COCKBURN SOUND ENVIRONMENTAL STUDY

Progress Report : June 1978

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Introduction

Although this three year study was to commence at the start of fiscal year 1976-77, operations began in November 1976 when the Project Leader was appointed. The project expanded during the next few months as staff were recruited and equipment obtained. Thus, while some segments have been operational for almost 18 months, others began less than a year ago.

The report of the Study is due at the end of June, 1979. Rather than wait until the definitive report is available, it was agreed by the Steering Committee that a progress report should be prepared at this stage. As data are still being collected, analysed and interpreted, such an interim report can describe only what is being done rather than attempt to draw conclusions or consider options for multiple purpose use of the Sound's resources.

The work of the past 18 months has enabled a much closer examination to be made of environmental pressures being applied in this area, and also of the impact of similar types of pressures applied to different degrees at other localities throughout the world. In reviewing such problems we do not necessarily imply that each is critical at present in Cockburn Sound: an assessment of each is being carried out as part of the present environmental study.

HISTORY OF DEVELOPMENT

The first to recognise the advantages of Cockburn Sound as a safe anchorage was Captain James Stirling who, on 7 March 1827, moved his ship HMS Success from Gage Roads to the shelter of the Sound (Fall 1972).

With the completion of a railway from Jarrahdale to Rockingham in 1872, Rockingham enjoyed an era as a significant port; over 500 ships calling there for jarrah and sandalwood between 1873 and 1905. These ships entered the Sound through the shallow (5 m) Challenger Passage between Carnac and Garden Islands.

Though the protected beaches and waters of the Sound have long been valued for various kinds of recreation, the potential of the deep basin as a harbour could not be developed until an access channel had been cut. Planning to establish a naval base in the Sound the Commonwealth Government began dredging a channel through Success and Parmelia Banks in 1919. A rather narrow channel, 7.9 m deep, was completed in 1926 but the naval base did not eventuate at that time. The channel was subsequently widened and deepened until by 1967 it was 152 m wide and 13.7 m deep.

Development of the Sound as the outer harbour for the Perth-Fremantle area really began in the 1950's 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 (opened in 1955), then a steel rolling mill (1956), an alumina refinery (1964), a sewage works (primary treatment only) (1966), a blast furnace (1968), a fertiliser plant (1968), a power station (1970), a nickel refinery (1970) and a bulk grain terminal (1976). Many ancillary industries developed in association with the major industries in this area.

Another significant development was initiated in 1971 when the W.A. Government ratified an agreement giving a cement manufacturing company the right to dredge lime sands from Parmelia and Success Banks for the next 40 years. The dredging to date has been along the line of a proposed second shipping channel.

In 1969 the Commonwealth Government announced plans to build a naval establishment on Garden Island. A solid fill causeway with two open bridge sections (305 m and 610 m) was begun in January 1971 and completed in April 1973. The main naval berths have been built in Careening Bay, and an explosives berth at Sulphur Bay (Figure 1).

Early in the growth of the Perth metropolitan area the land adjacent to Owen Anchorage was designated as a noxious trades area. Several meatworks, hides processors, fish processors, etc. discharge wastes into this basin. A power station is also sited at Owen Anchorage.

With these developments, limited options remain open today for alternative land use in this area (Figure 2).

EVENTS LEADING TO THE PRESENT STUDY

In 1970 the Commonwealth Government and the Fremantle Port Authority (FPA) commissioned the consultants Environmental Resources of Australia Pty. Ltd. (ERA) to study water exchange in the Sound, beach morphology and sand movements, and also to carry out baseline studies of the ecology of the Sound. From 1970 to 1974 ERA prepared for the Commonwealth some twelve reports on hydrology, seven reports on beach morphology, and one on recreation (on Garden Island). During the same period ERA prepared for FPA eleven reports on the ecology of the Sound and four reports on industrial discharges. In 1975 these studies were continued by R.K. Steedman and Associates (two reports on hydrology) and Meagher & LeProvost (report on eutrophication).

During 1974 the Environmental Protection Authority's (EPA) Estuarine and Marine Advisory Committee (EMAC) became involved in one aspect when the gypsum waste being discharged by the fertiliser works into the Sound (at a depth of 14.6 m) resulted in a mound which became a hazard to shipping. Because of the presence of heavy metals in the mound, EMAC recommended that when dredged the material be pumped ashore rather than be dispersed in the Sound. Subsequently (March 1975) the mound was dredged and 12,000 m^3 removed.

