beneath the Aloca, BP, Chemical Industries, Commonwealth Industrial Gases, and CSBP plant sites is contaminated with process liquors, chemicals and effluents. Contaminants include ammonia, organic nitrogen, chromium, nickel, aluminium oxide, liquid and dissolved hydrocarbons, phenol, 2,4-D and 2,4,5-T. The Safety Bay Sand and Coastal Limestone beneath and north-west of the Western Mining Corporation nickel refinery are contaminated with process liquors. Contaminants include ammonia, nickel, sulphate and chloride.

Of these industries, Alcoa and BP are actively involved in recovering the contaminated groundwater.

### 5.2.4 Recommended Actions

The consultant's report includes a number of recommendations for corrective actions and these are summarised below.

The recovery of contaminated groundwater through production bores is an effective method of reducing the volume and concentration of contaminants in the shallow aquifers. It is, however, a costly and time-consuming exercise which may be warranted only if the occurrence of the contaminant is very localised. Another limiting factor on contaminant recovery systems is the availability of suitable disposal sites for large volumes of contaminated groundwater.

In some cases, such as Western Mining Corporation, suitable sites for disposal of a moderate volume of recovered groundwater already exist in the form of sealed effluent disposal lagoons. Provided a suitable groundwater monitoring system is installed around these lagoons, leaked effluents may be detected very quickly and efficient recovery systems designed and installed before the effluents become too widely dispersed in the groundwater.

In other cases, such as Alcoa and BP, the contaminated groundwater may be recovered and recycled through industrial processes from which the contaminants originated.

However, many industries in the study area do not operate sealed effluent disposal lagoons and are physically incapable of recycling large quantities of contaminated groundwater. For these industries recovery systems are out of the question.

If the levels of contamination in the groundwater beneath the industrialised foreshore of Cockburn Sound are to be kept within acceptable limits, the quantity and quality of effluent disposed directly to the ground must be controlled and effluent storage and disposal techniques upgraded.

Such measures would ultimately benefit the industrial sector as the majority of industries within the study area rely on the shallow groundwater resources for part or all of their water supply requirements.

Continued monitoring of groundwater quality, water table levels and the position of the salt water/fresh water interface should be carried out in the existing observation bores so that seasonal variations may be identified and contaminant concentrations more accurately defined.

**TABLE 5.1 SUMMARY OF WASTEWATER VOLUMES AND LOADINGS**

| | OWEN ANCHORAGE | | | | COCKBURN SOUND | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WAME | OTHER MEAT | HIDES, ETC. | TOTAL O.A. | WPTP | SEC KWINANA | BHP | AIS | BP TOTAL | KNC[a] | CSBP[a] (Includes KNC) | PPTP | TOTAL C.S. |
| Table reference in Technical Report on Industrial Effluents | 11.8 | 11.8 | 11.8 | – | 3.2, 3.7 3.11 8.4 | 3.2, 3.7 | 3.2, 3.7 3.11 | 3.2, 3.7 3.11 | 3.2, 3.7 3.11 | 3.5 | 3.2, 3.7 3.11 | 8.4 | – |
| Volume, ML/d | 2.2 | 1.5 | 0.3 | 4.0 | 30 | 1000 | 0.5 | 175 | 332 | 65 | 81 | 1.1 | 1620 |
| **Load, Kg/d** | | | | | | | | | | | | | |
| $BOD_5$ | 5450 | 2300 | 1200 | 8950 | 8900 | | | | | | | 25 | 8925 |
| COD | 7700 | 3900 | 3000 | 13700 | | | | | | | | | |
| Susp. Solids | 3600 | 1640 | 960 | 6200 | 4000 | | 4 | 1225 | 261 | | b | 20 | 5510 |
| Grease Solids | 1120 | 670 | 310 | 2100 | 1230 | | | | | | | | |
| MBAS | 0.7 | 2.8 | 0.7 | 4.2 | 320 | | | | 4.3 | | | 0.33 | 325 |
| Phenolics | <0.1 | <0.1 | 1.1 | 1.1 | | | | | 514[c] | | | | 514 |
| Petroleum hydrocarbons | | | | | | | | | 1000 | | | | 1000 |
| Cyanide | <0.1 | <0.1 | <0.1 | <0.1 | | | | | | | | | |
| Ammonia–N | | | | | 1114 | – | 0.2 | 51 | 271[c] | 2100 | 2350 | 0.44 | 3786 |
| Tot. Kjeldahl N[d] | 310 | 190 | 120 | 620 | 1422 | 110 | 0.3 | 49 | 310 | 2160 | 2410 | 2.4 | 4304 |
| $NO_2 + NO_3$ N | | | | | <10 | – | 0.6 | | 4.2 | 565 | 665 | 4.4 | 674 |
| Total N[d] | 310 | 190 | 120 | 620 | 1422 | 110 | 0.9 | 49 | 322[c] | 2725 | 3075 | 6.8 | 4986 |
| Total P | 71 | 34 | 3 | 108 | 261 | 220 | <0.1 | 2 | 7.9 | 47.2 | 3275 | 9.7 | 3776 |
| Sulphides[e] | | | | | 300 (Ann.A) | | | | 592[c] | | | | 892 |
| Cadmium | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | – | <0.1 | – | – | <0.1 | 4.3 | <0.1 | 4.3 |
| Chromium | <0.1 | <0.1 | 21.7 | 21.7 | 2.6 | – | <0.1 | 0.2 | 0.6 | <0.1 | 2.5 | <0.1 | 5.9 |
| Cobalt | | | | | 0.2 | – | <0.1 | – | – | <0.1 | 0.4 | | 0.6 |
| Copper | <0.1 | <0.1 | 0.4 | 0.4 | 2.6 | 2.0 | <0.1 | – | 3.1 | 0.3 | 1.5 | <0.1 | 9.2 |
| Iron | | | | | 10 | 80 | 1 | 200 | 85 | 14.2 | 140 | | 516 |
| Lead | <0.1 | <0.1 | <0.1 | <0.1 | 1.6 | – | <0.1 | 0.5 | 1.3 | <0.1 | 0.35 | <0.1 | 3.8 |
| Mercury | <0.1 | <0.1 | <0.1 | <0.1 | 0.1 | – | <0.1 | 0.1 | <0.1 | <0.1 | 0.1 | <0.1 | 0.3 |
| Molybdenum | | | | | <0.1 | – | <0.1 | – | 0.3 | | | – | 0.3 |
| Nickel | | | | | 0.4 | 3.0 | <0.1 | – | 0.7 | 0.2 | 0.6 | | 4.9 |
| Vanadium | | | | | <0.1 | – | <0.1 | – | 1.8 | | | | 1.8 |
| Zinc | 1.0 | 0.6 | 2.1 | 3.7 | 3.5 | 3.0 | <0.1 | 2.0 | 4.9 | 2.6 | 7.8 | 0.1 | 21.3 |
| Arsenic | <0.1 | <0.1 | 0.3 | 0.3 | 0.3 | – | <0.1 | 0.4 | 1.2 | <0.1 | 0.1 | | 2.0 |
| Fluoride (Sol) | | | | | 24 | – | | | | | 6050 | | 6074 |

**Footnote for Table 5.1**

Blanks in the table mean that the concentration of the constituent was not determined.

In most cases, concentrations of constituents in the waters of the Sound or of bore or scheme water used for industrial purposes have been deducted from the concentrations found in wastewater; thus the loads are "incremental" loads.

Dashes in the table mean that the concentration of the constituent was determined to be the same as in waters of the Sound and, therefore, there was no input of that constituent.

Most loads have been adjusted to reflect normal operating or production levels and are believed genererally representative of conditions during the period March 1977 to May 1979.

[a] KNC wastewater loadings are included with those of CSBP and are estimated averages based on a single sampling period in October 1977.

[b] Approximtely 350 000 kg/d (350 t/d) of gypsum in slurry form is discharged by CSBP in addition to values listed; the ratio between dissolved and particulate gypsum varies with other characteristics of the discharge and with sampling location.

[c] Sampling programme was carried out before the "sour water" stripper commenced operation. The stripper removes about 260 kg/d of ammonia, almost all sulphide and about 30 per cent of phenolics. Loadings shown should be reduced accordingly to determine effect of stripper.

[d] Total kjeldahl N includes ammonia; total N is sum of $NO_2$ + $NO_3$ (N) and total kjeldahl N.

[e] Sulphides as determined by methylene blue method for water and wastewater.

CHAPTER 6

# WATER CIRCULATION AND SAND MOVEMENT

This chapter presents results of studies of the physical characteristics of the Sound and adjacent waters.

Section 6.1 describes the studies of currents and mathematical modelling of water mass movement and circulation in the Sound and nearby waters which were carried out by R.K. Steedman & Associates.

Section 6.2 presents brief summaries of three studies related to sediments of the Cockburn Sound area. Section 6.2.1 covers the sediment studies of Cockburn Sound conducted by a graduate student at the University of Western Australia for the Cockburn Sound Study.[14] Section 6.2.2 describes the principal findings contained in the report on the status of coastal dunes prepared for the Cockburn Sound Study by a member of the Soil Conservation Service.[15] Section 6.2.3 summarises information in the report on recent changes in the eastern shoreline assembled for the Cockburn Sound Study by an officer of the Harbours and Rivers Branch, Public Works Department.[16]

## 6.1 WATER MASS MOVEMENT AND CIRCULATION

Water mass movement and circulation patterns in Cockburn Sound, along with exchange through its northern and southern openings into the Indian Ocean, play very important roles in determining where industrial effluents will go and what impact they will have on water quality. R.K. Steedman & Associates were retained as consultants in February 1977 to review earlier work, carry out current and other measurements in the Sound, and develop a numerical model capable of predicting water circulation patterns and the distribution of contaminants in the Sound. The report on the study was received in March 1979.[13] It presents the results of a series of highly technical analyses and procedures employed to collect basic oceanographic data about the Sound and to structure, calibrate and operate the numerical model.

In addition to the work presented in this report, the model was used by other segments of the study to simulate the dispersion of effluent released from the major outfalls within Cockburn Sound.

It would be very difficult to summarise the report in a step-by-step fashion. Nor would this be of value to the non-technical or technical reader. Instead, it appears reasonable to work from the comprehensive introduction and the summary contained in the consultant's report and to draw details or examples from the body of the report as appropriate. The technical reader can refer to the consultant's report for details and explanations.

### 6.1.1 Scope of Study

The scope of the study was divided into two sections: field measurements, and the development and application of a numerical model which described the circulation.

To obtain data to support the model study, the field survey was planned:

1. To monitor the flow with fixed continuous recording current meters at locations in Mangles Bay, James Point, North Lead and outside the Sound just west of Garden Island;
2. To support the fixed location current metering with detailed profiles of salinity, temperature and current speed and direction;
3. To monitor autumn to early winter conditions during periods of light winds, when eutrophication problems are known to occur, by obtaining fixed current metering and profile data.

The numerical model study of the Cockburn Sound basin and surrounds was planned to include the following items:

1. To develop a two-dimensional numerical model to describe the gross wind driven horizontal circulation features of Cockburn Sound;
2. To verify the model results by comparison with data from field measurement programmes of this and previous studies;
3. To examine ways by which the occurrence of various circulation patterns are generated;
4. To determine the amount of exchange through the northern opening;
5. To form the basis of an effluent dispersion analysis.

### 6.1.2 Background Information

Between 1969 and 1976, the Commonwealth Department of Housing and Construction and the Fremantle Port Authority undertook a wide variety of studies on the biological and physical aspects of the marine environment of Cockburn Sound. These studies established environmental base lines particularly related to the construction of the Garden Island causeway.

The circulation patterns within Cockburn Sound, and exchange through the northern and southern openings to the Indian Ocean, play an important role in determining water quality within the Sound. The water movement in Cockburn Sound was shown in the early studies to be complex and not easily understood. In an effort to unify the field observations, the Commonwealth Department of Housing and Construction commissioned the Danish Hydraulic Institute to conduct a numerical model study programme to compare the water movement in Cockburn Sound before and after the construction of the causeway. The model was detailed and allowed for variable winds, tides, longshore currents and bottom topography. Operation of this model provided the first understanding of the large scale circulation patterns of Cockburn Sound and surrounding coastal waters.

In order to experiment and test ideas about the water movement and the dispersion of effluent in the Sound, the decision was made that the Cockburn Sound Study activities would include development of a numerical model of the Sound which could be run in Perth to aid in assessing biological, physical, oceanographic and engineering considerations of present and future plans.

The study programme involved checking the model results against fixed current meter observations once some additional detailed water movement data had been taken in autumn along the eastern coastline of Cockburn Sound and Owen Anchorage.

### 6.1.3 Regional Currents and Longshore Drift

Monthly averaged speeds of 20 to 30 cm/s may be expected in the surface waters near the edge of the continental shelf. The direction of the flow is possibly south during summer but the pattern is not well defined because of insufficient knowledge.

The influence of these regional currents, which run parallel to the continental shelf, on the nearshore waters to the west of Garden Island is surprisingly small. It appears from the limited number of observations that a very low speed counter-current exists in these waters, and that it flows north in summer and south in winter. Analysis of the current meter records shows that the drift velocities induced by the regional circulation are about 3 cm/s. Because of these low velocities, it is expected that the net exchange between the nearshore and midcontinental shelf region is very low.

Tides along this section of the coast are diurnal, i.e. there is one high and one low tide per day, and the mean range between high and low water of 0.3 m is small compared with other locations in Australia. As a result, the astronomical tidal currents are small and have an amplitude of about 1 to 2 cm/s, which makes the flow along this part of the coast unique. There are very few places in the world where the tidal velocities are so low on an open true oceanic coastline. Under these conditions, the wind plays an important role in driving the water along the coast.

Consequently, regional currents and longshore drift have little or no effect on water movements into or out of the Sound or on circulation patterns within the Sound.

### 6.1.4 Winds

The Fremantle Port Authority's wind and tide height records, covering 26 years and 82 years respectively, constitute the most important set of data relating to the movement of the coastal waters. The data are continuous and as such, short to long term events may be examined. The general weather patterns are well described for the Perth area. Low pressure systems and associated cold fronts (extratropical cyclones, gales), which mainly occur in the winter, provide the main driving force for the coastal waters.

The number of gales varies from year to year in a seemingly random fashion, although there may be a 7 to 10 year cycle in the annual frequency of occurrence of these events. The hourly average wind speed rarely exceeds 20 m/s, with durations of 6 to 15 hours. Dissipating tropical cyclones are rare storm events and may have hourly averaged wind speeds up to 25 m/s, with durations of 2 to 4 hours. Calm conditions occur throughout the year and the number per year varies greatly. Again, there is possibly some long term cyclic variation in the annual frequency of occurrence.

Calms ($< 1.5$ m/s) often exceed 4 hours in duration, and once or twice a year the duration may exceed 17 hours.

A preliminary wind pattern classification has been devised from an analysis of 25 years of wind records from the Fremantle Port Authority. Table 6.1 describes the seven classifications.

### 6.1.5 Field Measurements in Cockburn Sound—1977

During the period March-July fixed continuously recording current meters were deployed in Cockburn Sound. Meters were located about 2.5 m above the seabed at Mangles Bay (at a water depth of 10 m), James Point (7 m) and North Lead No 2 (19 m). A fourth meter was located at a depth of 21 m west of Garden Island. The locations are shown in Figure 6.1 and were chosen to approximate the locations used in earlier work by the Maritime Works Branch. The fixed meters suffered from fouling by marine growths. In addition, the speed of the currents was often below the threshold speed capability of the meter, quoted at 3 cm/s by the manufacturer. Instantaneous current speeds typically ranged up to 10 cm/s at stations in the Sound and up to 30 cm/s at the West Garden Island station.

Detailed salinity, temperature and current profiles were made along the transects shown in Figure 6.1.

From analysis and evaluation of data from the fixed meters and the profiling work, it was concluded that currents in the Sound could be divided into three categories:

1. Density, tidal, drift and wind driven currents when wind speeds are below 3 m/s; this condition occurs about 20 per cent of the time.
2. A transitional period between density and wind driven currents when wind speeds are in the range of 3 to 5 m/s; this condition occurs about 27 per cent of the time.
3. Dominant wind driven currents when wind speeds are in excess of 5 m/s; this condition occurs about 53 per cent of the time.

### 6.1.6 Numerical Model of Wind Driven Circulation

The field studies and analyses by the model showed that wind was the most important force driving the water circulation within Cockburn Sound.

The numerical model employed is capable of representing movement in two horizontal directions but it averages movement throughout the water column. Technical details of the theory and formulation of the model are given in an appendix contained in the consultant's report.

The model was tested against currents and water levels observed in the Sound. For observations made at moderate wind speeds its predictions correlated with the actual observations. At lower wind speeds (less than 5 m/s), however, correlation was poor because the model does not simulate the effects of density currents.

In order to simulate the effects of density currents, a three-dimensional model would be required. This is not yet practicable on the scale required for the Sound in terms of computer availability and cost. In addition, highly sophisticated equipment would be required for collection of field data against which to test the model.

### 6.1.7 Results of Model Operation

The numerical model was operated for the most common wind patterns; sea breeze, low pressure system (gales), dissipating tropical cyclone and two other moderate wind categories. The results give an insight into the gross water circulation within the Cockburn Sound and adjacent waters.

Table 6.2 lists seven wind and weather patterns, and simulations were made for several of these to show the behaviour of the wind driven circulation in the Sound as predicted by the numerical model. The model was run using real wind data from Fremantle Port Authority for selected periods chosen to be representative of the wind pattern categories.

The model was not run for an extended period of calm since, as discussed earlier, the model cannot simulate currents during calms or periods of low wind speeds.

Figure 6.2 shows streamline patterns which illustrate the locations of gyres within the Sound. The comparative spacing of the streamlines is a measure of the current velocity, with higher velocity corresponding with more closely spaced lines.

### 6.1.8 Exchange Processes with the Open Sea

Model runs were made for several of the wind categories used for predicting current patterns to estimate the exchange rate at the southern and northern openings of the Sound.

Previous measurements had shown that exchange through the southern opening was small and, accordingly, it was concluded that flow through it only produces small changes in the circulation patterns within the Sound.

Results of model runs to simulate exchange through the northern opening are listed in Table 6.3. It is recognised that no field measurements are available to test the accuracy of the predictions. However, the calculated exchange rates when compared with the total volume of the Sound, approximately $1.2 \times 10^9 m^3$, indicate that there is little interaction with the open ocean. In other words, the model predictions substantiate the concept that the Sound acts, to a large extent, as a closed system. The same concept, of course, explains why high concentrations of conservative (non-degradable) contaminants remain in the waters of the Sound and are not passed out to sea with tidal exchange.

### 6.1.9 Model Dispersion of Effluent

The circulation model was used during the study of nutrient enrichment to predict the dispersion of phosphate in seawater from both the CSBP and WPTP effluent outfalls. In addition, the model was used to predict the dispersion of cadmium released from CSBP in Cockburn Sound surface waters (Figure 6.3a shows an example of one model run) which was compared with cadmium concentration isopleths drawn from results of analysis of water samples (Figure 6.3b). It can be seen that the gross features of the dispersion model pattern correlate with the results of the real chemical data.