As the local operational body, FPA included management of the environment of the Sound as part of its responsibility. However, not only were the increased environmental problems outside its sphere of professional expertise, but also there were limitations in its powers to act. Some of those discharging effluents directly into the outer harbour were government instrumentalities, while a number of the major industries were discharging under earlier agreements ratified by Acts of Parliament. Feeling that it could not act further, the FPA sought the aid of the EPA.

Early in 1975 the EPA let a contract to another firm of consultants to make a comprehensive review of the relevant studies to date, to identify problems and to propose approaches to solutions. This report (Scott, 1976) was received in February 1976. As well as summarising available information, the report pointed out deficiencies needing attention.

After the report had been considered by the EPA and the Conservation and Environment Council, the Western Australian Government allocated $500,000 for the present three year study.

PURPOSE OF THE STUDY

The objective as approved by Cabinet is to obtain the information necessary to manage the Sound for multipurpose use, accommodating recreational and fishing activities as well as utilisation for port and industry. For this the present use and potential for each of these types of activity must first be quantified. Then the impact of each activity on the environment of the area needs to be assessed. Finally options for management should be considered with the aim of maintaining as wide a range of these activities as possible.

USES OF THE SOUND

Recreation

Apart from some beaches within the Swan River estuary, Cockburn Sound affords the only sheltered beaches close to Perth. As well as being protected from ocean surf, some of these beaches are favoured for their shelter from the prevailing southerly sea breezes during summer. However, very little data were available on the type and extent of recreational activities in Cockburn Sound.

From the outset of the Study, high priority has been given to surveying present recreational activities in the Sound and projecting future needs. This survey is being carried out by a consultant working closely with the rest of the Study team. Liaison has been maintained with the Community Recreation Council as well as with local government authorities. Field surveys of beach and boat users, with interviewers to record origins, activities, attitudes, etc., were begun in January 1977 and continued through the summer of 1977-78. From meetings and correspondence with clubs and other organisations, further information has ranged from yachting to horse training. The adequacy of existing facilities and the needs for their future extension are being assessed.

Data gathered from this survey are being compared, where possible, with levels of recreational activities in other localities so that these uses of the Sound can be put into perspective.

Fish Production

The value of the Sound in contributing directly or indirectly to harvestable marine resources is generally accepted but is not well quantified. The Department of Fisheries and Wildlife had studied selected species, but the total catch by both professionals and amateurs has not been determined for this area. In close collaboration with the Department of Fisheries and Wildlife, the Cockburn Sound Study Group is carrying out a survey of fish resources in the area. The species in the various habitats are being sampled using trawls, set nets and beach seine nets. From these samples, the seasonal cycles in availability are being followed.

Information on catches by amateurs has been gained from the recreational survey. This is being expanded into a creel census by extending the interviews of anglers. Catches by professional fishermen are being recorded by the Department of Fisheries and Wildlife, the area of the Sound having now been designated as a separate zone for the recording of commercial catches. Further information is being obtained by direct contact with fishermen. When catches by amateurs and professionals are considered together, the present resources of the Sound for fish production are substantial.

The role of the Sound as a breeding or nursery area is also being investigated. Some of the fish which begin their lives in the shelter of the Sound may later move out and be fished elsewhere.

Industries

The area zoned for industry is extensive (Figure 2). Some of the industries established so far rely on the Sound for the import of raw materials and export of products. Seawater is used extensively by industry for cooling purposes. The Sound also receives the discharges of a variety of other industrial wastes.

One segment of the present study is concerned with determining what is entering the Sound from the various industries. Those discharging wastes directly into the Sound have been co-operative in supplying information on water usage, processes, rates of discharge and the major constituents in their effluents. In addition the Study Group is sampling effluents and having these analysed independently. On occasions round-the-clock sampling is continued for several days. The Government Chemical Laboratories and private analysts are carrying out the analyses.

A less direct input to the Sound could be by way of the groundwater carrying material spilt or discharged on to the relatively porous sandy soils of the area. Some of the larger industries have already engaged consultants to report on contamination of groundwater by their own operations. The Study Group is extending this work to obtain a broader coverage of the condition of groundwater along the eastern and southern margin of the Sound.

Shipping

In 1976-77 a total of 408 ships entered the outer harbour (Cockburn Sound) while 1403 ships entered the inner harbour of Fremantle (FPA, Annual Report 1976-77). Although in numbers only 22.5 percent of the shipping for the Port of Fremantle used the Sound, this represented 42.9 percent of the gross tonnage.

The total cargo brought into the Sound in 1976-77 was 7,549,500 tonnes, far more than that entering the inner harbour (1,025,594 tonnes). Exports from the Sound totalled 5,414,877 tonnes (inner harbour 3,353,811 tonnes). Thus in terms of imports and exports, Cockburn Sound is already a major port in its own right. Further shipping berths are planned.

Defence

With the completion of the causeway in mid 1973, construction of the naval facilities on Garden Island began. The commissioning of HMAS Stirling is expected in July 1978. Naval personnel have been based there for some time, and will build to approximately 400 staff.

Access to Garden Island by the public is presently limited to those landing from private boats in unrestricted areas, during daylight hours.

Mindful of the fragile natural environment on Garden Island, the Commonwealth Department of Construction has taken steps to re-establish vegetation on cleared areas. Plant species have been selected with care to avoid problems of exotics spreading on the island.

ENVIRONMENTAL PROBLEMS REVIEWED

General Planning

The most frequent response of those asked for an opinion on the development of the area has been that much of the foreshore has been alienated. In early planning, careful thought was given to the needs for port and industry but in that period there was less stimulus for consideration of needs for recreation or fish production. At that time there was little information on the long-term environmental consequences of what appeared then to be innocuous actions. In the case of effluents the current attitude was that provided there was not a direct hazard to public health and that the effluent could be discharged with little visual impact (less likely to cause complaints), there was no further problem.

Attitudes and values have been changing rapidly in recent years. Also the Corridor Plan is now guiding further urban development southwards so that people are looking increasingly to the south for recreation. In planning more recent developments, increasing attention has been given to environmental aspects. However, in some instances the environmental impact of a specific proposal has been considered separately rather than as an addition to the total sum of pressures already being applied to this ecosystem.

Recreation

Recreation clearly ranked low in priority during early planning. Utilisation of the foreshore for industry, shipping and defence purposes has extended around the Sound leaving less beach accessible for recreation. Indeed, at one stage there appears to have been an intention to progressively eliminate recreation reserves from the foreshore of the Sound. This attitude was demonstrated in 1962 when the Inter-departmental Committee for the Development of Cockburn Sound and Kwinana stated that ...."Existing beach reserves north of Rockingham be maintained as far as possible, but that the position be recognised that permanent use of such reserves for recreation is incompatible with the rational industrial utilisation of the waterfront".

Most of the planning for industry and shipping occurred before the development of the Corridor Plan 1970. This document appears to be the first major planning statement which advocated extensive residential development in the S.W. Corridor. The T.S. Martin Report on the S.W. Corridor for the MRPA (1974) subsequently established that it was possible for some 370,000 people to be living in the S.W. Corridor by 2000AD.

The recently published N.W. Corridor Report refers to a potential population of 330,000 in that Corridor. The plan provides for these residents to have some 44 km of shoreline virtually unaffected by industry. Great emphasis is given in that report to reserving the shoreline for recreation.

Not only does Cockburn Sound afford recreation potential for the S.W. Corridor, but it is also the nearest shoreline for the S.E. Corridor which has a projected population of 215,000 by 1996. Some of these people will use beaches farther south (e.g. Warnbro Sound to Mandurah), but none of these beaches afford the same degree of shelter as Cockburn Sound.

Around Cockburn Sound reserves have been, and are still being, encroached upon for other uses. Reserve Number 27853 at Cape Peron is a clear example. When passing this land to the State in 1966, the Commonwealth made a condition that the whole of the area (180 ha) be used solely for recreation purposes. At the request of the W.A. Government this condition was later rescinded. Subsequently various portions of this recreation reserve have been excised for a sewage treatment site; for port ancillary services; 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 (p.24) has left only 104 ha for recreation, i.e. 57.8 percent of the original reserve. The northern (Mangles Bay) side of this reserve afforded one of the most protected beaches in the region. This beach is to be replaced by shipping berths after reclamation of some 65 ha from the waters of the Sound.