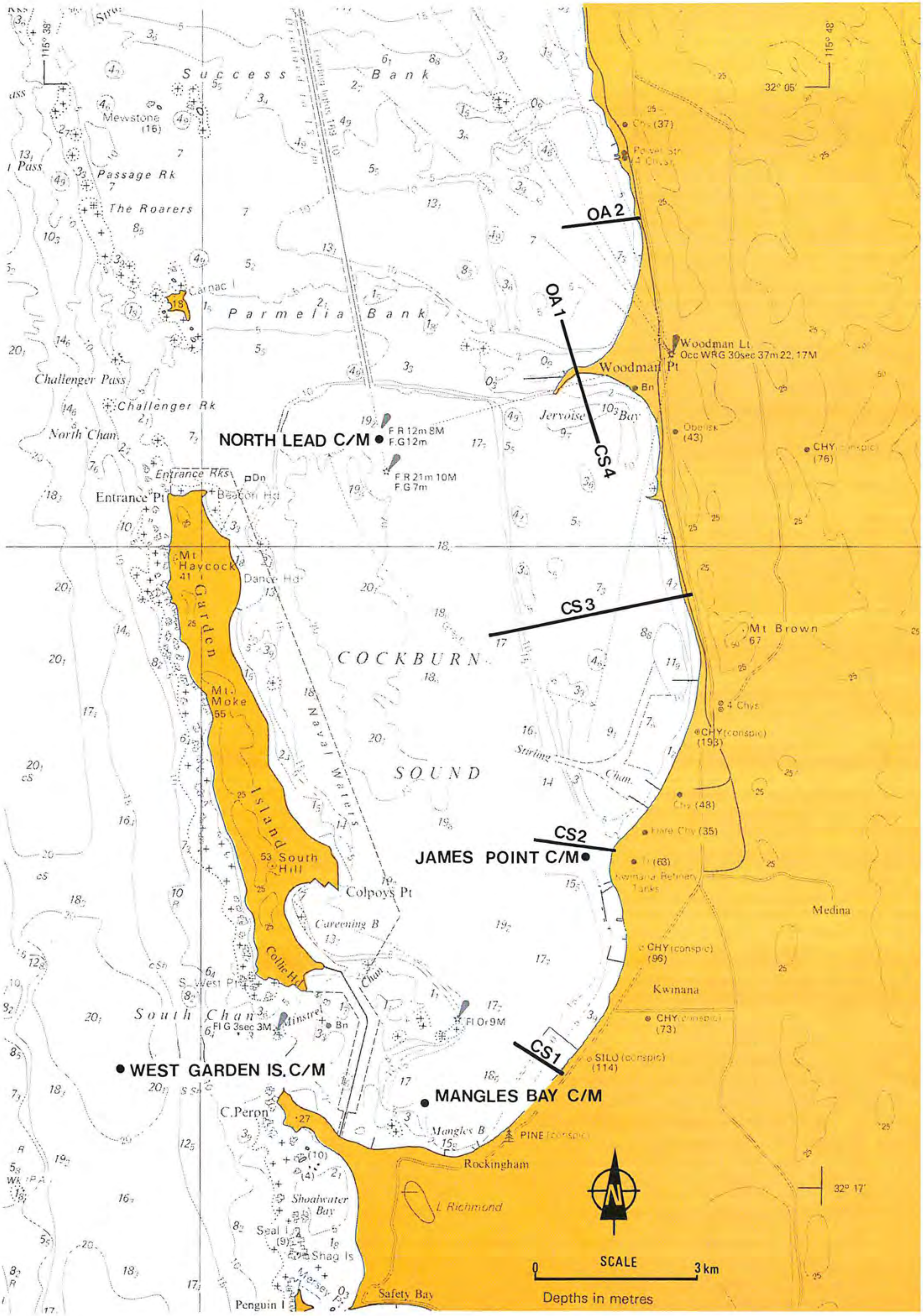
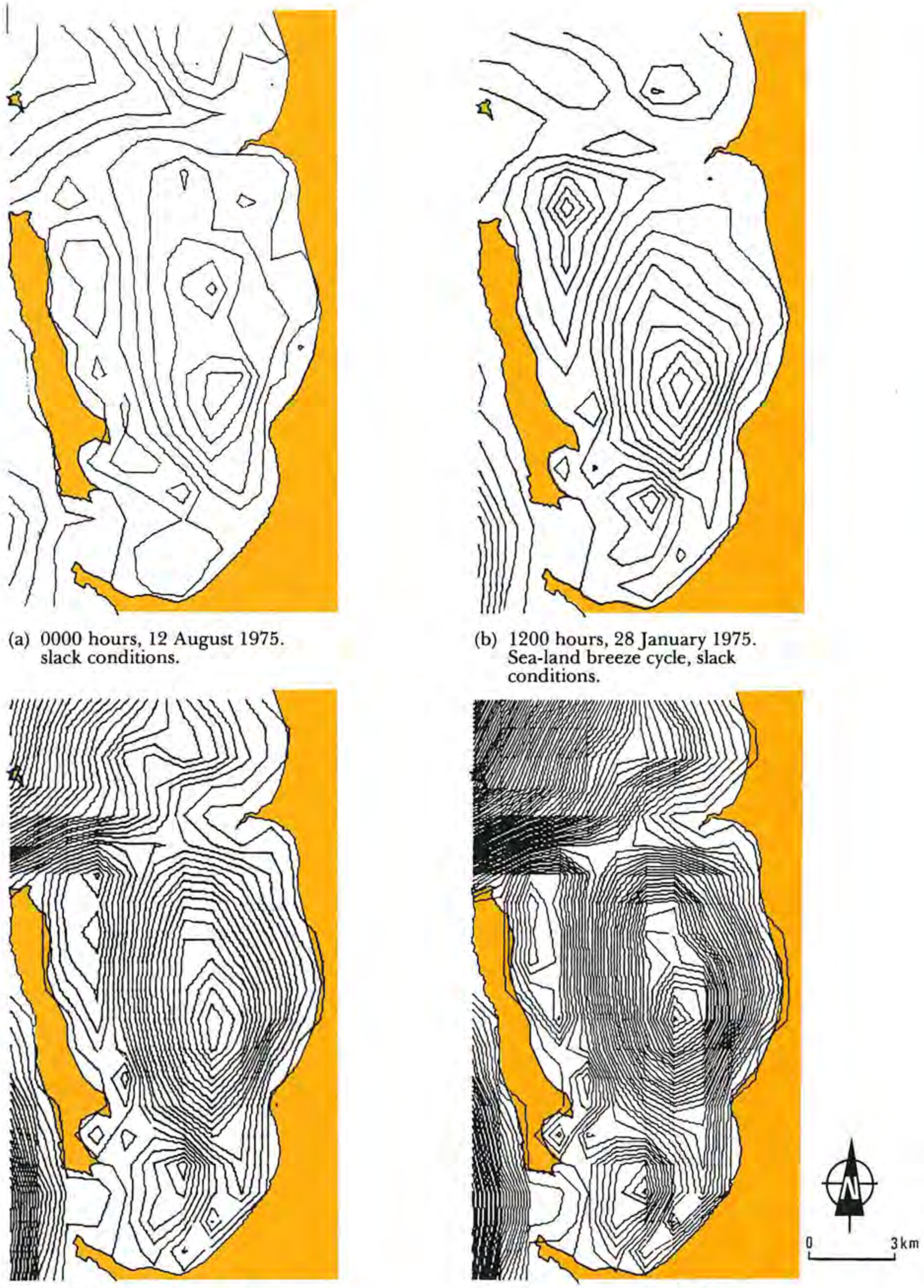



FIGURE **6.1.** Continuous current meter (C/M) locations and salinity, temperature and current profiling lines.




(a) 0000 hours, 12 August 1975. slack conditions.

(b) 1200 hours, 28 January 1975. Sea-land breeze cycle, slack conditions.

(c) 0000 hours, 29 August 1975. Sea-land cycle, peak velocity conditions.

(d) 1200 hours, 20 March 1975. Peak velocity conditions under cyclone "Vida."

Streamline spacing 200 $m^3 s^{-1}$

FIGURE **6.2.** Streamline patterns under various weather conditions.

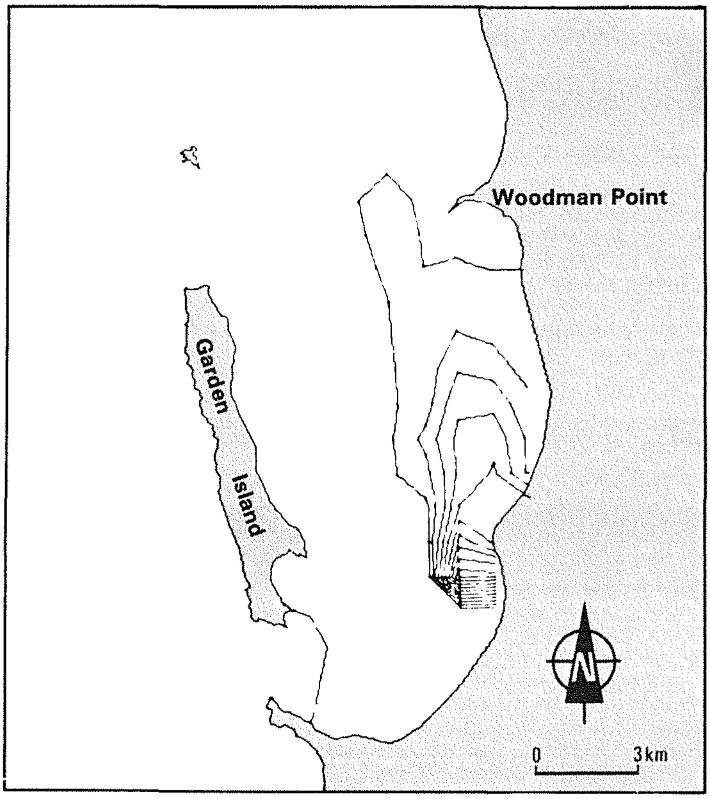



FIGURE 6.3(a). Circulation model predictions for the dispersion of cadmium released by CSBP on 29.11.79

### 6.1.10 Recommendations

Many recommendations have emerged from the numerical modelling study. However, for present purposes, the following are believed sufficient.

1. Since currents and circulation of water masses in the Sound are attributable in whole or in part to small, fine scale differences in density structure about 50 per cent of the time, a study should be carried out to obtain a better understanding of the various factors producing density currents in the Sound. This knowledge will help in estimating effects of changes in quality or quantity of existing discharges or of assessing the impact if new discharges are proposed.
2. The relative percentage of Sound water which flows out with the circulation pattern and actually is "lost" to the open ocean and, therefore, does not return subsequently should be determined for various flow conditions.
3. If further numerical modelling of the Sound is undertaken in the future, the programmes should be designed to account for the factors producing density currents.

## 6.2 SAND MOVEMENT

Information about the formations of the existing sediments in Cockburn Sound and about their response to activities affecting them at present was developed during the Cockburn Sound Study from three different sources.

A grant was made to the Geology Department, University of Western Australia, to enable a post-graduate student to study and report upon selected aspects of sedimentology in the Sound.[14] The status of coastal dunes was examined and reported upon by a member of the Soil Conservation Service.[15] Recent changes in the eastern shoreline were examined and reported upon by the Harbours and Rivers Branch, Public Works Department.[16] Each of these separate activities is outlined briefly in this section and the individual reports can be referred to for further information.

### 6.2.1 Sedimentology Study

During the one year allotted to this study, three general areas of interest were developed. These included:

1. The distribution and structure of Holocene sediment bodies within and bordering Cockburn Sound;
2. The physical and biological processes that control and influence the distribution and deposition of sediment in the Cockburn Sound area;
3. The effects on sediment distribution and deposition caused by recent changes to those same controlling physical and biological processes.

Summary information from the report[14] is presented below for each of these topics.

**Holocene Sediment Bodies.** During the Holocene rise in sea-level, two major types of sediment have built up in Cockburn Sound. First the fringing and barrier banks formed, drawing their sediment supply from the seagrass community, from material eroded from the Garden Island and Spearwood Ridges, and from material moved north along the coast from south of Cockburn Sound. These banks show a change from seagrass-related sediments to sandflat-related sediment, which is thought to be caused by a combination of bank-shoaling, and sea-level fall. In general, the Holocene bank sediments are predominantly carbonate sands, with grain sizes ranging from 0.3 mm to 0.7 mm.

Secondly, sediments accumulated in the Cockburn Sound and Owen Anchorage basins. These muds have accumulated along with the bank sediments and consist mainly of clay-sized carbonates.

**Controlling Physical and Biological Processes.** Bank build-up and substrate stabilisation are primarily controlled by the seagrass community, by the wave-pattern predominant within the Sound, and by the amount of sediment available to the meadows.

The seagrass community is the main biological factor in the build-up and maintenance of the banks. The fauna and flora associated with the seagrass contribute skeletal carbonate debris to the sediment pile in amounts much greater than produced by other biologic associations in Cockburn Sound. The seagrass meadow itself acts as a wave-energy baffle while its root-mesh binds and stabilises the substrate against erosion.

In the absence of significant tide or current action, the wave patterns are the main physical agent influencing the banks. In the past, this was the south-westerly swell. Under its influence, zones of wave

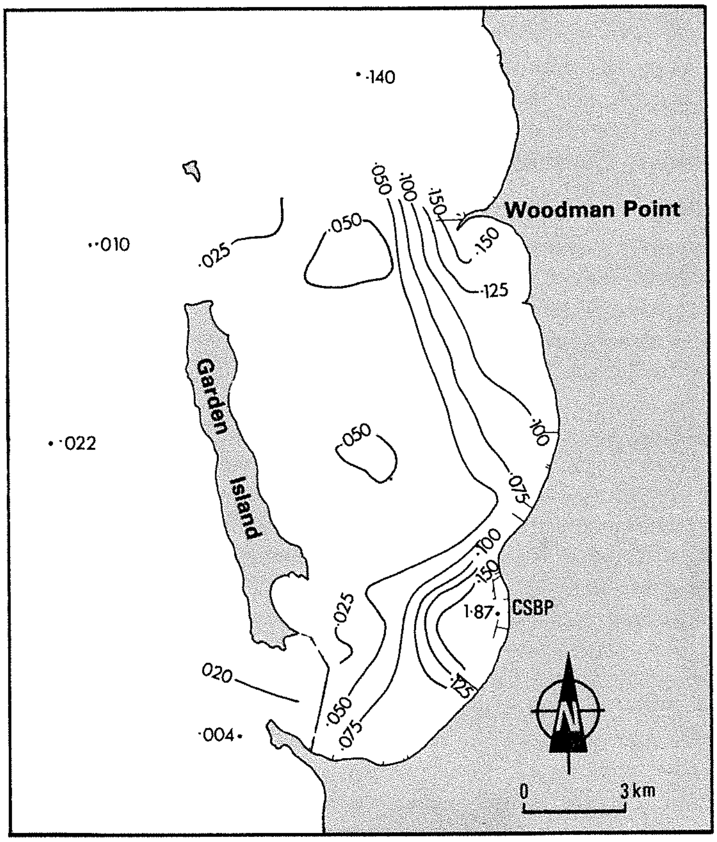



FIGURE **6.3(b).** Concentration Isopleths of Cadmium in Surface Waters Drawn from Analyses of Water Samples Collected on 29.11.79.

interference, and hence of sediment deposition, were localised behind islands and shoals of the Garden Island Ridge. Thus, areas of initial spit development were stabilised by seagrass, prograded into the Warnbro-Cockburn Depression and formed the barrier banks extending between the Garden Island and Spearwood Ridges. On the Spearwood Ridge, local pre-Holocene sediment highs also localised seagrass growth and aided in bank development. The process of wave-induced localisation still operates to some extent on Parmelia and Success Banks, and probably in Warnbro Sound. However, due to the slow-down in erosion of the eolianite ridges and the cut-off of the southern littoral drift sediment supply, this action is probably only maintaining sediment presently in position, without adding significant new amounts.

The final major physical factor involved in bank growth centres around the influx of foreign sediment. Where sedimentary material cannot be supplied by the community's skeletal debris, the difference must be made up by material transported from elsewhere. In Cockburn Sound, sediment supplied from the Garden Island and Spearwood Ridges was important, as was that supplied by littoral drift from the south. Under these conditions, the seagrass meadows were healthy, and enabled thick structures to be built over a geologically short period of time.

In Cockburn and Warnbro Sounds, the combination of these factors has produced a beach and sublittoral profile unique to the south-west coasts of Australia. This is characteristically a very narrow beach, backed by beach dunes of the eolianite basement, while offshore there is a flat fringing platform of varying width, plunging steeply (often up to 30°) to a flat basin floor consisting of fine carbonate muds.

**Effects of Changes to the Controlling Factors.** Two major changes have occurred in the physical-biological environment of Cockburn Sound: first, the physical change which took place approximately 10 000 years ago, that resulted in linking the Rockingham Plain to Cape Peron; and second, the widespread die-off of seagrass meadows within the Sound over the last 20 years or so.

The physical change, which took place thousands of years ago, has had two major effects. First, it has blocked the passage of the south-westerly wave trains into Cockburn Sound and has diverted the littoral drift sediment supply northward around the Sound. The loss of the south-westerly swell's influence means that the north-westerly winter waves are now the major influence on the interior of the Sound. The construction of the causeway to Garden Island completed this change of wave regime. The barrier and fringing banks will adjust to the change in wave regime by assuming profiles in equilibrium with it. Profiles probably will feature a long shallow slope and involve some erosion and cut-back into the beach and beach-ridge. Sediment removed to the central basins by wave action will be lost to the shoreline system. Since natural physical-biological environments are continually undergoing change, it is reasonable to expect that Cockburn Sound is evolving toward a new equilibrium. The widespread seagrass depletion over a relatively very short period has been superimposed on this process of change.

**Recommendation.** With the extent of present knowledge, it is not possible to predict the precise nature or time of geomorphic change. However, considering the importance of the barrier banks in blocking high energy waves from Cockburn Sound, a programme should be set up to monitor periodically bank profiles, particularly those of the Parmelia and Success Banks.

### 6.2.2 Coastal Dunes Study

Some of the detailed information provided by this study has been integrated into various portions of the report on the Recreation Survey.[1] However, it contains comments on existing erosion and potential erosion which are appropriate to include here.

The report was compiled using data from ground inspections and aerial photographs and from general knowledge and discussion. No specific monitoring programmes or observations over time were undertaken.

**Existing Dune Erosion.** Sites were noted along the shores of Cockburn Sound and of Owen Anchorage where soil erosion was taking place on coastal land. The effects of this erosion vary from destruction of adjacent vegetation, to sand drift onto developments such as roads and railways.

If erosion is to be cured remedial treatment is required at all these sites. However, the naturally harsh coastal environment makes control of coastal sand dune erosion normally difficult. The additional effects of numbers of people using the areas frequently makes control very difficult; in these situations, management to control people becomes an essential additional part of the erosion control method.

**Potential Dune Erosion.** Sites were noted along the shores of both Cockburn Sound and Owen Anchorage where there was potential for environmental deterioration to occur, particularly if numbers of people increase, and where coastal management would be particularly appropriate.

Coastal management aims at use of the natural features of the coastal environment consistent with conservation of those same features for the use of future generations. Management involves people and attempts to minimise harmful effects such as destruction of the vegetation which protects sand dunes from wind erosion. For example, concentration of people's movements onto defined paths so that the bulk of the plants can grow unhindered is one of the commonly used management methods. There are a number of options available for different conditions and each of the sites needs to be considered individually.

### 6.2.3 Shoreline Stability Study

The shoreline stability report identifies specific locations where shoreline erosion or accretion presently is taking place. Some of the relevant data in this report were considered during the preparation of the Recreation Survey report.

The author concludes that the shoreline from Fremantle to Cape Peron is now largely stable, with its stable forms generally controlled by structures erected at the shore. However, future stability and the future character of the shore will depend in many instances on the actions of the managers or developers of adjacent shore land. Some sites of erosion or accretion do exist and must be considered in the planning of their future use.

Plate 10. Erosion along the shoreline of Mangles Bay extending to the Garden Island causeway.

**Shoreline Erosion Sites.** Seven sites have been identified at which shoreline erosion presently is taking place. These are (i) Rockingham—from Bell Street to Garden Island causeway; (ii) James Point; (iii) Kwinana power station; (iv) oil rig construction site; (v) Coogee Beach; (vi) south of the South Fremantle power station; and (vii) south of the Catherine Point groyne.

**Shoreline Accretion Sites.** Five sites have been identified at which shoreline accretion is taking place. These are (i) west of Garden Island causeway; (ii) industrial frontages between Alcoa and the Kwinana Wreck, particularly at James Point; (iii) northern shores of Woodman Point, to southern edge of Coogee Beach; (iv) north of the South Fremantle power station; and (v) northwards from Catherine Point.

**Need for Control.** The sandy sections within Cockburn Sound are quite isolated from the natural inputs of littoral drift sand which previously came from external sources. Within Owen Anchorage, external sand inputs also have been reduced at most of the sandy beaches. Because of this, any use or development in the active shore zone, (foredune, beach and adjacent shallow water) which permanently removes sand from that zone must result in erosion. Any increased use of this shoreline should thus be planned to allow for sand loss and erosion, or to replace the lost sand if erosion is to be avoided.

### 6.2.4 Recommendations for Control of Dune and Beach Erosion

1. Sites where dunes are eroding owing to destruction by man of protective vegetation should be carefully managed to minimise this trend.
2. Further shoreline use should be planned taking into consideration the likely effects, if any, of sand loss and erosion.

**TABLE 6.1**
**ESTIMATES OF THE ANNUAL FREQUENCY OF OCCURRENCE IN DAYS OF THE PRELIMINARY WEATHER PATTERN CLASSIFICATIONS**

| Category | Wind pattern | Wind m/s | Year 1973 | 1974 | 1975 | 1976 | 1977 | Average annual occurrence (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | Sea breeze | 0-15 | 106 | 131 | 149 | 134 | 122 | 35 |
| 2 | Winter high pressure system | ~5 | 37 | 58 | 49 | 103 | 85 | 18 |
| 3 | Low pressure system | 5-20 | 140 (4) | 118 (3) | 81 (4) | 79 (5) | 100 (3) | 28 |
| 4 | Summer high-low pressure system | ~5 | 11 | 15 | 33 | 21 | 6 | 5 |
| 5 | Dissipating tropical cyclone | 10-30 | 0 | 0 | 2 | 2 | 0 | <<1 |
| 6 | Calms | <1.5 | 17 | 7 | 19 | 17 | 9 | 4 |
| 7 | Other (unclassified) | 2-15 | 54 | 36 | 31 | 9 | 43 | 10 |

**TABLE 6.2**
**SUMMARY OF COCKBURN SOUND WIND DRIVEN CIRCULATION CHARACTERISTICS**

| Category | Wind Pattern | Wind speeds m/s | Main Gyre Speeds cm/s | Main Gyre Direction | Month | Estimated annual occurrence (%) |
|---|---|---|---|---|---|---|
| 1 | Sea breeze | 0-15 | <5-20 | Anticlockwise well developed | Oct-May | 35 |
| 2 | Winter high pressure system | ~5 | <5-10 | Anticlockwise poorly developed | Apr-Oct | 18 |
| 3 | Low pressure system | 5-20 | <5-40 | Poorly developed otherwise clockwise under storm conditions | All | 28 |
| 4 | Summer high-low pressure system | ~5 | <5-10 | Anticlockwise poorly developed | Oct-May | 5 |
| 5 | Dissipating tropical cyclone | 10-30 | 10-30 | Clockwise well developed | Dec-Apr | <<1 |
| 6 | Calms | <1.5 | – | Model fails, density currents important | All | 4 |
| 7 | Other (unclassified) | 2-15 | <5-15 | Anticlockwise most of time, clockwise if north to north-east wind | All | 10 |

**TABLE 6.3**
**SUMMARY OF WIND DRIVEN MODEL EXCHANGE RATES THROUGH NORTHERN COCKBURN SOUND EXCLUDING THE INFLUENCE OF THE SOUTHERN OPENING**

| Category | Wind pattern | Wind speed m/s | Exchange Rate $m^3/s$ | Month | Estimated annual occurrence (%) |
|---|---|---|---|---|---|
| 1 | Sea breeze | 0-15 | 0-300 | Oct-May | 35 |
| 2 | Winter high pressure system | ~5 | 0-250 | Apr-Oct | 18 |
| 3 | Low pressure system | 5-20 | 0-1800 | All | 28 |
| 4 | Summer high-low pressure system | ~5 | ~150 | Oct-Mar | 5 |
| 5 | Dissipating tropical cyclone | 10-30 | 0-700 | Dec-Apr | <<1 |
| 6 | Calms | <1.5 | 0 ? | All | 4 |
| 7 | Other (unclassified) | 2-15 | – | All | 10 |

# CHAPTER 7

# CHEMICAL AND BIOLOGICAL CHARACTERISTICS

This chapter presents results of studies of chemical and biological characteristics of the Sound and adjacent waters.

Section 7.1 summarises the work by the Study Group in determining the distribution of waste substances (other than nutrients) in seawater, sediments and biota once they have entered the Sound.[7]

Section 7.2 outlines the brief study and assessment of microbiological quality of seawater and mussels conducted jointly by the Study Group and the Department of Health and Medical Services.

Section 7.3 describes the extensive study, which was conducted by members of the Study Group, of nutrient enrichment and its effect on algal productivity in the waters of the Sound.[12]

Section 7.4 presents the key aspects of the study by the Botany Department of The University of Western Australia to extend previous investigations into causes of disappearance of seagrass from the eastern shores of the Sound.[10–11]

It must be noted that these studies have involved many thousands of manhours and thousands of laboratory analyses. The individual reports contain about 450 pages of text, tables and figures.

As a result, they can only be dealt with here in a brief manner which indicates (i) their objectives and scope, (ii) how they were carried out, and (iii) their findings and recommendations which are of particular relevance in the context of this present report. The reader who requires specific data, explanations, or discussions may refer to the technical reports.

## 7.1 DISTRIBUTION OF CONTAMINANTS IN THE SOUND

This study which was carried out by members of the Cockburn Sound Study Group determined the distribution of waste substances, other than nutrients, once they have entered the Sound.

Nutrient and nutrient enrichment studies are summarised in Section 7.3. The report on distribution of contaminants[7] documents the distribution in water, biota and sediments of waste inputs after they are discharged to the Sound.

### 7.1.1 Objectives and Scope

The specific objectives of the study were:

1. To determine present levels of heavy metals in the sediments of Cockburn Sound and contour the results;
2. To investigate uptake of heavy metals by biota;
3. To assess whether hydrocarbons of non-biogenic origin are having a serious impact upon the plant or animal community; to test for toxicity to *Posidonia australis* and *Posidonia sinuosa*;
4. To assess the impact of other substances entering the Sound which are likely to have significantly harmful effects.

### 7.1.2 Heavy Metals in Waters of the Sound

This phase of the study dealt with the distribution of metals known to be contained in effluent discharges to the Sound. Special analytical techniques were developed in collaboration with the Physics and Chemistry Departments of the Western Australian Institute of Technology.

Following a preliminary study early in 1978, the major sampling programme was initiated late in 1978. More than one hundred samples were collected during two separate sampling runs. The samples were analysed for cadmium by two techniques, Mass Spectrometric Isotype Dilution (MSID) and Anodic Stripping Voltammetry (ASV), and for lead and copper by ASV. In the light of current literature, it is believed that the MSID cadmium analyses represent the most accurate available for waters containing very low concentrations. ASV proved to be a technique well suited to routine analysis of cadmium, lead and copper at the low levels found for these elements in seawater.

Studies concentrated on cadmium, lead and copper. The results for lead and copper showed no clear distribution patterns. However, for cadmium, there was good correlation between concentrations and observed water movements relative to the CSBP discharge, which is the major source of cadmium discharged to the Sound (Table 5.1). Maximum concentrations in the water were about 0.2 µg/L, excluding samples at the CSBP discharge. Mean values for the Sound were about 0.065 µg/L and 0.1 µg/L in the sampling series carried out on 29 November and 28 December 1978, respectively. Levels of cadmium in Cockburn Sound waters were above those of adjacent oceanic waters.

### 7.1.3 Contaminants in Sediments

This phase of the study was carried out to highlight the different sediment characteristics of Cockburn Sound, Owen Anchorage and Warnbro Sound.

Sediment samples were collected from a total of 87 stations from September to November 1977. There were 75 stations in Cockburn Sound, and 6 each in Owen Anchorage and Warnbro Sound.

Core samples of 30 mm diameter were collected and analysed using atomic absorption spectrophotometry, gas-liquid chromatography and anodic stripping voltammetry. Analyses were made for heavy metal content, particle size, organic matter content, Eh* and pH**, hydrocarbon and pesticide levels.

Sediment contamination was found to be related to point sources of effluent input. Levels of accumulation of heavy metals were localised around the James Point and Woodman Point areas and on the eastern shores of Owen Anchorage. The two major sedimentary systems within Cockburn Sound, the fringing banks and the deep basin, were clearly differentiated by particle size distribution and organic matter content. All surface sediments sampled exhibited similar Eh and pH values except for the area around the CSBP gypsum outfall where conditions were anaerobic. Hydrocarbons showed little accumulation in the sediments except for the area adjacent to the petroleum refinery at James Point. Chlorinated pesticides and polychlorinated biphenyl (PCB) analysis showed no positive results in Cockburn Sound sediments; however dieldrin was detected in Owen Anchorage.

### 7.1.4 Contaminants in Biota

This phase of the study was carried out to determine the levels of various contaminants in marine fauna and flora collected from Cockburn Sound and surrounding areas, and to compare the results with various public health criteria.

The fauna sampling programme included the common mussel, *Mytilus edulis,* blue manna crabs, *Portunus pelagicus,* mud oysters, *Ostrea angasi,* and the polychaete worm, *Chaetopterus variopedatus.* Mussels were examined periodically from November 1977 to February 1979, for heavy metal accumulation and to a lesser degree for hydrocarbon uptake and enteric bacterial contamination. Crabs were sampled during the 1978-1979 season and analysed for heavy metals and hydrocarbons. Polychaete worms were surveyed once for heavy metal content. *Mytilus* were analysed for chlorinated hydrocarbon content but none was detected. The results from these programmes suggest that contents of heavy metals, hydrocarbons and enteric bacteria are elevated to various degrees in the biota of the study area.

The species of flora sampled and analysed were the seagrasses, *Posidonia australis* and *Posidonia sinuosa,* and the sea lettuce, *Ulva lactuca.* The results suggest some accumulation of heavy metals in the flora but there was little evidence of a build-up of the alkane fraction of petroleum-derived hydrocarbons in the samples.

The findings for heavy metals in either mussels or crabs, or both, which are consumed by the public, are of particular interest. Concentrations of cadmium, lead, and zinc in edible portions of some specimens from various parts of Cockburn Sound exceeded accepted health limits, and levels of chromium and nickel were elevated above background levels. In Owen Anchorage, chromium levels were above the Western Australian standard, and lead levels were just below the National Health and Medical Research Council recommended value (Table 3.3).

Results of the analyses for mussels were reported as the mean of concentrations for five individual specimens at each sampling location. In the November 1977 series, a total of 51 sets of specimens was collected in Cockburn Sound and Owen Anchorage.

There is no Western Australian standard for cadmium in fresh seafood and as shown in Table 3.3 a "blanket" standard of 5.5 μg/g is used for cadmium, nickel, chromium and cobalt in processed seafoods in containers. The data for the November 1977 series showed that only 2 (4 per cent) of the sets of specimens exceeded this level for cadmium. Mean concentrations in 8 sets (16 per cent), however, exceeded the standard for cadmium currently advocated by the NH&MRC of 2.0 μg/g of wet weight (Table 3.3). Most of the sampling locations where specimens exceeded either the NH&MRC or both the NH&MRC and the Western Australian standards, were located along the edge of the Sound adjoining the Kwinana Industrial Area.

Sampling of mussels for cadmium was carried out at intervals from November 1977 until February 1979 and variations with time were noted at several locations. Of particular interest were the mean concentrations at the Palm Beach Jetty which varied from 0.5 μg/g in November 1979 to 3.0 μg/g in November and December 1978 sampling periods. During the period covered by the increase, the nozzles on the CSBP outfall were replaced with ones designed to achieve greater dispersion of waste gypsum. Unfortunately, this wider dispersal of gypsum was followed by a significant spread in the cadmium contamination of mussels.

A series of trials was carried out to determine cadmium uptake and depuration rates in mussels. Cadmium uptake rates showed an initial period of increase in levels of cadmium in the test mussels,

* Eh—a measure of whether oxidising or reducing conditions prevail.
** pH—a measure of the hydrogen ion concentration which indicates whether acidic or basic conditions prevail.

increasing from about 0.3 μg/g to more than 2 μg/g in less than a month. Depuration trials, on the other hand, indicate that cadmium levels remain high even after five months in clean seawater. In fact, the apparent small loss of cadmium concentration may be accounted for by the increase in flesh weight as the animals grow.

Description of findings with regard to other metals in mussels as well as for other substances and other animals and plants are contained in the technical report.

In conclusion, a few comments should be made with regard to the findings generally, and with regard to cadmium particularly. This phase of the study shows conclusively that many specimens have metal concentrations in excess of recognised health standards.

Review of these standards, however, indicates a wide variation in acceptable concentrations. Thus, while the results show that a potential health hazard exists, the actual degree or magnitude of hazard cannot be assessed. This assessment requires special expertise not available within the Cockburn Sound Study team. In recognition of the fact that some degree of hazard exists, it is appropriate to consider ways and means of reducing inputs of heavy metals and other suspect substances in developing water quality management options for the Sound and adjacent waters.

### 7.1.5 Fish

This phase of the study was carried out to determine the levels of various contaminants in fish found in Cockburn Sound and adjacent areas, and to compare the results with various public health criteria. Its general procedures and activities were parallel to that for other biota (Section 7.1.4).

The wet and dry weight concentrations of cadmium, zinc, copper, lead, iron, manganese, nickel, chromium and cobalt were measured in muscle taken from samples of 12 species of teleost fish caught in Cockburn Sound.

The maximum concentrations of the nine metals were well below the Western Australian and presently advocated NH&MRC standards for these elements in seafood. Furthermore, the metal concentrations in fish flesh were many times lower than in invertebrates such as the common mussel, *Mytilus edulis,* from the same area.

The low levels in fish flesh probably reflect the relatively low rate at which heavy metals are accumulated by teleost muscle and also the movement patterns and feeding habits of fish within the polluted and relatively unpolluted regions of the Sound and between the Sound and the Indian Ocean. However, the sublethal effect of metals on the fish population in Cockburn Sound may be more subtle than simple accumulation in muscle tissue.

Petroleum-derived hydrocarbons were found in fish from the Sound and are associated with occasional reports of tainted fish caught in the Sound near the oil refinery. Apart from oil spillages, the principal input of petroleum-derived hydrocarbons is from the BP Refinery. The input of this source averages about 1000 kg/d. Although various constituent hydrocarbons have been found in research elsewhere to contribute to a variety of sublethal effects, tainting was the principal problem identified during the study. Further work is needed to distinguish between fuel spillage and refinery effluents and their toxic effects on fish. In addition, the public health implications related to specific types of hydrocarbons need to be established.

### 7.1.6 Principal Findings

In the comprehensive technical reports a great many findings, conclusions and recommendations have been drawn, but all need not be given here. At the risk of omitting other important items, the following appear most relevant to the Cockburn Sound Study as a whole.

- Heavy metals were found in a number of shellfish specimens, particularly those collected in areas along the eastern shoreline. Concentrations near or above those used to assess health standards were found in a significant number of specimens.
- There is some evidence of the occasional presence of petroleum-derived hydrocarbons in flesh of various species of fish which may be associated with the occurrence of tainting.
- The results of the study need to be assessed by appropriately qualified specialists to determine the actual risk to human beings and further work needs to be carried out on lethal and sublethal effects on all growth stages of the biota.

## 7.2 MICROBIOLOGICAL QUALITY OF SEAWATER AND MUSSELS

A study of microbiological quality of seawater and mussels was undertaken by the Department of Health and Medical Services and the Cockburn Sound Study Group during the period March 1977 to April 1978. The work was a joint effort between the Enteric Diseases Unit of the Department of Health and Medical Services and members of the Study team working on the Distribution of Contaminants segment. Information presented below has been drawn from the report on the work.[9]

### 7.2.1 Objectives of Study

The objective of the study was to determine the microbiological quality of shorewaters and mussels in the areas exposed to effluent discharges from the WPTP and from abattoirs discharging to Owen Anchorage.

### 7.2.2 Results of Field and Laboratory Studies

Samples of seawater and mussels were collected from a number of locations in the vicinity of these discharges and analysed by the Department of Health and Medical Services. Analyses were made for *E. coli* and for various Salmonella serotypes.

*E. coli* is a non-pathogenic baterium found in the intestines of warm blooded animals, including man, and is used as an "indicator" of recent faecal pollution. Salmonella, on the other hand, includes serotypes associated with gastroenteritis and other diseases including typhoid fever. It should be emphasised here that no typhoid serotypes were found during the study. It also should be noted that, over the years covered by Department of Health and Medical Services' records, no cases of Salmonella in humans have been traced to water-based recreational activities in the Cockburn Sound or Owen Anchorage areas.

*E. coli* levels and Salmonella positive isolations were determined on samples collected from 31 different locations. For convenience, the locations have been grouped into the following five categories and results are discussed for each group.

1. WPTP outfall and related sites approximately 100 m from the discharge point;
2. Abattoir outfalls and associated trade outfalls;
3. Shoreline groynes and jetties not in general use for public recreation;
4. Offshore pylons and beacons located a minimum of 1000 m from outfall sites;
5. Public recreation beach sites comprising South Beach, Fremantle and Coogee Beach.

For purposes of evaluating the significance of the results, the investigations adopted *E. coli* counts of less than 500 organisms/100 mL and less than 10 organisms/100 mL as representing "safe" levels for waters used for public recreation and culture of shellfish, respectively. The occurrence of Salmonella serotypes in waters exceeding these *E. coli* levels was assumed to represent a potential health hazard. For shellfish, an *E. coli* level of less than 10 organisms/g was adopted as a "safe" level as long as Salmonella serotypes were absent. It should be noted that these levels differ from those recommended by the Marine Water Quality Criteria Committee whose conclusions were available only subsequently.

The findings of the study are summarised below for seawater samples and for mussel samples.

**Seawater.** Overall, in a total of 313 seawater samples from 31 locations, 85 had *E. coli* levels greater than 500 organisms/100 mL, and 54 were positive for Salmonella. Of the 85 *E. coli* samples, 71 were collected at abattoir or sewage outfall sites and only 5 were from recreational beach sites. The latter were at South Beach and Coogee Beach. Salmonella were isolated in most of the samples with high *E. coli* counts at the abattoir or sewage outfall sites and in only two samples at the Coogee site.