Air Emissions

Emissions by industry to the atmosphere are not being considered within the Cockburn Sound Study. These are being examined by the Kwinana Air Modelling Study (KAMS), convened by the Department of Conservation and Environment in collaboration with the Clean Air Section, Public Health Department.

Groundwater

Although much remains to be done to survey the extent of groundwater contamination, pollution of groundwater in the industrial area has already occurred. In some instances the contaminated water is unsuitable for use by industry. While two of the industries have initiated recovery programmes, these will remove only part of the contaminants. Even if further escape to groundwater could be prevented, the contamination which has already occurred has the potential to enter the Sound for some decades.

It is difficult to assess the impact of contaminated groundwater on the Sound ecosystem until more is known of the rates and points of entry and of the form of the contaminants reaching the Sound. As stressed earlier, this problem should not be considered in isolation as it is one of a series of environmental pressures which are accumulating.

Water Circulation

While planning and building the causeway to Garden Island, the Commonwealth Department of Construction investigated the rates of exchange of water between the Sound and the ocean. A computer model was developed, simulating the passage of water through the Sound.

The present Study is seeking more information on the fine structure of water circulation within the Sound under various meteorological and oceanographical conditions. This is of importance in determining where discharged effluents will be carried and dispersed. After an initial period of direct measurements of currents and hydrological conditions within and outside the Sound, these and earlier data have been used to refine a computer model of circulation in the Sound (Figure 3). This model is being used to simulate the dispersal of substances such as nutrients in point source discharges.

Weather data of recent years are being analysed to determine the frequency of north west storm conditions which are responsible for flushing the Sound. From four to seven storms may occur in any one year.

Hydrocarbons

Quite apart from spillages by ships and contamination of groundwater, hydrocarbons are present in the refinery effluents discharged directly into the Sound. Some 1200 litres of oil enter the Sound daily in this way. Although emulsified or dissolved in approximately 330 million litres of water, the potential effects of hydrocarbons and related substances in refinery wastes need to be considered.

Experimental transplanting of seagrass in the Sound and also the exposure of seedlings to effluents in laboratory trials, indicate that refinery effluents are toxic to seagrass. Further experiments are aimed at identifying the substances responsible for this toxicity.

The rapidly increasing literature demonstrates the growing concern over non-visible hydrocarbons in effluents discharged into the sea. Côté (1976), states that "Chronic low-level oil pollution is potentially more damaging to ecosystems than isolated catastrophic spills". Tanacredi (1977) stresses the same point.

Levels of dissolved hydrocarbons lethal to various algal species are given by Mironov (1975), while Côté (1976) reviews lethal thresholds of specific refinery constituents to various aquatic fauna.

Not all plants are inhibited; Parsons, Li and Waters (1976) observed that the growth of certain species of phytoplankton was enhanced by low levels of hydrocarbons. Naphtha and kerosene fractions are highly toxic to aquatic plants (Côté 1976). Two species of green algae were killed by perinaphthenone at a concentration of 0.25 ppm (Winters, Batterton and van Baalen, 1977).

Aromatic hydrocarbons inhibit cell growth and photosynthesis in algae (Vandermeulen and Ahern, 1976). Organisms already under other environmental stress are even more sensitive.

Sub-lethal effects are receiving more attention. Takahashi and Kittredge (1977) showed that the crab Pachygrapsus crassipes ceased to respond to an appetite stimulant (taurine) on exposure to soluble extracts of crude oils. Côté (1976) records sub-lethal effects on the lobster Homarus americanus at 1 ppm oil. In aquarium experiments Percy (1977) found that one species of amphipod (Onisimus affinis) strongly avoided settling in oil contaminated sediments while other species showed no such selectivity. Such behaviour has the potential to alter community structure.