A total of 176 samples had *E. coli* levels less than 10 organisms/100 mL and Salmonella were isolated in only two of these. This indicates the trend for Salmonella to be found in samples having a high *E. coli* count.

**Mussels.** Overall, in the total of 200 samples of mussels from 18 sites, *E. coli* counts greater than 10 organisms/g were detected in 70 samples, and Salmonella were isolated in 74 samples. Not surprisingly, contamination levels with *E. coli* and Salmonella were highest at sites close to abattoirs. At the Anchorage Butchers and WAME shoreline sites, *E. coli* levels were consistently in excess of 1000 organisms/g and Salmonella were detected in 80 per cent and 100 per cent of the samples, respectively.

Salmonella serotypes were isolated in at least one mussel sample from 17 of the 18 sampling sites.

*E. coli* levels exceeding 10 organisms/g also were found in mussel samples from shore waters at the explosives jetty, Coogee Beach, Coogee jetty, the South Fremantle power station jetty, and the South Beach recreation jetty. In addition, levels exceeding 10 organisms/g were found in mussel samples from offshore waters at the Success Spit pylon (about 1200 m offshore) and at the Nook Spit pylon (about 1500 m offshore).

### 7.2.3 Conclusions from Study

Mussels harvested direct from the Owen Anchorage-Woodman Point area frequently do not conform to widely recognised standards for shellfish hygiene, and present a significant hazard to health if consumed without adequate cooking by the public. However, at present, access by the public to shoreline mussel harvesting sites is for the main part limited to recreation sites and areas close to shoreline groynes and jetties, and contamination levels are lower at these locations than closer to the WPTP outfall or the abattoir outfalls to Owen Anchorage. In the future, with the development of the

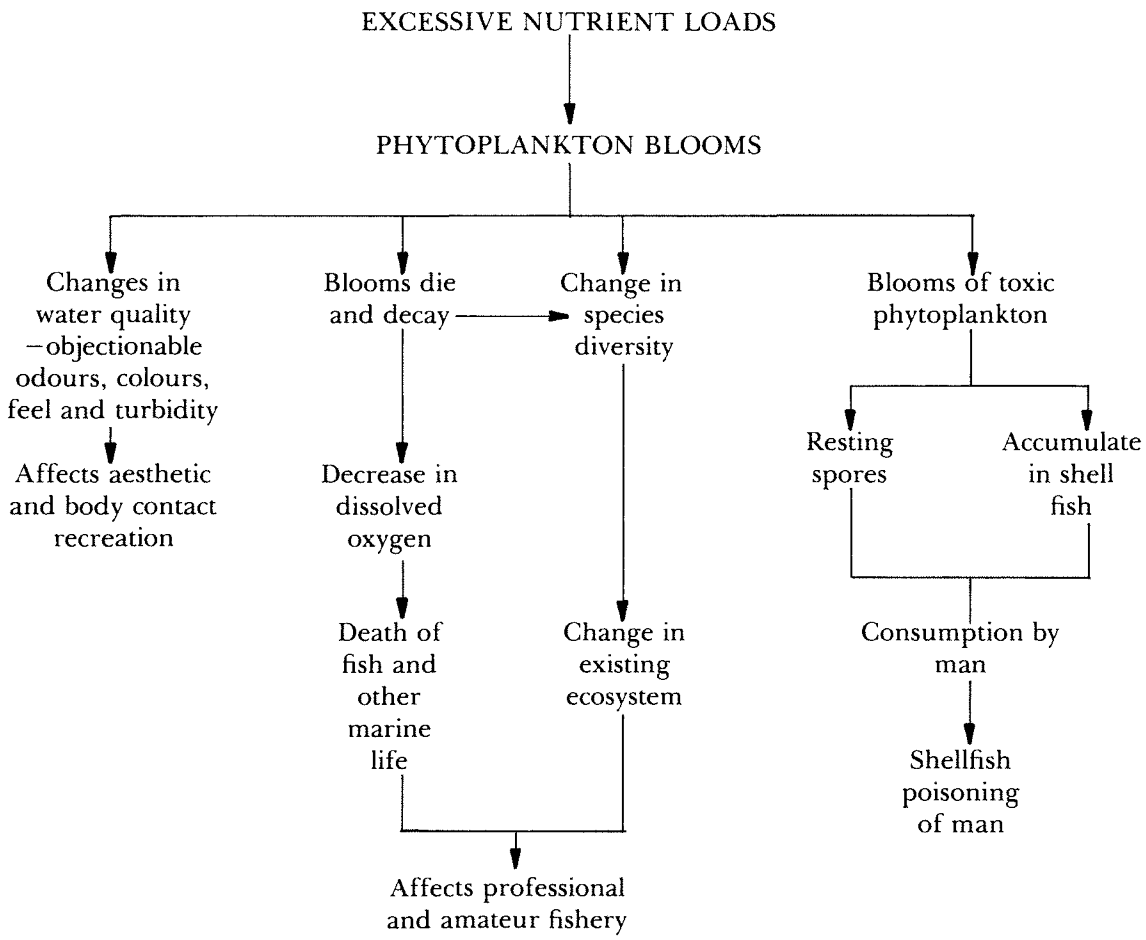
Jervoise Bay complex, access will be given to areas presently showing substantially poorer bacteriological quality in terms of seawater and mussels.

In summary, it should be emphasised again that mussels were not implicated as a direct source of human Salmonella infection in Perth or elsewhere in the State. It was also noteworthy that *S. typhi* and *S. paratyphi B* were not detected. However, the absence of cases contracted from eating mussels does not detract from the potential public health hazard revealed by the results of these studies, particularly when the wider range of potential microbiological hazards is taken into consideration.

## 7.3 NUTRIENT ENRICHMENT AND EUTROPHICATION

The term eutrophication now is commonly used to imply excessive nutrient enrichment (natural or otherwise) of lakes, rivers, estuaries and nearshore coastal areas. The effects of eutrophication are many and varied but are always associated with extensive changes in water quality. All too often this means a loss of amenity to some parts or all of the communities which use these water bodies. The eutrophication process may eventually interfere with man's use of such water bodies for recreational purposes as well as for fishing etc., through the production of very high levels of phytoplankton commonly known as algal blooms.

The effects of excessive phytoplankton production on uses of water bodies may be summarised as follows:




The eutrophication of Cockburn Sound is a comparatively recent phenomenon which has not demonstrated all the effects mentioned above but it can be definitely ascribed to man-made changes to the Sound. Intense algal blooms are generally regarded as having only occurred within the Sound over the last five years. However, descriptive and photographic documentation was given of algal blooms during the spring and summer of 1973-1974 in the 1974 report by the consultants, Environmental Resources of Australia, which noted that phytoplankton biomass was consistently high throughout the summer period of 1973-74 over the eastern and southern areas of the Sound. At times the levels intensified to the point of forming visible, short-lived blooms. The blooms still occur most frequently on the eastern and southern sides of the Sound.

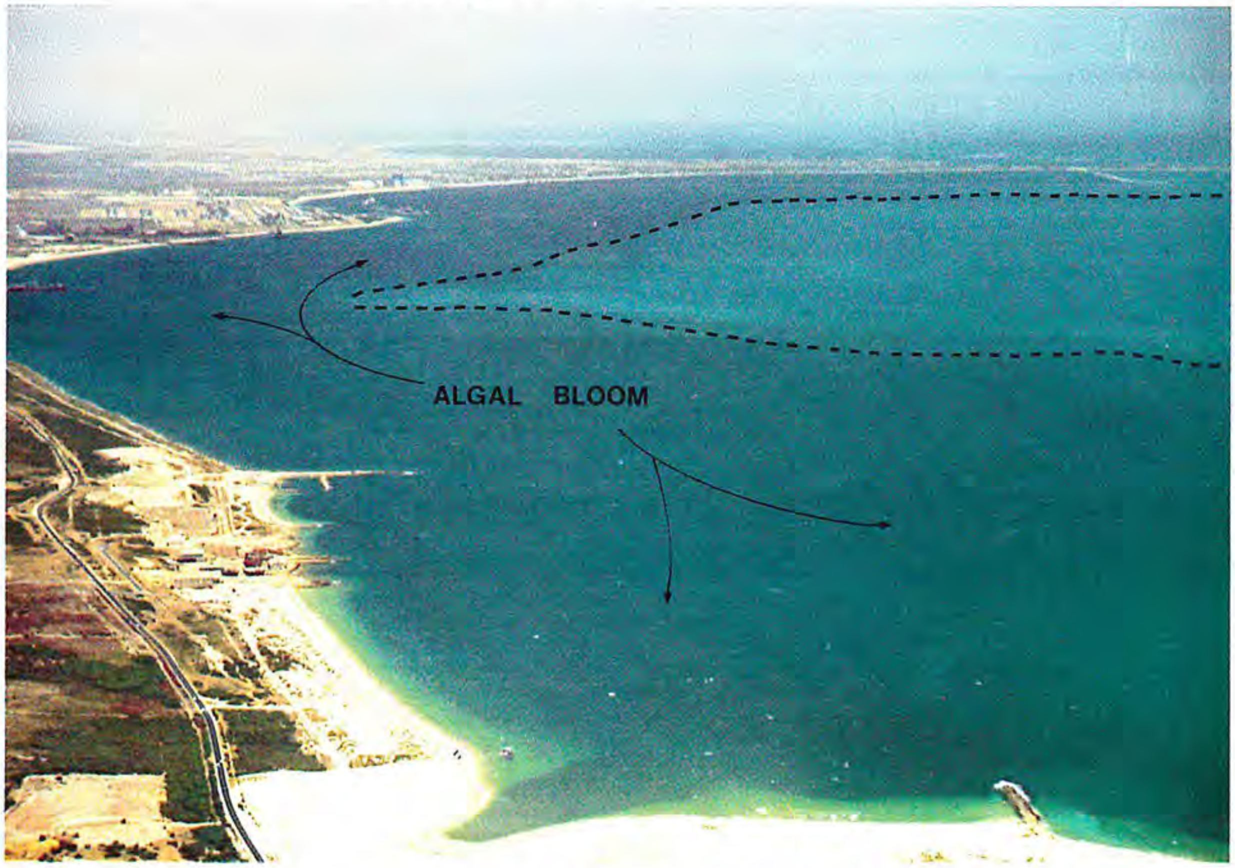



Plate 11. Extensive algal bloom covering the eastern half of Cockburn Sound from Jervoise Bay in the north to Mangles Bay in the south.

It is possible that blooms could have taken place earlier, but were not recorded because their possible importance to the degradation of the ecosystem was not recognised.

Previous studies provide substantial qualitative data about high phytoplankton biomass but more quantitative data were required to determine the likely causes and to determine appropriate measures to stop the present trend and to move toward improved water quality in the Sound. The nutrient enrichment and phytoplankton study was carried out to obtain this type of information. Much of the following section has been taken from the Technical Report[12] on this major activity carried out by members of the Cockburn Sound Study Group, with considerable assistance from the Botany Department, University of Western Australia.

For convenience in reference, Figure 7.1 graphically shows the nitrogen and phosphorus cycles and illustrates the movements of these elements within the plants, animals, waters and sediments making up the marine environment.

### 7.3.1 Objectives and Scope of Study

The objectives of the study can be condensed into four categories, as follows:

1. To describe the phytoplankton communities of Cockburn Sound; to quantify seasonal changes in diversity and abundance; and to assess the factors limiting phytoplankton biomass;
2. To quantify the main sources of nutrients in the Sound; to develop an understanding of the effects of the Sound's hydrological behaviour on the accumulation and dispersal of nutrients, and also of the effects of biological processes in the cycling of nutrients;
3. To derive an understanding of the relationship between nutrient cycling in the Sound and changes in phytoplankton abundance; then to consider the effects of any reduction in nutrient levels as a result of the control of point sources to the Sound;
4. To consider the impact of blooms upon the ecosystem of the Sound, and also upon recreation and industry.

### 7.3.2 Study Programme

A number of data collection programmes were set up. These included the following:

**Surveys of Nutrients and Chlorophyll *a*.** To assess the nutrient status of Cockburn Sound on a seasonal basis, nine surveys or cruises were undertaken over the 16-month study period. Samples were

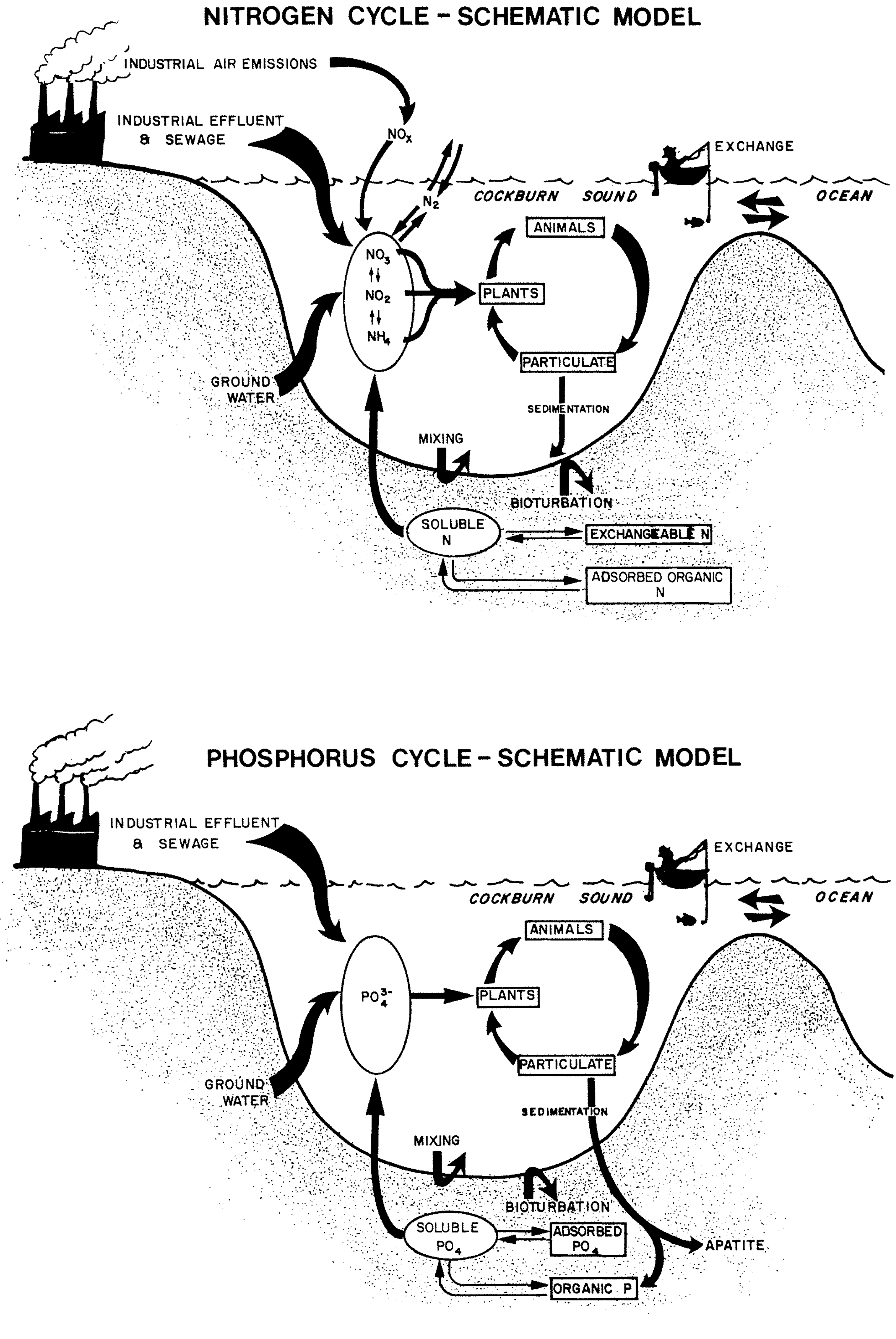



FIGURE **7.1.** Schematic model of the nitrogen and phosphorus cycles.

collected not only in Cockburn Sound, but also in Owen Anchorage, Warnbro Sound and out to sea from the southern end of Garden Island. Five sample stations were located in Owen Anchorage, 22 in Cockburn Sound, one in the middle of Warnbro Sound, and one 5 km south-west of the high-level bridge in the causeway (coastal station). Three replicate sets of samples were collected on each occasion at the coastal station and Warnbro Sound station.

**Weekly Sampling.** To allow a closer surveillance of nutrient and phytoplankton changes between major cruises, sampling was also undertaken on a weekly basis at a site in the southern part of Cockburn Sound (the CBH jetty) and also at a site in Owen Anchorage (the end of the Woodman Point explosives jetty).

**Phytoplankton.** Phytoplankton species diversity and abundance were studied at two sample sites on a weekly basis for a period of 51 weeks, from July 1977 to August 1978. Samples were collected at the same time as those for nutrients and preserved, and later phytoplankton numbers were counted using a membrane filter techniqe.

**Daily Sampling over the Summer Period.** In order to obtain some understanding of the stochastic relationships between the phytoplankton and environmental changes, sampling was undertaken daily at two sites in the southern part of the Sound. One of the sites was the same as that used in the weekly sampling, i.e. the CBH jetty, the other was the Palm Beach jetty. Sampling was continued over a period of 36 days (10 January to 12 February 1978).

**Algal Assays.** A series of nutrient enrichment assays was carried out to determine experimentally what nutrients were limiting to the growth of phytoplankton in the Sound. The first two assays were run using additions of nitrogen and phosphorus, a combination of both, and a total enrichment medium which included nitrogen and phosphorus. Water containing the natural phytoplankton assemblage from the two sampling locations sampled weekly was used.

Two later assays were done using a number of combined levels of nitrogen and phosphorus only. The first such assay was carried out with water from the CBH jetty during a bloom, and the second done with water from the Palm Beach jetty which was low in chlorophyll *a*.

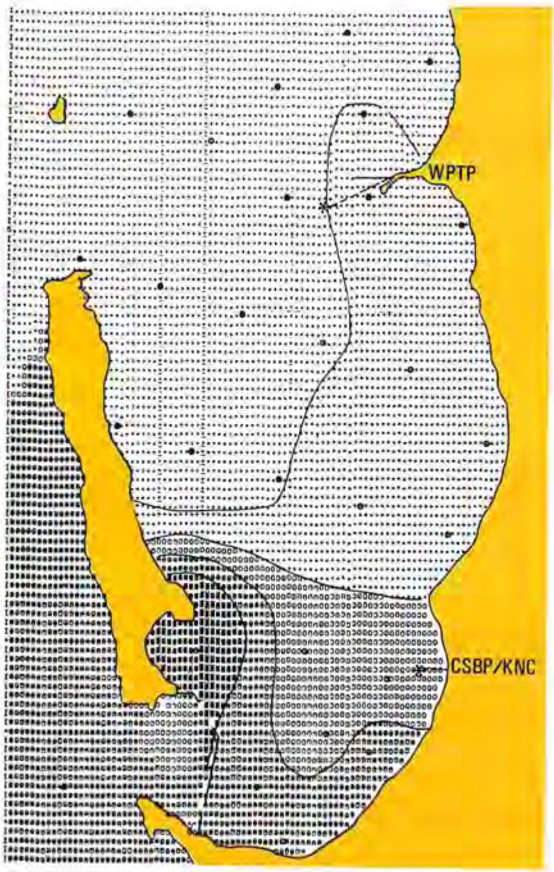
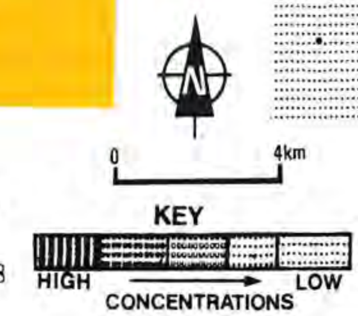



FIGURE 7.2
Distribution of Orthophosphate−P in water during winter storm pattern, 20-21 September 1978



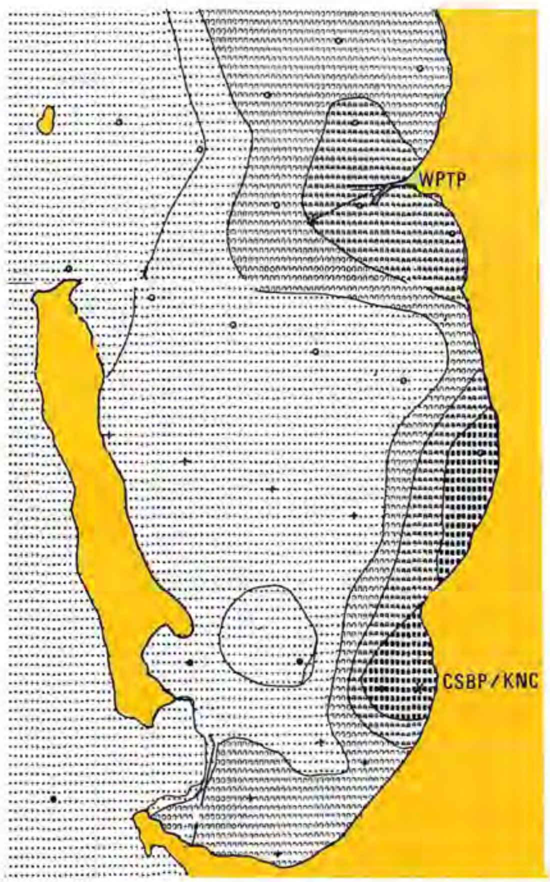




FIGURE 7.3
Distribution of Orthophosphate−P in water during sea breeze Circulation pattern, 23 May 1978

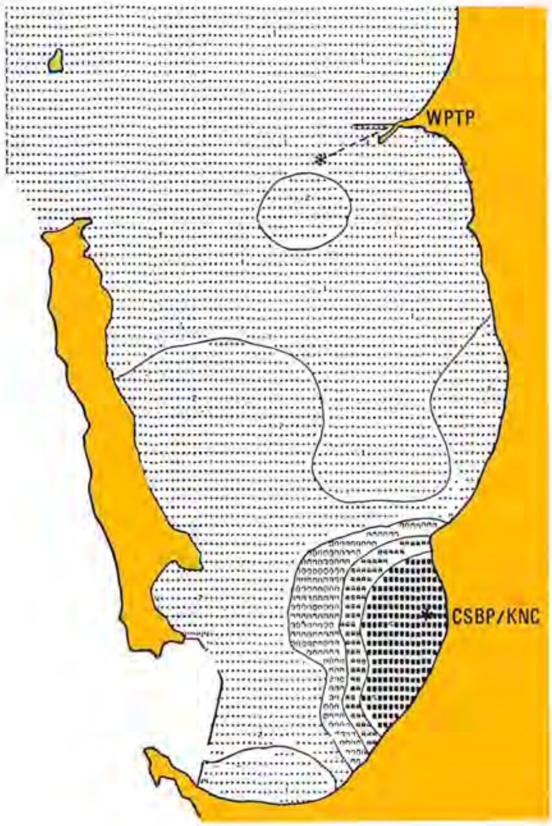



FIGURE 7.4
Orthophosphate–P
distribution in sediments

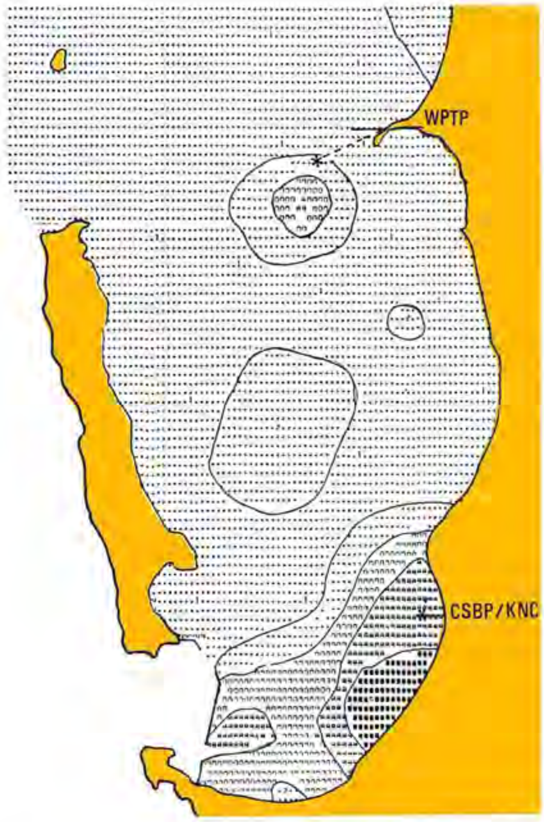
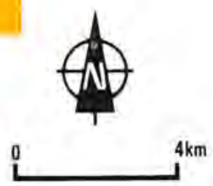
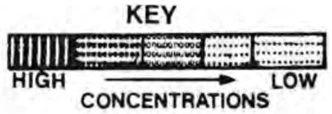



FIGURE 7.5
Ammonia–N distribution
in sediments




**Nutrient Status of the Sediments.** The amount of immediately available nitrogen and phosphorus under resuspension conditions was determined for the sediments of Owen Anchorage, Cockburn Sound and Warnbro Sound. Six sites were sampled in Owen Anchorage, 20 in Cockburn Sound and one in Warnbro Sound.

The top 2 cm of each of four replicate samples was shaken for 15 minutes within a known volume of the overlying water. After centrifuging and filtering (0.45 μm membrane filter, Millipore), the water was analysed for phosphorus in the form of orthophosphate ($PO_4$ -P), nitrogen in the form of ammonia ($NH_4$ -N), nitrite and nitrate ($NO_2$ + $NO_3$ -N). Total nitrogen and total phosphorus determinations were made on additional unfiltered samples and the values were corrected for the ambient levels in the overlying water.

### 7.3.3 Results of Study

Rather than repeat or try to summarise all of the results of the many field study programmes described above, it is appropriate to give a few examples and to discuss the results of most relevance to development of management options. The distribution of nutrients in the waters of the Sound is related to the location of inputs and to the water circulation pattern.

**Inputs.** Studies of inputs described in Chapter 5 identified the three principal sources of nitrogen during the period of the field study as KNC (through the CSBP outfall), WPTP and the BP Refinery (See Table 5.1 footnote c). Similarly principal sources of phosphorus are CSBP and WPTP. Inputs from (i) direct freshwater inflows during periods of rainfall, (ii) groundwater, (iii) nearshore coastal waters, and (iv) fallout from air emissions are believed to be small.

**Distribution in Water.** The waters of Cockburn Sound and, to a lesser degree, Owen Anchorage have very much higher values of phosphorus than the ocean or Warnbro Sound, which was used as a control area. Cockburn Sound is the only area receiving large loads of phosphorus. It is evident that these loads are being accumulated within the Sound and some phosphorus being transferred by circulation to Owen Anchorage.

The accumulation of phosphorus in Owen Anchorage shows a seasonal pattern with the highest levels in summer. It is most likely that the low levels in winter are a result of increased water exchange with the ocean. In Cockburn Sound this pattern is not evident, which reflects the poor exchange, even in winter.

Nitrogen levels in the Sound and Owen Anchorage are uniformly low and have a range comparable to that observed for the open coastal water and Warnbro Sound. Considering the large loads entering the Sound, and the evidence from algal assays that nitrogen is limiting, it can be assumed that concentrations are maintained in the Sound at low levels because of utilisation by phytoplankton.

Figures 7.2 and 7.3 illustrate the seasonal distribution patterns of orthophosphate in waters of the Sound. Figure 7.2 shows the distribution measured on a cruise during the winter period when storm conditions produce strong southerly movements of water in the Sound. The areas of highest concentrations were to the south of the CSBP outfall and in Mangles Bay.

Plate 12. Some of the phytoplankton species (minute plants) which, in very large numbers, cause algal blooms.

During the summer, the wind driven circulation is dominated by the general sea breeze pattern. Figure 7.3 shows the distribution measured during a summer cruise.

During the study, the distributions measured in the Sound for orthophosphate were compared with results of simulations with the mathematical model of the Sound described in Chapter 6. Generally, good correlations were obtained.

**Distribution in Sediments.** The accumulation in sediments is an important source of nutrients for phytoplankton. The rate or extent of release from the sediments was assessed to determine the exchange under high energy conditions from the sediments to the overlying waters. Figures 7.4 and 7.5 show the results for orthophosphate and ammonia, respectively, since these two forms of phosphorus and nitrogen are most readily assimilated in plankton growth. The correlation with location and magnitude of input is evident, with concentrations highest at the CSBP outfall and the WPTP outfall.

**Phytoplankton and Chlorophyll *a*.** The study has shown that the phytoplankton of the Sound is dominated by diatoms and dinoflagellates, and that these major groups show characteristic changes in species succession but these changes occur at a much higher frequency than would normally be expected for a coastal environment.

Measurements of chlorophyll *a* were made throughout the study as a measure of algal biomass. Values at the coastal reference station were always less than 1 μg/L whereas mean values in Cockburn Sound ranged between 1 and 5 μg/L with an individual mean station value as high as 14 μg/L being recorded. Individual values recorded during cruises varied widely. The highest chlorophyll *a* concentration recorded was over 110 μg/L during a dinoflagellate bloom in February 1979. Values in Owen Anchorage on average reflected those in Cockburn Sound but the range was very much smaller. There is a definite suggestion of a seasonal pattern in the Cockburn Sound values.

**Relationships between Nutrients and Phytoplankton.** Extensive use was made of a variety of methods for statistical analysis of the data collected and, particularly, to examine the relationship between nutrients and phytoplankton. Analyses show that there is a very good correlation between chlorophyll *a* and $PO_4$ -P both spacially and in the short term. Long term data support the conclusion that the input of nutrients from the CSBP/KNC outfall is the primary reason for the increase in phytoplankton biomass in the Sound with effluent from the WPTP being a secondary source at present.

There is good correlation both spacially and temporally between nitrogen and phosphorus. This is expected as they originate from common input points, the CSBP outfall and WPTP outfall. In addition, there was a good correlation between chlorophyll *a* and the nitrogen:phosphorus (N:P) ratio which indicated that, as the amount of nitrogen relative to phosphorus increases, so does the chlorophyll *a*.

**Algal Assays.** A number of algal assays were run to test the hypothesis that nutrients were limiting further growth of phytoplankton in Cockburn Sound. Tests were carried out using various treatments of nitrogen and phosphorus as well as a complete enrichment medium. The resulting change in chlorophyll *a* was taken as an indication of the change in biomass of phytoplankton over the period of the test. Tests were run under the natural light regime and at temperatures of the Sound.

Analyses of the results of the assays demonstrated that relatively small increases in the concentration of nitrogen will cause increases in phytoplankton biomass. The results also showed that growth rates were faster in the summer period than the winter. Even so, further growth can be stimulated in the winter, when temperatures are lower, by the addition of nitrogen.

### 7.3.4 Comparison with Other Places

Phytoplankton production rates and standing crop data were compared with similar information for coastal and estuary locations elsewhere. The primary production rates in Cockburn Sound were found to be high when compared with well-eutrophied estuaries such as the Parramatta, San Francisco Bay, and Chesapeake Bay. Again the comparison of chlorophyll *a* and nutrient levels shows Cockburn Sound is comparatively highly enriched by nutrients and has high levels of phytoplankton standing crop, particularly under bloom conditions.

### 7.3.5 Implication of the Study

Two sources, the CSBP outfall which carries effluent from KNC and the WPTP outfall, contribute almost all of the nitrogen and phosphorus to the Sound.

Of the two nutrients, field observations and algal assays have demonstrated that nitrogen is the growth limiting factor. Research elsewhere has shown that this is the case even when nitrogen and phosphorus are available in a ratio of 20:1 (by atoms). Thus control of algal blooms can be achieved by substantial reductions in the amount of nitrogen in waste discharges to the Sound but not phosphorus.

If this is done improvement in conditions should be evidenced by a reduction in the frequency of occurrence and extent of blooms.

Referring back to Figure 7.1, however, it must be remembered that the sediments represent a nutrient "bank" from which both nitrogen and phosphorus can be released over a number of years.

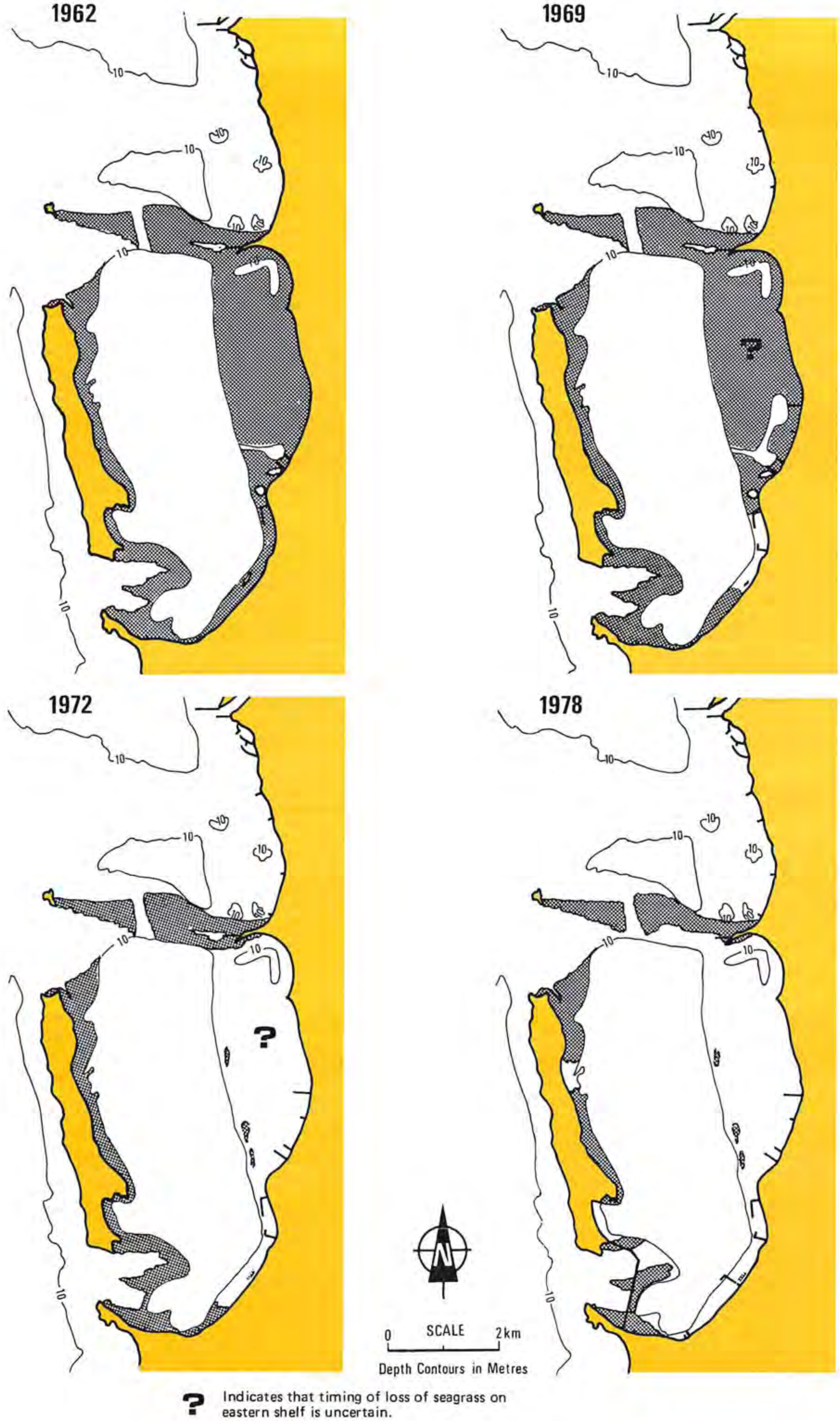



FIGURE 7.6. Progressive changes in seagrass distribution

However, the rate at which nutrients can be made available from the sediments should be lower than that at which they are added by waste discharges. So the net result would still be a substantial reduction in nutrients.

In summary, in developing water quality management plans, attention must be directed at reducing the nitrogen input at the two major sources.

## 7.4 SEAGRASS STUDIES

Before industrial development began on the eastern shore of Cockburn Sound in 1954, seagrass meadows occupied about 4000 ha of the sand banks rimming the deep basin of the Sound and extended down the sand slopes to a depth of about 11 m. In 1979 only about 900 ha remain, mostly along the Garden Island shore and across the northern barrier bank, Parmelia Bank. This loss of seagrass is of concern from the physical and biological standpoints. Seagrass stabilises the bottom and reduces the opportunity for erosion during periods of high energy waves. It also provides a habitat for fish and the detritus, or breakdown product of leaf material, is food for organisms near the base of the food chain.

Estimates of the annual production of seagrass at its "original" pre-1954 extent and at its present extent can be used as a measure of the loss to the biological system in the Sound. In 1954, it is estimated that about 4000 ha of *Posidonia* produced almost 23 000 tonnes of leaf material each year. This leaf material enters the food chain via the detrital cycle. In 1978, with 900 ha of seagrass estimated to remain and a number of areas showing decreased productivity (for example, areas of Southern Flats and Parmelia Bank) about 4000 tonnes of leaf material were being produced. This represents a loss of approximately 80 percent in primary production.

The seagrass study was one of the important segments of the Cockburn Sound Study. It was carried out by post-graduate researchers in the Botany Departments of The University of Western Australia with the assistance of various members of the study team. The summary information presented in this section draws heavily from the Technical Report[10] and it may be referred to for details.

### 7.4.1 Objectives and Scope

The scope of the study included the following tasks:

1. Measurement of the present distribution of seagrasses within the Sound, in order to compare with that prior to industrial development;
2. Determination of whether the seagrasses continue to recede;
3. Research under controlled conditions designed to identify specific causes of the decline of the seagrass;
4. Studies (jointly with other workers) upon the effects of loss of seagrass (a) biologically (b) mechanically;
5. Assessment of the environmental conditions necessary if seagrasses were to be re-established in the now denuded areas.

Results obtained with respect to these tasks are outlined in the following sections.

### 7.4.2 Distribution of Seagrasses

The past distribution of seagrass was fixed using aerial photographs from the W.A. Department of Lands and Surveys. These were augmented by core samples from sediments which were examined to determine the presence or absence of seagrass rhizome mesh. These fibre deposits were used to obtain information for areas on the eastern shelf not covered by the aerial mosaics.

The earliest set of photographs was taken in 1942 but, as underwater penetration was very poor, they were of very limited use. Photographs of the Sound's eastern shoreline in 1954 had excellent penetration and enabled plotting of the "original" distribution prior to industrial development.

Figure 7.6, based on analysis of the photographs and cores as well as recent field observations, shows the distribution for four successive periods from 1954 to 1978. The change along the eastern shoreline after 1969 is striking, as is the change in the Southern Flats area since 1972. Roughly 20 per cent of the seagrass cover in 1954 presently remains.