Many polycyclic aromatic hydrocarbons are carcinogenic; 3, 4-benzopyrene being one of the most potent (Suess, 1976). Generally, aromatic hydrocarbons are accumulated by marine animals to a greater extent and are retained longer than alkanes (Neff et al, 1976). Fish and prawns can metabolise them but molluscs lack the detoxifying enzymes. DiSalvo, Goard and Try (1976) found that the algae Ulva and Enteromorpha survived well in hydrocarbon polluted waters but accumulated polycyclic aromatic hydrocarbons, raising the possibility of transfer of potential carcinogens through food webs. Perhaps it is significant that on the bank where the refinery effluents are discharging into Cockburn Sound, prolific growth of Ulva has replaced the seagrass.

A problem already encountered in the vicinity of the refinery is a tainting of fish (generally said to have a "kerosene" flavour). Not all species of fish in the area are affected; mullet and tailor are more strongly tainted than skipjack, and whiting do not appear to be affected. Within a school (or single net haul) not all specimens are affected. In a taste trial one fish in five was so flavoured. One Cockburn Sound fisherman reported a catch of 3000lb of tainted fish. Such tainting has been recorded and studied elsewhere in Australia (Sidhu et al, 1970: Connell, 1974). Taste and odour problems in fish have been caused by hydrocarbons at ppb levels, e.g. 10 ppb of oil caused tainting of oysters in Canada (Côté, 1976). Taste thresholds of specific hydrocarbons range from 1.0 mg/l for phenol to 0.005 mg/l for 2, 4 dichlorophenol (ibid).

Pathogenic Bacteria

As an indicator of contamination by enteric organisms of human or animal origin the faecal E.coli count is widely used. While this shows when gross contamination of waters has occurred, it is less reliable at low levels of pollution. In fact Salmonellas may still be present even when the faecal E.coli density is negligible. One of the reasons for this is that Salmonellas appear to survive longer in seawater than faecal E.coli.

Filter feeding molluscs such as mussels are more reliable indicators of contamination by enteric organisms than sampling of seawater as the mussels concentrate the organisms quite effectively. The Study Group is assisting the Public Health Department in sampling seawater and mussels in Owen Anchorage and near Woodman Point to check for pathogenic bacteria. On occasions, mussels from a wide range of stations carried Salmonella bacteria (Figure 4). Identification of serotypes gives some indication whether these Salmonella originated from the sewer outfall or from meatworks effluents.

Concerned at the wastes being discharged into Owen Anchorage from abattoirs, hides and fish processors, the Department of Conservation and Environment has commissioned sanitary engineering consultants to investigate the feasibility of pumping these wastes for treatment at Woodman Point when the re-designed sewage treatment works is built in 1981. This study is being given support by the Metropolitan Water Supply, Sewerage and Drainage Board with advice as well as chemical analysis of the wastes involved.

So far no attention has been given to enteroviruses in these waters. Because of the types of discharges into Owen Anchorage and Woodman Point, enteroviruses warrant consideration as they survive in seawater much longer than bacteria. In other localities, viable enteroviruses have been isolated several miles from the nearest sewage outfall (Vetter, 1971).

Heavy Metals

Carefully planned sampling of sediments has been carried out (Figure 5) and samples analysed for heavy metals. This is giving an up-to-date picture of the distribution of metals in surface sediments (Figure 6) and also useful profiles showing diminishing concentrations with increasing depth. Sediments adjacent to the main industrial area contain higher levels of metals than elsewhere in the Sound. If these metals could remain locked in undisturbed sediments, there would be less likelihood of a problem. But even if not dredged or lifted by ships' propellors (Figure 7), sediment is continually being turned over by animals living within it. If sediments become anaerobic some metals are converted to a soluble form (Wakeman, 1977). Sediments adjacent to the outfall of the fertiliser works are highly anaerobic (see next section).

Results from recent analyses of mussels show that in certain areas concentrations of metals such as cadmium, zinc and copper are elevated considerably, levels being highest in mussels taken from the bulk cargo wharf adjacent to the outfall of the fertiliser works. On 13 December 1977 the levels of cadmium in mussels from this wharf ranged from 4.6 to 6.9 ppm (mean 5.6 ppm): similar values have been recorded each month since them. Mud oysters, crabs and polychaete worms from this area also have elevated levels of cadmium.