### 7.4.3 Sequence of Decline

The first stage in establishing an hypothesis to account for decline in the seagrass was to examine the time pattern of deterioration in aerial photographs. The major events in the sequence of dieback can be summarised as follows:

- The loss of a patch of four hectares of seagrass on James Point south-west of the BP outfall between 1961 and 1962.
- The loss of seagrass from the narrow northern edge of the James Point bank south of the AIS jetty between 1960 and 1962, with seagrass persisting over the rest of James Point.

- The loss of seagrass south of James Point as far as the Bulk Cargo Jetty between December 1967 and October 1969.
- The loss of the major portion of seagrass on James Point and the dieback south of the Bulk Cargo Jetty as far as the Rockingham Navigation Beacon between 1969 and 1972.
- The loss of seagrass on the eastern shelf at some stage between 1960 and 1976.
- The loss of the seagrass on Southern Flats at some stage between 1970 and 1976.

It is useful to link this sequence of dieback to the time of initial release of effluents from dischargers along the eastern shore. The timing of the major dieback events corresponds to the release of effluents high in nitrogen. In the case of KNC, extensive dieback of seagrass on the banks south of James Point rapidly followed discharge beginning in November 1968. The association of release of high nutrient effluent with the death on James Point and to the north is less clear-cut as underwater detail was poor in most of the relevant aerial photographs. The first area of dieback was localised on James Point and appeared suddenly between 1961 and 1962 south-west of the BP outfall, about six years after the first discharge began; other substances including hydrocarbons were being released over the same period and could also have contributed to this localised dieback.

Nitrogen from the Woodman Point sewage outfall, representing a loading approximately half to two-thirds that of the KNC effluent, contributed to the nutrient budget of the Sound from 1966 onwards. Seagrass on the eastern shelf was lost at some time between 1960 and 1976. Nutrient enrichment of the Sound waters began to be evident in early 1971, construction began on the 3000 m long causeway to Garden Island and was completed by early 1973. Breached by bridges at two points, the causeway runs across Southern Flats, the southern barrier bank of Cockburn Sound. The relatively high velocity of water through the bridges resulted in localised scouring of the seagrass within a year of completion, but by 1976 there was widespread deterioration of seagrass on Southern Flats which could not be attributed to the scouring effects. Of the 550 ha of seagrass present in 1970 about half was dead or showing reduced vigour and much of the remaining seagrass was patchy, invaded by mussels or carrying heavy epiphytic algal growths.

### 7.4.4 Causes of Decline

The study considered a number of factors which may have lead to the decline.

**Cause of Localised Loss of Seagrass.** A number of activities including the construction of groynes and breakwaters, dredging and the dumping of dredge spoil have been observed to lead to the localised depletion of seagrass.

Similarly, excessive grazing of seagrass by sea urchins was implicated in the disappearance of some of the seagrass meadows north of Rockingham.

The release of industrial discharges could also be directly implicated in the death of seagrass by the introduction of toxins. Aquarium trials showed that the BP refinery effluent is toxic to seagrasses. In the time span of the trials, however, toxicity was only at concentrations considerably in excess of those likely to be found even a short distance from the outfall. However, during rare calms, dilution and mixing of the effluent with waters of the Sound would be minimal and relatively undiluted effluent could be carried for some distance by slow moving currents. In addition when healthy seagrass plants were transplanted to a point opposite the BP refinery outfall, growth was reduced when compared with that of control plants in Warnbro Sound. Results of this experiment are shown graphically in Figure 7.7. It appears reasonable, therefore, to conclude that localised death of seagrass around the BP outfall was attributable to toxic effects. It has not been possible, however, to positively identify the toxin or toxins responsible.

Long term exposure to low concentrations of pollutants could inhibit seagrass growth, especially if they accumulate in sediments. However, it seems more likely that there were other causes in the elimination of seagrass from the entire eastern shore.

**Sand Accretion and Seagrass Growth.** Continued accretion of sand is the key to vigorous growth of *Posidonia* species which dominate the submarine meadows of Cockburn Sound. *P. australis* and *P. ostenfeldii* seem to flourish only in areas where the accretion rate is high. However, *P. sinuosa* tolerates far less sand accretion and even develops a growth pattern of elevated rows separated by sand depressions in response to the limited sediment supply.

With low sand supply, the growth is slower but, as observed along the Garden Island shore, seagrass appears to be quite capable of persisting as a dense meadow and producing seeds. Changes in seagrass growth brought about by changes in sand accretion occur over a relatively long time scale. Thus, they do not account for the recorded rapid death of seagrass, first on the eastern shore, and then on the Southern Flats and Parmelia Bank.

**Reduction of Light Owing to Phytoplankton Shading.** As discussed in Section 7.4, the waters of the

a b

Plate 13. *Posidonia sinuosa* seagrass plants six weeks after transplanting to Warnbro Sound and James Point.

(a) The plants on the left were from Warnbro Sound and show long seagrass leaves free of heavy epiphytic growth, and vigorous root growth.
The plants on the right were from James Point close to industrial effluent discharge points in Cockburn Sound; They have stunted leaves covered with epiphytic growth, and reduced root growth.
(b) The plants from James Point were also photographed under water to show the heavy epiphytic growths more clearly.

Sound are subject to nutrient enrichment and this has led to increases in the density of free-drifting algal forms of phytoplankton. The waters of Cockburn Sound now have a higher population of phytoplankton than the open ocean or Warnbro Sound. Reduction of water transparency and shading of the benthos to a point where benthic plants are unable to persist has been recorded in the literature on eutrophication of lakes and estuaries. Close consideration of the light requirements of *Posidonia* and the degree of light attenuation resulting from shading by phytoplankton shows that phytoplankton shading could have been an important secondary factory in the recession of the seagrass meadows from the deeper water, say from depths between 10 m and 5 m. However, it is not sufficient to explain the loss of the wide meadows once present in depths less than 5 m.

**Excessive Growth of Epiphytes.** Excessive growths of epiphytic algae on declining seagrass have been observed and recorded since field studies began in the early 1970s under sponsorship of the Commonwealth Department of Housing and Construction and the Fremantle Port Authority. The growth of these epiphytic algae has been increased by the increased nutrient, particularly nitrogen, input by industry.

During the field work of the Cockburn Sound Study between 1976 and 1979, heavy growth of epiphytes was observed in two areas where the meadows were in decline, the Southern Flats and the southern sector of Parmelia Bank. Rapid growth of thick mats of filamentous algae took place on equipment placed along the eastern shore during underwater tests.

Observations on the rate of build-up of epiphytes was recorded for *P. sinuosa* plants transplanted to James Point. Prior to transplanting, the plant's leaves supported no filamentous algae. Within two weeks the leaves were encrusted within two centimetres of the base with the heaviest growths on the senescent leaf ends. By the third week the leaf surfaces of all plants were thickly coated by epiphytes in contrast to transplants made in Warnbro Sound where the plants remained relatively free of filamentous epiphytes. At James Point, strong wave action during the fourth week tore most of the senescent leaf ends and filamentous algae from the leaves. Rapid build-up of ephipytes, however, occurred again before termination of the trial at six weeks. This shows clearly in Plate 13 where plants from the two transplant stations are compared.

Dense epiphytic stands can put severe stress on aquatic plants such as seagrasses. The severe stress may be explained in terms of direct shading by the epiphytes. In addition the weight of the epiphytes puts the seagrass leaves under some mechanical stress, particularly under strong wave action conditions. The seagrass study concludes that epiphytes have been and continue to be the major factor in the decline of the seagrass meadows in Cockburn Sound.

**Other Factors.** Other factors may contribute indirectly to deterioration once thinning or patchiness has begun in the meadow. The most notable of these factors has been the reduction in capacity of the meadow to act as a sediment trap and binder. As a result, sand is winnowed out by wave action from around the bases of the seagrass plants.

To summarise, the sequence of events likely to have led to the general decline of seagrass in Cockburn Sound was as follows:

- Increased nutrient loadings stimulated the growth of epiphytes and filamentous algae dependent on nutrients dissolved in the water.
- Increased epiphytic and filamentous algal growth then reduced the light available to the seagrass leaves.
- A greater proportion of fixed energy was required for maintenance and less for growth of the seagrass.
- Phytoplankton growth continued to increase and the resulting turbidity further reduced light availability.
- As the stored reserves in the *Posidonia* rhizomes were used, the number of shoots declined and the leaf canopy thinned.
- With the thinning of the leaf canopy the seagrass meadows became more vulnerable to other factors such as wave action and grazing by sea urchins, ultimately leading to widespread death of the seagrass.

### 7.4.5 Effects of Loss of Seagrass

The effects of the loss of seagrass can be considered from two aspects: (i) biological and (ii) mechanical. Each is discussed separately below.

**Biological Effects.** The biological effects of the loss of the seagrass meadows on Cockburn Sound can be illustrated by considering the contribution of seagrasses in general to the ecosystem. These contributions include (i) seagrasses have high growth rates and, depending on location, produce from 3 to 6 t/ha/y above-ground dry weight, not including root and rhizome growth; (ii) epiphytes and bacteria on living leaves and the detritus formed from shed leaves are an important and constant source of food for detritivores; (iii) leaves of a dense meadow retard wave and current action promoting sedimentation of organic and inorganic materials, and hence increase the food supply of the resident detritivores; and (iv) seagrasses take up nutrients and release metabolites including oxygen and complex organic compounds through their roots and leaves.

The original 4000 ha of seagrass probably had production rates of seagrass leaf material in the range of 5 to 6 t/ha/y, depending on location. Based on an assumed location-weighted value of 5.8 t/ha/y, the original production would have been about 23 000 t/y. The present 900 ha probably produces in the range of 3 to 5 t/ha/y, again depending on location. With an assumed location-weighted value of 4.4 t/ha/y the present production would be about 4000 t/y. This represents a loss of approximately 80 per cent of seagrass leaf production in the last 25 years.

**Mechanical Effects.** When the seagrass leaf canopy on the fringing banks of Cockburn Sound thinned and then completely disappeared it is likely that the following events occurred, particularly along the eastern fringing banks:

- The sand was winnowed by wave action, with loss of fine sediment including the detrital portions which accumulated beneath the leaf canopy.

- Coarser sediments remained but were eventually transported during storm events leaving the rhizome mesh exposed.
- The rhizome mesh eroded at weak points leaving a scarp face on the remaining mesh which eroded slowly in storms.
- Dissipation of wave energy by the seagrass leaf canopy ceased, so that reduction in energy was a product solely of bottom friction on the shelving bank. Thus, more wave energy was expended on beaches.
- More wave energy reached the shallows adjacent to the beaches when the seagrass meadows further offshore were removed. Sediment transported seasonally off the beaches was subject to more wave energy and subsequent currents once the seagrass meadows had been removed. Instead of being held as a reservoir for the next season's onshore movement, some of the sand was transported elsewhere resulting in changes in beach form.

Known effects on the fringing banks have all been localised;[16] less is known about the effect of the loss of the seagrass on the stability of the barrier banks and hence the bathymetry of the Sound.

The seagrass study concludes that the loss of seagrasses on the eastern sector of Cockburn Sound and on Southern Flats is likely to have only localised effects on shoreline and bathymetric stability because these relatively sheltered areas are disturbed only by storm events. The effects of very severe storms or cyclones could be expected to be more marked with removal of the influence of the seagrass leaf canopy in damping wave energy and trapping and binding sediments. The long term stability will depend on the durability of the seagrass rhizome mesh, at present capping the banks to a depth of up to one metre. This will be particularly important on Parmelia Bank which is exposed to greater wave action and which dissipates some of the energy of storm waves with a westerly and northerly component before they enter the Sound.

### 7.4.6 Re-establishment of Seagrass

The re-establishment of seagrasses, either naturally or artificially, is unlikely to succeed until water quality improves. Conditions of sedimentation probably are unsuitable for the natural recolonisation of the *Posidonia* meadows, although other species could be expected to vegetate the banks. Further investigation on colonisation by southern Australian seagrasses would be needed to detail the species likely to colonise the denuded banks.

### 7.4.7 Conclusion of Study

The principal conclusions drawn from the seagrass study are listed below:

1. Before industrial development commenced in 1954, there were about 4000 hectares of seagrass in the shallow water fringes of the Sound; the area now has been reduced to about 900 hectares located largely on the shore of Garden Island and Parmelia Bank; and the eastern shoreline is virtually denuded of seagrass.
2. Heavy epiphyte growths have been observed consistently on dying seagrass. This is likely to be the major factor involved in and continuing to cause the widespread depletion of seagrass meadows. In addition excessive growth of free-drifting algae reduce light penetration and retard growth of seagrass. The growth of both epiphytes and free-drifting algae are linked with the release of nutrients by BP, KNC and the WPTP.
3. BP oil refinery effluent could have killed seagrass adjacent to the outfall by chronic toxicity (toxic agent unknown) but dilution to sublethal levels would have precluded this as the primary cause of seagrass death over the entire area of dieback.
4. Localised deterioration of seagrass can be attributed to construction of groynes and shore structures altering wave patterns and sediment stability, scouring by increased water movement through the causeway bridges, dredging and seaurchin grazing.
5. The re-establishment of seagrass, either naturally or artificially, is unlikely to succeed until water quality improves; conditions of sedimentation probably are unsuitable for the natural recolonisation of the *Posidonia* meadows although other species could be expected to vegetate the banks; further investigation on colonisation by southern Australian seagrasses would be needed to detail the species likely to colonise the denuded banks.

# PART III

# ENVIRONMENTAL PROBLEMS AND SOLUTIONS

This part of the report consists of two chapters and outlines the principal environmental problems in the Sound and the range of options available for achieving short and long term solutions. Chapter 8 draws upon the results of the detailed investigations carried out during the study to define and discuss specific problems and factors affecting them. Chapter 9 describes options available for short and long term solutions to these problems and also outlines some of the steps needed to implement solutions.

## CHAPTER 8

# DESCRIPTION OF PRINCIPAL ENVIRONMENTAL PROBLEMS

This chapter draws upon the findings of segment and other studies and briefly outlines the major environmental problems in Cockburn Sound. Concepts and options for control of the problems are given in Chapter 9.

### 8.1 NUTRIENTS

It has been shown that present day loads of nutrients have lead to excessive growths of phytoplankton, particularly along the eastern edge of the Sound, which have caused or contributed to the following:

i) Increased turbidity of the water which makes it less attractive for swimming and wading and reduces the amount of light reaching seagrass, particularly in deeper waters.

ii) Blooms which occur under certain conditions and discourage water contact activities, represent an aesthetic nuisance and may contain species which are consumed by shellfish and are harmful to man. When the phytoplankton within a bloom dies and decays, dissolved oxygen levels may be reduced sufficiently to cause fish kills.

In addition, excessive growths of filamentous epiphytic algae on seagrass leaves have resulted in stress on the plants from shading and smothering effects. Epiphytes are likely to have been the main cause of the widespread dieback of the seagrass meadows, although it is recognised that localised loss may well have resulted from other causes.

Bio-assay work has shown that nitrogen is the growth limiting factor for phytoplankton in summer, when temperatures are high, and that nitrogen, temperature or light are limiting in winter. Control of the limiting factor or factors is the key to water quality management. In this case, increases in nitrogen input to the Sound's waters are likely to cause more dense phytoplankton bloom with their attendant consequences. On the other hand, decreases in nitrogen levels should reduce the amount of growth.

Nitrogen is added to the waters of the Sound, principally by wastewater discharges. Chapter 5 indicates that KNC, WPTP and BP (See Figure 5 footnote c) were the main sources. Nitrogen also is released from the sediments of the Sound as part of the nitrogen cycle illustrated in Chapter 7.

Figure 8.1 shows historical and projected loadings of nitrogen to the Sound from the three sources. Historical data for BP and KNC were provided by BP Refinery and WPTP data by the Metropolitan Water Supply, Sewerage and Drainage Board (MWSS&DB).

As shown, loadings ranged between 200 and 400 kg/d of nitrogen after the BP Refinery began discharging in 1955 and rose to about 500 kg/d when WPTP began discharging in 1966. A major rise to a total of about 2200 kg/d occurred in November 1968 when KNC commenced discharging and the loading to the Sound stayed close to 2000 kg/d for some years. Then a substantial increase up to a total of about 5000 kg/d occurred during the period 1972 to 1975 as ammonium nitrate manufacture for the iron ore industry increased. Levels remained at about this point until the BP Refinery "sour water" stripper was placed in operation in 1979. This resulted in removal of about 260 kg/d and shows on Figure 8.1 as the small drop in 1979. KNC proposes to improve the process dynamics in its ammonium nitrate plant and to reduce the free ammonia in the ammonium nitrate product. It will also consider recycling of wastewaters containing ammonium nitrate to its nitric acid manufacturing plant. These should reduce KNC loadings by 97 per cent. A recommendation to install the necessary equipment is being considered by the KNC Board at present (October 1979) with a view to installation in 1980 and 1981.

The graph shows projected total loadings from 1980 to the year 2000 for two conditions, one with and the other without the proposed reduction by KNC. The graph also shows the projected loading for WPTP alone. Industries contacted during the study did not forecast any activities producing appreciable additional loadings of nitrogen. Therefore, for the future, it has been assumed that the remaining industrial load, other than for KNC, will remain constant. At WPTP, however, rates of flow will increase and nitrogen levels will go up as shown by the lowest line of the three projections. By the year 2000, total projected nitrogen loads will be in excess of 6000 kg/d with about 5700 kg/d or 95 per cent from WPTP, assuming the reduction of KNC input. With the KNC input at the present level, the total nitrogen load would approach 9 000 kg/d by the year 2000.

In this report two levels of control of nitrogen discharges to the Sound are suggested. The first is to reduce inputs of total nitrogen to levels occurring in the early 1970s before nuisance blooms of free-drifting algae were recorded. Figure 8.1 shows that the total nitrogen load was about 2000 kg/d during that period.

The second is to reduce inputs of total nitrogen to levels occurring in the late 1960s before regional dieback of seagrass occurred southward from James Point, in an attempt to limit further dieback of seagrass in the Mangles Bay-Southern Flats area. Figure 8.1 shows that the total nitrogen load was somewhat below 1000 kg/d before KNC began operation.

Figure 8.1 also shows that the total input projected for 1980 is about 5000 kg/d and that the total could be reduced to about the 2000 kg/d objective for nitrogen input if the reduction proposed by KNC were achieved at that time. In following years, however, the total would increase.

## 8.2 MICROBIOLOGICAL QUALITY OF SHORES AND INSHORE WATERS

It has been shown that micro-organisms in waters along several segments of the eastern shoreline of the Owen Anchorage-Woodman Point area include faecal coliform and Salmonella serotypes in concentrations of concern from a public health standpoint. Values significantly in excess of suggested water quality criteria for faecal coliforms have been recorded at times in recreation areas, particularly near Woodman Point, and are associated with discharges from the abattoirs into Owen Anchorage and with the WPTP discharge.

While faecal coliform organisms are non-pathogenic themselves, they serve as "indicators" of relatively recent faecal pollution by warm-blooded animals, including man. A more direct confirmation of potential health hazard is the observed presence of Salmonella serotypes which include those identified in gastroenteritis episodes in the Perth area.

It is appropriate here to note that disinfection of public water supplies is often used to protect public health. Chlorine is most often used for this purpose. However, in the seawater environment, residual chlorine or chemical complexes formed between chlorine and organic matter in wastewaters can be detrimental to marine life. Thus, as shown in Table 3.3, water quality criteria include a stringent limit for residual chlorine.

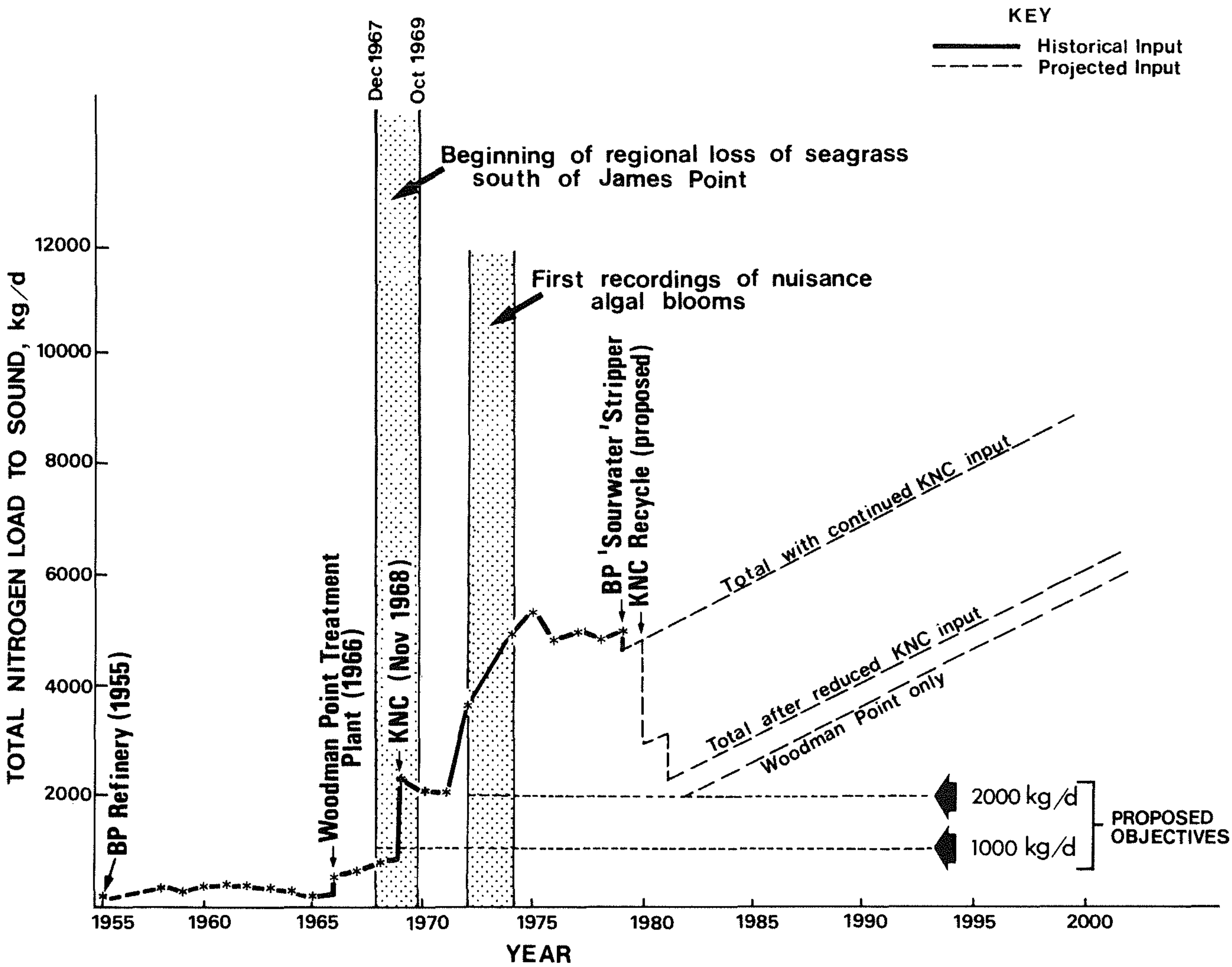



FIGURE 8.1. Historical and projected nitrogen loads to Cockburn Sound.

## 8.3 GROUNDWATER CONTAMINATION

It has been found that chemical constituents from a wide variety of process wastes, spillages and effluents are present in the unconfined aquifers underlying the eastern shores of Cockburn Sound, particularly at Kwinana. Since the natural flow of groundwater is toward and ultimately into Cockburn Sound, any contaminants will reach the Sound eventually unless they are intercepted or immobilised.

Process liquors from the Alcoa Refinery are reaching the groundwater under the refinery site. Analyses showed contamination mainly by caustic substances. The residue from bauxite refining at the Alcoa Refinery is pumped to special "mud lakes" which are sealed to prevent contamination. However, the sealed bottoms have leaked on occasion and wastewater has seeped into the aquifer. In general, recovery operations have been successful in limiting the spread of polluting plumes.

At the BP Refinery, the safety basins surrounding storage tanks are unsealed. Water routinely drained from the tanks and portions of oil were allowed to seep into the groundwater. Estimates based on analyses of samples from bores in the refinery area show that about 25 ML of liquid hydrocarbons and 14 ML of absorbed hydrocarbons are presently beneath the refinery site. The liquid hydrocarbons floating on top of the water table would constitute a substantial and long term input if they continue their observed migration toward the Sound.

At the Western Mining Corporation nickel refinery (WMC), ammonia, sulphate, chloride and nickel (in concentrations ranging up to 44 μg/L) have been found in groundwater near the land disposal operation. At Chemical Industries Kwinana and CIG, phenol, 2,4-D and 2,4,5-T have been found in analysis of samples from bores.

In the Owen Anchorage area, many of the industries dispose of their wastewaters by various land disposal practices. However, the groundwater pollution problem created thereby is small in comparison with that of the Kwinana area.

## 8.4 CONTAMINATION OF FISH AND SHELLFISH

Shellfish in various parts of the Sound are subject to contamination by heavy metals and by *E. coli* and Salmonella micro-organisms; these types of contamination relate to public health. Shellfish containing relatively high concentrations of faecal coliform and Salmonella micro-organisms were found in shore and offshore areas affected by the discharges from abattoirs into Owen Anchorage and from the Woodman Point Wastewater Treatment Plant into Cockburn Sound. If the shellfish are eaten raw or improperly cooked, there could be concern from a public health standpoint.

Another type of contamination which results in tainting or "off-flavour" of fish probably relates more to aesthetics than to health, since it is unlikely that persons would continue to eat tainted fish consistently over a long period of time. This tainting of fish flesh may be associated with hydrocarbons. The major source of hydrocarbons causing tainting may be either spills or leakages from process heat exchange at the BP Refinery into its cooling water discharge. Tainting is more a function of pollutant concentration at a given time rather than of accumulation (as in the case of metals in shellfish).

Extensive investigations of the content of heavy metals in mussels and crabs were carried out as part of the study segment dealing with the distribution of contaminants.[7] Many individual specimens from various portions of the Sound had concentrations of one or more metals in excess of those listed in Table 3.2 as Western Australian standards. Elevated levels of cadmium are attributable to the CSBP waste discharge because it is the major source discharging to the Sound and because of the observed distribution patterns of the results of analyses.

## 8.5 AESTHETIC QUALITY OF WATERS AND SHORES

To many persons, perhaps the casual beach user, for example, this "problem" may be the most important. Results of interviews with individuals and community groups described in Chapter 4 indicate a widespread concern for the characteristics and conditions which collectively come under the heading of "aesthetics."

Many conditions relate to local and regional land use aspects and it is beyond the scope of this study to examine options for their solution. However, the two principal conditions relevant to the present study are phytoplankton growth and discolouration of nearshore waters.

As described in Section 8.1, phytoplankton growth is a result of nutrient enrichment. From the aesthetic standpoint, excessive growths which occur along the eastern fringes of the Sound reduce visibility in the water and give it a turbid appearance. This reduces the visual and physical enjoyment of the shoreline of the Sound for swimming and wading and can be a deterrent to pleasure boating.

Discolouration of nearshore waters occurs at or near a number of discharges to the Sound and Owen Anchorage. However, the blood red colour from abattoir discharges into Owen Anchorage would be the most noticeable, particularly with onshore winds.

## CHAPTER 9

# DEVELOPMENT AND EVALUATION OF SOLUTIONS

This final chapter of the study report describes actions which can control the principal environmental problems identified in Chapter 8. Briefly, these include the following conditions or characteristics: (i) nutrients in waters of the Sound, (ii) microbiological quality of shore and shore waters, (iii) groundwater contamination, (iv) contamination of fish and shellfish, and (v) aesthetic quality of shore and near shore waters.

Some actions can be accomplished readily and some are already being implemented by industries. Other actions require engineering and economic investigations and analyses before the best option can be selected. In any event, many of the short term actions can improve specific conditions or prevent further degradation of Cockburn Sound and the community resources it provides.

For convenience, the chapter is divided into six sections, as follows:

Section 9.1 describes the possible disposal options for dealing with discharges having objectionable or undesirable constituents.

Section 9.2 discusses short and long term solutions for specific environmental problems.

Section 9.3 deals with ocean disposal of wastewater and compares several alternative discharge locations.

Section 9.4 evaluates the concepts and solutions contained in sections 9.2 and 9.3.

Section 9.5 gives brief conclusions about the effectiveness of the solutions described in this chapter.

Section 9.6 gives specific recommendations for the initial steps in implementing the solutions. It should be noted here that this study points out appropriate solutions and actions, but that it is not intended to replace decision-making responsibilities of industries or governmental authorities.

## 9.1 POSSIBLE DISPOSAL OPTIONS

There are two broad options for dealing with unsatisfactory contaminants contained in effluent discharges: one involves diverting the effluent to a different part of the marine environment where the contaminants no longer have a significant adverse effect, the other removing the contaminants on shore.

### 9.1.1 Diversion of Effluent or Contamination

Most of the water quality problems in Cockburn Sound arise from the poor flushing and lack of interchange with the sea. As a result, pollutants have the opportunity to accumulate and reach concentrations which would not have arisen had the circulation of water been more vigorous.

For this reason, it is now apparent that relocation of the outfalls within the Sound is not likely to achieve the dispersion and dilution required. However, if these effluents were carried out into deep water, which is part of the oceanic circulation system, the present problems would disappear. Some form of in-plant treatment would still be necessary before discharge, particularly to remove floatables.

### 9.1.2 Removal of Contaminants

Existing discharges could continue if the undesirable pollutants were removed by in-plant treatment or process change prior to discharge of a purified effluent. The feasibility and cost of this effluent treatment will vary widely from plant to plant depending on the concentration and type of pollutant.

## 9.2 SOLUTIONS FOR SPECIFIC PROBLEMS

This section considers each of the five conditions or characteristics associated with the principal environmental problems. It discusses the actions which the major sources, contributing to each problem, are or could consider taking to eliminate or minimise contributions. Except where noted, information presented here was obtained from the various discharges during work on the Technical Report on Industrial Effluents and the report can be referred to for additional details.

### 9.2.1 Nutrients

As described in Chapter 8, the input of nutrients in wastewater discharges to the Sound is an underlying cause of periodic blooms of phytoplankton in the waters of the Sound and of filamentous algal growths leading to the loss of seagrass from large areas of the periphery of the Sound. Nitrogen has been identified as the limiting nutrient and, therefore, reduction in the quantity of inputs of nitrogen compounds is an action of primary importance.

Table 5.1 shows that loadings of total nitrogen (as N) amount to about 5000 kg/d for Cockburn Sound. Major sources discharging to the Sound and their loadings as listed in the table are KNC (2700 kg/d), Woodman Point Wastewater Treatment Plant (1400 kg/d), and BP Refinery (320 kg/d, now reduced to 60 kg/d since "sour water" stripper was installed). The Owen Anchorage Industries as a group account for a total of 620 kg/d.

As described in Chapter 8, KNC is considering improvements which could reduce the present load of 2700 kg/d by a total of 97 per cent, to a load of about 100 kg/d. However, KNC has indicated that further in-plant reduction would involve an expensive ion exchange process. Thus, it appears that the future KNC input can be expected to be about 100 kg/d, if the presently proposed in-plant improvements are made.

Reduction of nitrogen loads from the Woodman Point Wastewater Treatment Plant (WPTP) could be achieved by the addition of a nitrogen removal process at the plant or by relocating the plant discharge to an ocean location outside the water circulation patterns affecting the Sound. A number of in-plant processes exist for nitrogen removal. All involve major capital investment as well as substantial operating costs. Relocating the discharge also would involve major capital investment. In any event, detailed investigations of factors affecting cost would have to be carried out and preliminary economic analyses made to determine the most appropriate action.

Since carrying out the intensive sampling work (on which the input loadings were based) the BP Refinery has installed and is operating a "sour water" stripper as a part of a major expansion of its catalytic cracker facility. The stripper effectively removes ammonia, hydrogen sulphide and phenol, but has no effect on nitrate or nitrite forms of nitrogen. Loadings calculated after the expansion and with the stripper in operation are presented in the technical report and show that the total nitrogen load from the three BP Refinery outlets is now about 60 kg/d, an overall reduction of 83 percent from the 320 kg/d given above. It should be noted, however, that the stripper itself has an efficiency of 99 percent or higher for ammonia removal.

Several alternatives exist for coping with the nitrogen load of 620 kg/d contained in waste discharged to Owen Anchorage. These include (i) one or more treatment works in the industrial area, (ii) conveyance to the WPTP for treatment and disposal along with effluent from the plant, and (iii) conveyance to an ocean disposal location well offshore. Possible methods for dealing with wastewaters from the Owen Anchorage industries have been studied several times in the past, but no general plan has been adopted. It would appear appropriate to consider these alternatives as part of the assessment of the WPTP alternatives mentioned above.

In summary, recorded reductions or those that could be achieved within 2 or 3 years should reduce the present total nitrogen loading to the Sound from 5000 kg/d to about 1800 kg/d. The WPTP loading of 1400 kg/d represents 80 percent of the total remaining. This represents a very substantial reduction and results in a total loading comparable with the 2000 kg/d objective for total nitrogen loadings with respect to limiting excessive blooms of free-drifting algae. However, it is more than twice the 1000 kg/d objective with respect to limiting seagrass dieback. As shown in Figure 8.1, nitrogen loadings in the future will parallel the increases at the Woodman Point plant. It should be emphasised that KNC modifications at this stage are no more than proposals.

### 9.2.2 Microbiological Quality of Shores and Shore Waters

As described in Chapter 8, the microbiological quality of shores and shore waters studied during the period March to December 1977 by officers of the Department of Health and Medical Services and the Cockburn Sound Study Group, showed contamination by faecal coliform bacteria and by Salmonella serotypes. Contamination was found at shoreline sampling stations ranging from South Beach to Woodman Point and at several stations offshore from this section of shoreline. Two sources of contamination were identified: abattoirs in the Cockburn Road Special Industrial Area and the WPTP.

In-plant treatment would involve a high degree of disinfection, but to achieve this on a consistent basis it would be necessary to remove a substantial proportion of the suspended solids since microorganisms contained therein are shielded from contact with the disinfectant.

Alternatively, wastewater from these sources could be disposed of outside the circulation systems of Cockburn Sound and Owen Anchorage.

### 9.2.3 Groundwater Contamination

As noted in Chapter 8, a wide variety of contaminants has been found in the unconfined aquifers which underlie the shoreline of Cockburn Sound and Owen Anchorage. Since the general movement of the groundwater is toward the sea, corrective measures should be aimed at (i) preventing entry of contaminated surface or process waters into the ground, and (ii) recovering contaminants by pumping from strategically placed bores in areas with localised contamination thereby preventing the contaminated water from reaching either the Sound or Owen Anchorage.

Unsealed lagoons, seepage pits and a disused bore are used by many establishments for disposal of effluents. Lagoons should be sealed and the practice of using seepage pits or disused bores for effluent disposal stopped as soon as practicable. In addition, unsealed ground surfaces in storage or other areas where spills could occur should be sealed, and presently sealed areas checked for effectiveness.

Contaminated groundwater recovered by pumping presently is used for process water by Alcoa, BP and CSBP. This practice also serves to slow the progress of contaminated groundwater toward the sea. Pumping for reuse or recovery is useful as a means of reducing possible effects of past practices.

### 9.2.4 Contamination of Fish and Shellfish

As stated in Chapter 8, three conditions are of concern. These are (i) heavy metals, (ii) *E. coli* and Salmonella micro-organisms, and (iii) tainting. Solutions for achieving control of each are given separately below.

**Heavy Metals.** Concentrations of cadmium, lead, chromium and zinc have been found to exceed various health standards in certain edible shellfish species. The CSBP discharge to Cockburn Sound is the major source of cadmium (4.3 kg/d) and with BP, WPTP, SEC and AIS, also makes up the significant portion of the input of the other heavy metals in the Sound. Effluents from tannery operations discharging to Owen Anchorage contain about 22 kg/d of chromium.

Since the metals from CSBP are present as impurities in the gypsum discharged to the Sound, control of the addition of metals from CSBP must involve changes in present gypsum disposal practice. This is particularly important since CSBP proposes to increase the gypsum present production of 350 tonnes per day to 1000 t in 1982 and eventually to 1700 t.

Disposal in deep offshore waters of the open ocean with no opportunity for accumulation of metals can be accomplished either by barging or by an outfall pipeline. Land disposal is a practical alternative if adequate protection of groundwater can be achieved by sealing pond bottoms and providing berms or dikes high enough to prevent overtopping during periods of heavy rainfall runoff.

CSBP has announced its intention to develop a land disposal system and has secured land for that purpose. Proposals for the new disposal system have been submitted for approval by relevant State government authorities. Sealing or lining the ground surface of the disposal area and monitoring groundwater quality to ensure its effectiveness are key requirements for satisfactory operation. Present time schedules call for the land disposal system to be in operation within two years. This system can be a long term solution only if large areas of land can be found within an economical haul distance from CSBP, and this matter is under study at present. It is appropriate, therefore, to include wastewaters from CSBP in studies of alternatives providing for deepwater disposal of various wastewaters to the ocean beyond the Sound. Control of discharges of chromium from tanneries to Owen Anchorage directly or by way of seepage ponds may be achieved by in-plant treatment prior to discharge, or by conveying effluent beyond the influence of circulation patterns of Owen Anchorage and Cockburn Sound. As mentioned elsewhere, treatment and disposal by a wastewater tributary to Woodman Point Wastewater Treatment Plant is another alternative.

***E. Coli* and Salmonella Serotypes.** Concentrations exceeding levels considered safe for human consumption have been found in mussels at shoreline and offshore sampling stations in the vicinity of Woodman Point and Owen Anchorage. This situation represents a potential hazard to health if the shellfish are consumed without adequate cooking. The principal sources of *E. coli* and Salmonella serotypes have been identified as the abattoirs discharging to Owen Anchorage and the WPTP. Alternatives for control of these microbiological contaminants were discussed earlier in this chapter in connection with the microbiological contamination of shores and shorewaters and will not be repeated here.

**Tainting.** Tainting of fish has been reported occasionally and may be related to discharge of petroleum hydrocarbons from the BP Refinery and from oil spills. Most of the hydrocarbons from the refinery are contained in low concentrations in the large volumes of salt water (465 ML/d) used for cooling purposes and are likely to be the result of very small leaks. It would be impractical to attempt to treat such a large volume of salt water, which is believed to contain about 60 per cent of the total petroleum hydrocarbons. However, consideration could be given to interception and separate treatment for as many as possible of the other sources within the Refinery. These could include ballast water, the API No. 1 separator, the sour water stripper and Tank No. 3, each of which is described in the report on Industrial Effluents. It is estimated that, as a group, the effluents from these sources have a volume of about 6.55 ML/d, and contain between 50 and 60 percent of the organic compounds defined in Chapter 5 as petroleum hydrocarbons. This volume could be provided for in alternatives of deepwater disposal.