In view of the increasing consumption of mussels there is a need to re-examine the regulations governing the levels of heavy metals permitted in seafoods. The concentrations of cadmium recorded above are marginally acceptable in terms of the W.A. Food and Drug Regulations which set an upper limit of 5.5 ppm for cadmium. However, the National Health and Medical Research Council (NH & MRC) favours a more stringent level. Of significance here is the observation that humans have a lower tolerance to cadmium if levels of copper and/or zinc are also elevated (Hart, 1974).

So far the main focus on metals has been upon health standards for humans. There is a growing amount of literature on the effects of sub-lethal concentrations of metals on aquatic plants and animals, but as yet no such studies are being carried out on marine species in Western Australia. Synergistic effects may be important here also. D'Agostino and Finney (1974) found that in a planktonic crustacean development was inhibited by levels of copper and cadmium only one tenth of the minimum concentrations at which either metal had an impact by itself.

Gypsum

Under an agreement ratified by Parliament, the fertiliser works is permitted to discharge up to 350 tons of gypsum per day into the Sound. This was considered to be an inert substance which could cause no harm to a marine environment. However, calcium sulphate is a standard enrichment for sediments when culturing and isolating marine bacteria, especially sulphur bacteria (Aaronson, 1970). In a Winogradsky column enriched with calcium sulphate there is stratification of bacterial species, with sulphur or sulphide oxidising bacteria at the surface and sulphate reducing bacteria below the surface. Such sediments are typically anaerobic, different species of bacteria being separated within the column as the levels of hydrogen sulphide increase.

The sediments in the Sound near the gypsum outfall are highly anaerobic. Organic levels are high (6-10 percent), consistent with a high bacterial flora. In such a habitat most other marine life does not survive.

During the latter part of 1977 the gypsum outfall was modified and is now at a depth of less than the minimum of 14.6 m specified in the Industrial Lands (Kwinana) Agreement 1964. The twin nozzles fitted to the end of the effluent pipe in August 1977 and the higher rates of discharge since then apparently achieve wider dispersal of effluent than before, but have increased the zone of anaerobic sediments rich in sulphur bacteria from a distance of 125 m from the pipe in September 1977 to 350 m in January 1978.

Dredging

This is usually carried out in the shallower waters where much of the primary production occurs. There is then direct destruction of the habitat and its associated flora and fauna. Dredging also increases turbidity (Figure 8). By itself this may be localised and short-term, but if turbidity is already high for other reasons or plants are already under stress, the cumulative effects may be significant.

Those sediments which have accumulated heavy metals and organic material present further problems when dredged, especially if they are anaerobic. During the dredging and again at the disposal site, there can be increases in seawater levels of phosphorus (to as much as 1000 times background levels), nitrogen and also heavy metals (Wakeman, 1977).

On Parmelia Bank the dredging of the main shipping channel has effectively drained off sediment being carried along the top of the bank. Recent studies indicate that sediment does not cross the channel but drops into it and is then swept by currents along the channel to be deposited as an alluvial fan in the deep basin at each end of the channel. Areas on the top of the bank having reduced sediment supply may no longer be suitable for seagrass species requiring a steady input of sediment.

The commercial dredging of lime sands from Parmelia and Success Banks appears to present a range of potential long-term problems associated with changes in wave refraction patterns, loss of flora and fauna, increased mobility of sediments with loss to deeper waters, and eventually a possible increase in wave energy entering Owen Anchorage and Cockburn Sound during north-west storm conditions. While it is beyond the scope of the present Study to assess adequately the best strategy for mining the lime sands of these banks, careful study and planning of future dredging is essential in order to ensure that the present protection afforded by these banks to all users of the Sound is not impaired.

Nutrient Enrichment

Prior to modern settlement of the area, the main source to the Sound of nutrients such as nitrates and phosphates was from ocean waters entering and passing through the Sound (there being little direct run-off from the land). As the adjacent ocean waters are low in nutrients, the total available nitrogen in ocean water entering the Sound during much of the year would be in the order of 300 to 400 kg per day and the total phosphorus 200 to 300 kg per day.

From analysis of effluents now being discharged directly into the Sound, there is an input of some 4000 to 6000 kg of nitrogen per day and 3000 to 4000 kg of phosphorus per day. Most of this is by direct discharge from the fertiliser works and the sewage outfall (primary treatment only). Further nutrients may be entering by way of contamination to groundwater; the extent of this is still being assessed.

Algal blooms occur in the waters of the Sound from time to time, discolouring the water and increasing turbidity (Figure 9). Beneath such blooms low levels of dissolved oxygen have been recorded (less than 50 percent saturation). Algal blooms therefore have an aesthetic effect (lowered amenity value) as well as the potential for biological impact (with effects upon fish production).

The Study Group is following seasonal changes in available nutrients, determining what triggers a bloom, and attempting to establish a relationship between sources and blooms.

The role of the sediments in acting as a repository for nutrients which may be recycled later needs further investigation. This could be of importance in trapping nutrients which otherwise might have been flushed out of the Sound during winter storms.

Seagrass

Seagrass meadows, once abundant around the perimeter of the Sound, began declining in 1957 adjacent to the discharge point of the first major industry established there. They have continued to recede since then. Today the seagrasses are not only much restricted in distribution but also much reduced in density in areas where the vigour of the plants appears to be weakened (Figure 10).

As well as mapping these changes, the present work includes measurement of seagrass growth patterns (Figure 11). Tests are also being carried out in aquaria under controlled conditions to determine which of the substances being discharged into the Sound may be toxic to seagrass seedlings. This is part of the research of the Study team which is aimed at a better understanding of how and why this recession is occurring, the biological consequences and also the effect upon the stability of sediments.

Sediment Transport

The present configuration of the Sound and adjacent banks is the result of sedimentary processes which have been operating since a rise in sea level cut off Garden Island about 7000-8000 years ago. When a bank had grown out from the region of Rockingham to Cape Peron, the supply of sediment into Cockburn Sound was much reduced. While some movement of sediments continues with erosion in certain areas and accretion in others, rates of transport of sediments in the Sound appear to be lower than on more exposed coastlines.

With considerable development taking place in the Sound the question arises whether man-made changes are affecting sediment movements significantly. This is difficult to answer in a short-term study since much of the sediment movement takes place during severe storms which are of low and variable frequency. Clearly the positioning of groynes has arrested the normal movement of sand along the coast (Figure 12), starving the beaches on the downdrift side. Recession of the shoreline on the northern side of James Point began after dredging and the death of the seagrass there in 1957, and is continuing (Figure 13).

Most of the Study's work to date on sediments has been concerned with the mechanisms controlling the growth of the banks and platforms around the Sound. An understanding of the processes involved in their formation and the changes being imposed on these processes, should enable some predictions to be made of their future stability.

Submerged pickets driven into the sediment are being used by the Study Group to measure the rates of movement of sand across banks.

The Commonwealth Department of Construction is monitoring beach profiles in the southern portion of the Sound and on Garden Island.

The Harbours and Rivers Branch, Public Works Department, is using aerial photographs as an aid in assessing long term changes in the foreshore to the south of Fremantle.

The stability of coastal dunes around the Sound and on Garden Island has been examined by the Soil Conservation Service, Department of Agriculture. Areas sensitive to wind erosion are being defined.

Thermal Wastes

The quantity of seawater being used for cooling purposes by industry and power stations is increasing. At present an average of 1600 million litres of seawater is returned daily to the Sound at a mean of 10°C above the intake temperature. At times of peak load on power generation, the heat input may be doubled.

Earlier checks at lower levels of cooling water demand showed that the waste heat was dissipated within a short distance of each outfall, the frequent winds typical of this region being of benefit in this regard. Because of these previous results, little attention is being given to thermal wastes during the present study. With the cooperation of CSIRO mapping of the surface water temperature of the Sound is being carried out using an infrared radiometer mounted in an aircraft.

The use of seawater as a coolant continues to increase, the average daily intake being expected to reach 2100 million litres in 1979. The effects of waste heat may require further attention in the future, especially under conditions of calm weather.

Discharges of warmed seawater are unlikely to be directly lethal to plants and animals in the vicinity of outfalls, but as in the case of other environmental pressures, the impact of heated seawater should not be considered in isolation. A moderate increase in temperature having no deleterious effect by itself, might lower the threshold of a species to some other pollutant. For example, an increase in temperature from 20°C to 24°C increases the toxicity of phenol considerably (Reynolds _et al_, 1975).