In addition to this source of hydrocarbons, the flow of groundwater underlying the BP Refinery is slowly transporting hydrocarbons towards the Sound. Present hydrocarbon input to Cockburn Sound from this source is believed to be as little as 0.1 kg/d, but if no remedial work is undertaken before 1983 this amount could rise substantially.

Tainting of fish may be related to the concentrations of hydrocarbons to which they are exposed rather than the effects of accumulation. The whole question of tainting is clearly one which requires further study.

### 9.2.5 Aesthetic Quality of Waters and Shores

As noted in Chapter 8, many conditions are interpreted by the public as impairing aesthetic quality and enjoyment of the waters and shores. However, in large part these can be traced to excessive phytoplankton growth due to nutrient enrichment or to discolouration of the shore waters by the blood red colour of abattoir wastes, particularly when onshore winds keep the wastes close to the shore. Solutions for dealing with nutrient enrichment and with abattoir wastes have been discussed earlier in this chapter and need not be repeated here.

## 9.3 OCEAN DISPOSAL

Disposal of wastewaters to the ocean represents a long-term regional solution for disposal of municipal and industrial wastewaters. Effluents whose characteristics are associated with environmental problems in Cockburn Sound or Owen Anchorage would be removed from these areas where mixing and exchange are restricted and capacity could be provided for future industries. In deep offshore waters, a high degree of initial mixing can be obtained since dispersion and coastal water movements greatly exceed those in the Sound or nearby waters.

It is recognised that some form of treatment would need to be provided prior to ocean disposal. Its type, cost and other features have not been considered in the present study but would be included in any feasibility study of schemes involving ocean disposal. In any case, however, the degree of treatment would be considerably less than that which would be required if discharge to the Sound or nearby water is continued.

This section is divided into four parts. The first briefly describes factors affecting ocean disposal; the second indicates the locations and quantities of inputs which could be included in an ocean disposal scheme; the third indicates conceptual layouts for several different ocean outfall schemes; and the fourth gives indicative or range estimates of construction costs.

### 9.3.1 Factors Affecting Ocean Disposal

In modern ocean outfall practice, effluent is carried some distance out to sea in a submarine pipeline laid on the seabed, and discharged through a diffuser, a length of pipe with many holes in the walls. The object of the diffuser is to distribute the discharge as uniformly as possible along the farthest offshore sections of the outfall. The amount of dilution produced by an ocean outfall depends on many factors. These include effluent density, ocean water density, diffuser port diameter, port discharge velocity, port spacing, port discharge angle, effluent discharge rate, length of diffuser, depth of ocean water above diffuser, diffusion and dispersion characteristics and ocean current velocities. Each of these factors is known or can be determined by ocean studies carried out for the specific purpose and outfall performance can be reliably predicted.

Design and construction of an ocean outfall must be based on a knowledge of specific local conditions. These include the bathymetry, topography and composition of the seabed as well as wind and wave climate, tides and currents. The procedures for determining these conditions are well known as are their effects and impacts on design and on construction methods.

There are a number of general methods which can be used either singularly or in combination to construct an ocean outfall. Alternative methods include tunnelling beneath the seabed, surface towing, bottom towing, laying prefabricated lengths, laying from barges, laying from movable platforms, or laying from a trestle. The choice depends on an evaluation of the factors and conditions listed above as well as the availability and cost of specialised marine construction equipment such as pipe-laying barges, walking platforms, jack-up barges, and offshore drilling rigs. Construction work on North West Shelf projects may involve use of several types of specialised marine equipment.

### 9.3.2 Sources and Quantities of Inputs

An ocean disposal system would not need to handle all wastewater flows from all sources. Indeed, a system capable of handling the large volumes of salt water used for cooling, about 1000 ML/d by each of the SEC power stations, for example, would be economically and physically impractical as well as unnecessary from a pollution control standpoint.

Table 9.1 lists the sources and potential quantities of effluent which could be intercepted for disposal in a submarine outfall scheme. Although some nutrients and heavy metals would continue to reach the Sound and nearby waters with cooling water discharges, removal of the quantities shown would achieve very substantial reductions in the loadings within the Sound and Owen Anchorage and, in addition, would result in a major improvement in microbiological quality.

To account for diurnal variations, rates of flow for use in conceptual design of submarine outfall schemes have been increased by a factor of 2.0 for industries in the Cockburn Road Special Industrial

Area and by 1.25 for the two wastewater treatment plants. Flows from the sources in the Kwinana Industrial Area are believed to be reasonably constant and have not been increased.

### 9.3.3 Conceptual Layouts for Submarine Outfalls

For the purpose of the Study, three alternative wastewater disposal locations have been assumed and several conceptual layouts of land and marine pipeline sections have been considered. Only one conceptual layout, with indicative costs, is given in Figure 9.1. In each case, it has been assumed that the discharge would have to be at an ocean depth of 20 metres.

The three locations are:

- to the north-west of the entrance to Fremantle Harbour;
- directly west from Woodman Point between Carnac Island and Garden Islands to the seaward side of Five Fathom Bank;
- west of Cape Peron, also to the seaward side of Five Fathom Bank.

These discharge locations are based on the assumption that water mass movements and other conditions would provide rapid mixing, dispersion and transport generally parallel to shore away from the discharge area. After collecting data on physical and other factors affecting outfall performance, it may be found that satisfactory conditions can be achieved with shorter outfalls. The possible performance of an outfall extending into Owen Anchorage north-west from Woodman Point also could be examined. Little is known about water circulation patterns in Owen Anchorage and about the potential for an accumulation of nutrients there. Observations during the Study showed that waters from Owen Anchorage move into Cockburn Sound under certain conditions. However, the effect of intermittent nutrient infusions on phytoplankton growth in the Sound is not known while Owen Anchorage itself may well be subject to the same eutrophication problems as Cockburn Sound. For the present, therefore, it is prudent to consider the discharge locations farther from shore.

A pipeline west from Woodman Point between Carnac and Garden Islands to the seaward side of Five Fathom Bank would involve by far the longest length of submarine outfall and the negotiation of shallow reef areas between the islands. The conceptual layouts which incorporate this discharge location would cost considerably more than that presented in Figure 9.1.

Navigational and environmental considerations make a discharge location north-west of the entrance to Fremantle Harbour undesirable.

### 9.3.4 Environmental Considerations

It may be thought that disposal of effluent into deep offshore water is merely transferring the problem from Cockburn Sound to ocean waters. However, this is unlikely to be the case. The nutrient loads of nitrogen and phosphorous which are a primary cause of water quality problems in Cockburn Sound would certainly create no problem in the well-flushed waters beyond Garden Island. The Indian Ocean is notably low in nutrients compared with other oceans, a fact which partly accounts for its relatively poor productivity. Biodegradable wastes are also unlikely to pose any problem provided all floating material including oil and grease is removed before discharge. The mortality of pathogenic bacteria is such that a remote discharge into such deep water would pose no risk from a health standpoint. The risk of heavy metal uptake in marine biota remains the only factor which would need serious environmental study if an ocean discharge was proposed.

### 9.3.4 Indicative Costs

Indicative costs were prepared for the conceptual layouts so that alternative solutions could be compared.

Costs for shore pipelines shown on Figure 9.1 were estimated using a unit price of $300 per kilometre per millimetre of diameter. The estimates are based on normal construction conditions, particularly with regard to ground conditions and access.

Costs for submarine pipelines are dependent on the diameter and on the oceanographic and other conditions mentioned in Section 9.3.1 and, accordingly, are more difficult to generalise than costs for pipelines on shore. Analyses of construction conditions and costs of 47 submarine outfalls in Australia, New Zealand and the United States were made by I.G. Wallis[17] and costs per unit of length developed for expensive, ordinary and inexpensive conditions. For present purposes, it has been assumed that construction conditions would be between the "ordinary" and "inexpensive" categories. It has also been assumed that differences between labour, materials and other costs would compensate for currency differentials between Australia and the United States. On this basis, an indicative cost of $2300 per metre of length has been used for the 1700 mm diameter outfall.

All construction costs exclude allowances for contingencies, engineering, rights of way, legal, administrative and other overhead charges. These allowances would need to be taken into account

TABLE 9.1

**SOURCES AND PROJECTED QUANTITIES FOR SUBMARINE OUTFALL DISPOSAL SCHEMES**

| Source | Contaminant or effect | | | | | Daily max. flow rate |
|---|---|---|---|---|---|---|
| | Nutrients | Heavy metals | Petroleum hydrocarbons, phenolics and sulphides | Micro-organisms | Aesthetic factors | ML/d |
| Kwinana Industrial Area (year 1978)[a] | | | | | | |
| BP Refinery (4) | X | X | X | | | ≃ 6.55 |
| KNC (3) | X | | | | | 0.7 |
| CSBP (3) | X | X | | | | 2.1 |
| WMC (2) | X | X | | | | 1.5 |
| Others (4) | | X | | | | 0.05 |
| Total | | | | | | 10.9 |
| Cockburn Road Special Industrial Area (year 1978)[b] | | | | | | |
| WAME (7) | X | | | X | X | 4.4 |
| Other meat proc. (6) | X | | | X | X | 3.0 |
| Hides (6) | | X | | | | 0.6 |
| Total | | | | | | 8.0 |
| Wastewater Treatment Plant (year 2001)[c] | | | | | | |
| Woodman Point (5) | X | X | | X | X | 156 |
| Cape Peron (1) | X | | | X | X | 14 |
| Total | | | | | | 170 |
| Grand total | | | | | | 188.9 |

Numbers in parenthesis indicate location of input shown on Figure 9.1.

[a] No long term increases are expected, except for CSBP.
The figure, 2.1 ML/d, assumes 1000 tonnes/d of gypsum being produced, with gypsum as 40% weight/weight in the slurry.

[b] WAME and Anchorage reportedly are planning major expansion but discharge forecasts are not available; daily maximum flow assumed 2.0 times the average rate.

[c] Daily maximum flow assumed 1.25 times the average rate.

during preliminary design studies.

It must be emphasised that the indicative costs shown are for shore and submarine pipelines only. At this stage, no attempt has been made to estimate costs for pumping stations or for pre-treatment by various contributors. These costs as well as refined costs for the pipeline would be developed during feasibility or preliminary design studies when specific information is obtained.

The most economical solution, bearing in mind the many unknown factors, would be for a small pipeline to start at the West Australian Meat Commission and pick up the remaining Owen Anchorage Industry effluents, converting to a large pipeline to include the Woodman Point Treatment Plant effluent. This pipeline could then collect effluent from the industries adjacent to Cockburn Sound before discharging well offshore from Cape Peron (Figure 9.1).

Such a scheme would involve a pipeline cost of the order of $27 million excluding pre-treatment costs, pumping station and all ancillary costs.

It must, however, be emphasised that preliminary studies of land routes, as well as studies of the many oceanographic and other factors relating to submarine outfall construction and performance, would have to be undertaken before a final decision is reached.

In addition, hydraulic studies must be carried out to determine the best arrangement for necessary pumping facilities, and predicted submarine outfall performance must be related to the various wastewater constituents to determine the nature of in-plant treatment required.

## 9.4 EVALUATION OF SOLUTIONS

Section 9.2 described specific improvements proposed by industries and the general courses of action available for industries to reduce their output of undesirable constituents. These can be classed as "local" solutions in comparison with the regional solutions developed in Section 9.3. No attempt has been made during the Cockburn Sound Study to estimate costs of in-plant work since the industries themselves are in a much better position to make meaningful economic analyses and comparisons.

The WPTP can be used as an example of evaluation of alternative actions. However, it is recognised that the MWSS&DB has the responsibility for decision making. Plans are well advanced for construction of a new primary treatment plant with an average dry weather flow capacity of 125 ML/d. The preliminary design report[18] indicates an estimated construction cost of about $10 million for the primary plant and an additional amount of about $20 million if biological treatment (secondary treatment) is provided.* Additional submarine outfall capacity also is required since the existing outfall does not have capacity for the increased design flows.

Secondary treatment will not reduce total nitrogen or phosphorus loadings. Therefore, an additional treatment process would be necessary to allow long-term continuation of the discharge to the Sound or to waters within its circulation pattern. The added construction cost for nitrogen removal at Woodman Point has not been estimated but it probably would be in the range of $10 million. Thus, a total of about $30 million in addition to the cost of primary treatment would be required. This figure is somewhat greater than estimates for the pipelines and outfall in the regional schemes which have been examined, but the differences probably are within the accuracy of the cost estimates. Annual operation and maintenance costs, however, would probably favour a deepwater submarine outfall scheme involving the discharge of effluent after primary treatment.

In general terms, there is a fundamental difference between the nature of discharges to Cockburn Sound and Owen Anchorage. In the case of the former, the discharges are largely inorganic (nitrogen, phosphorus, heavy metals, etc.) which are not biodegradable, but which those industries have the capacity to treat or remove on site with a high degree of reliability. However, Owen Anchorage receives discharges which are largely organic and readily biodegradable but which, by the nature of the industries, are not easily treated on a case by case basis. This is due to the wide variations in flow and loading resulting from the seasonal and market requirements of the industries. Moreover, several of them are small, low-capitalised industries which may not have the expertise or capability for adequate in-house treatment.

As an added incentive, a regional scheme for treatment and deepwater disposal could provide capacity for future connections of new industries whose wastewater characteristics might otherwise prevent their establishment in the Cockburn Sound or Owen Anchorage areas.

## 9.5 CONCLUSION

This chapter has described solutions whereby substances leading to or capable of leading to environmental problems in Cockburn Sound can be controlled, thus enhancing the Sound's value as a multiple use resource.

Solutions could include one or more of the following actions:

- In-plant treatment and continuation of present discharge practices.
- Process changes to eliminate or replace undesirable or objectionable substances or conditions.
- Disposal of wastewater, pre-treated as may be found necessary, to the open ocean through a regional submarine outfall scheme.

Various industries have or are taking steps to remove or reduce objectionable or undesirable constituents from their discharge. In addition, several regional schemes have been examined and referred to in this chapter. They would collect wastewater from industries in the Kwinana and Owen Anchorage areas and from the Woodman Point and Point Peron treatment plants and discharge them into deep water of the open ocean.

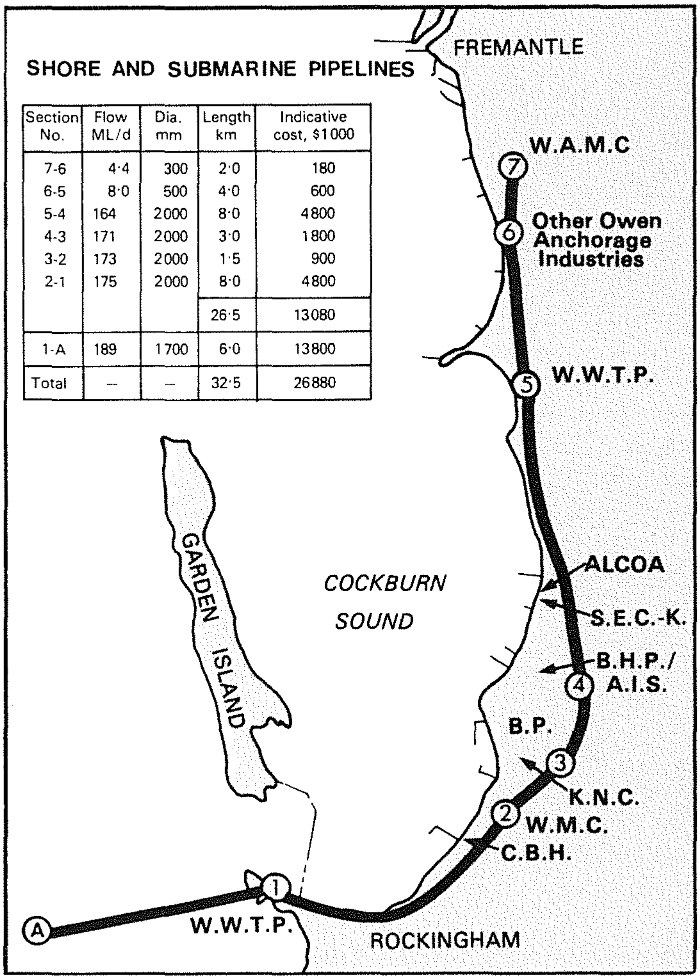
In most cases, a much lower degree of in-plant or preliminary treatment would be needed prior to discharge of industrial wastewaters to the open ocean than for continued discharge to more confined waters. At the WPTP primary treatment should be sufficient prior to open ocean discharge, but a much higher degree of treatment including nutrient removal would be necessary to continue discharging to nearshore waters in Cockburn Sound or possibly Owen Anchorage.

* Figure 7.1[18] shows a Recommended Implementation Schedule with indicative costs at 1977 values. For this Report, an inflation index of 7% per annum has been applied for the two subsequent years.

## 9.6 RECOMMENDATIONS

The principal recommendations which have been drawn from the information contained in this chapter are listed below.

1. Unless ocean discharge is available, all waste dischargers should proceed with such process changes, in-plant treatment, or removal of specific wastewater discharges from Cockburn Sound as necessary to achieve collectively the water quality objectives suggested in this report.
2. For the Woodman Point Wastewater Treatment Plant, it would appear less costly in terms of capital and operation costs to develop a new deepwater outfall to the ocean rather than provide facilities to remove nutrients, particularly nitrogen compounds. Since the plant is, or will become, the principal source of wastewater and nitrogen compounds which can be collected in a regional system, the Metropolitan Water Supply, Sewerage and Drainage Board should obtain oceanographic and other information necessary to evaluate the merits of disposal to ocean waters, in contrast to nearshore waters having restricted circulation.
3. Industries in the Cockburn Road Special Industrial Area should pretreat wastewaters to a degree compatible with connection to a regional wastewater treatment and disposal scheme.
4. Monitoring of the effectiveness of in-plant and other control measures should be carried out by periodic sampling of effluents, nearshore waters and sediments in the vicinity of existing outlets. The Fremantle Port Authority in collaboration with the Environmental Protection Authority should organise and evaluate this monitoring.




| Section No. | Flow ML/d | Dia. mm | Length km | Indicative cost, $1000 |
|---|---|---|---|---|
| 7-6 | 4·4 | 300 | 2·0 | 180 |
| 6-5 | 8·0 | 500 | 4·0 | 600 |
| 5-4 | 164 | 2000 | 8·0 | 4800 |
| 4-3 | 171 | 2000 | 3·0 | 1800 |
| 3-2 | 173 | 2000 | 1·5 | 900 |
| 2-1 | 175 | 2000 | 8·0 | 4800 |
| | | | 26·5 | 13080 |
| 1-A | 189 | 1700 | 6·0 | 13800 |
| Total | – | – | 32·5 | 26880 |

FIGURE **9.1.** Conceptual layout of a regional waste collection and disposal system.

## CREDITS FOR PHOTOGRAPHS

All photographs were supplied by courtesy of members of the Cockburn Sound Study Group except the following:

| | |
|---|---|
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| Plate 5 | Richard Woldendorp |
| Plate 7a & 7c | Richard Curtis |
| Plate 8 | Patrick Baker of Western Australian Museum |
| Plate 11 | Meagher & Le Provost |

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Part II: Coelenterata
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