Chlorination

Those using seawater as a coolant are obliged to chlorinate in order to inhibit the growth of marine organisms within the cooling system. Practices vary, one industry applying chlorine at a dosage of 1.5 ppm for ten minutes every three hours, while another applies a more continuous dosage at 0.25 ppm. On occasions during the past summer, one industry experienced difficulty in maintaining the desired level of residual chlorine in coolant seawater despite increasing the rate of chlorination. The problem was apparently caused by relatively high levels of organic material in the incoming seawater. The total application of chlorine to cooling waters by these industries is estimated to be at least 250 kg per day.

When returned to the Sound most of the discharges of coolant seawater are relatively low in free residual chlorine, one industry finding levels to be "less than 0.1 mg/l" while another reporting concentrations of 0.1 to 0.2 mg/l. However, the US EPA (1976) stresses that residual chlorine exceeding 0.01 mg/l poses a serious threat to marine life.

In the past it has been assumed that most of the chlorine used in chlorination of coolant seawater has been lost to the atmosphere. However, Goldman and Davidson (1977) point out that when seawater contains free ammonia and organic matter, the chlorine is bound into chloramines and organochlorines which are both more persistent and more toxic than the chlorine itself. For example, lobster larvae have been shown to be sensitive to chloramines even at the minimum level of detectability (0.01 mg/l). Cote (1976) observed that chlorine in cooling water of oil refineries may combine with other constituents in the effluents (e.g. phenols) to produce substances of greater toxicity.

Because of the input of ammonia to the Sound and the levels of organic material present in the seawater, chloramines may be expected to occur in coolant seawater which has been chlorinated. Tests are being carried out to determine actual levels.

Ship Discharges

Although infrequent, oil spillages from ships in the harbour are of concern. The Fremantle Port Authority stations wharf superintendents at the oil refinery berths, and has a beach inspector checking ships in general as well as material floating ashore. When oil is spilt the primary concern has been to avoid nuisance to the public, with less attention given to ecological impact. If floating, the oil is usually treated with dispersants; if on the beach it is scooped up and removed.

While the FPA and BP Refinery use BP1100X or BP-AB in conformity with the recommendation by the National Plan to Combat Pollution of Sea by Oil, ships' officers might on occasions use other dispersants. Some dispersants are highly toxic (Tokuda, 1977). Even the less toxic may cause behavioural changes in marine animals. For example, BP1100X in concentrations ranging from 1 to 100 ppm caused a decrease in the ability of the shrimp *Crangon crangon* to locate food (Evans, Lyes and Lockwood, 1977).

The quantity of dispersant used is sometimes in excess of that necessary to disperse the oil. The consequences can be acutely toxic to certain species, as shown by an occasion in Cockburn Sound when over 6,000 crabs (*Portunus pelagicus*) died following an oil spill.

Dispersants may not always achieve a final solution, as shown by the events following the oil spill which killed the crabs. A month after that spill, a thick grey sludge carrying fragments of the alga *Ulva* rose to the surface in a dense line along the edge of the bank in the same area (Figure 14). The sludge smelled of hydrocarbons and free oil was readily recovered by ether extraction.

Spillages of other cargoes (caustic soda, alumina powder, sulphur, rock phosphate, superphosphate, ammonium sulphate, etc.) have been reported from time to time but apparently records have not been kept of these. Complaints have also been made of garbage from ships coming on to beaches in the Sound.

With the long-term plans to build some twenty more berths in the Sound, very strict enforcement of regulations concerning discharges from ships will be necessary to maintain amenity values of beaches and waters.

In recent years increasing concern has been shown, both in Australia and elsewhere, of the possibility of exotic species being introduced from ship's ballast water (Hoese, 1973). This question was raised in the International Convention for the prevention of Pollution from Ships, 1973, and is being examined by a number of departments in Australia. The Japanese goby, *Tridentiger trigonocephalus*, recently identified in the lower estuary of the Swan River, may have been introduced in this way, (Lenanton, pers. comm.).

Fish Resources

Whether for recreational or commercial use, fish resources of the Sound are under increasing environmental pressures from the various stresses discussed above. Existing pressures may be grouped in the following manner;

(1) Direct toxicity: One example of this has been the death of crabs following treatment of a large spillage of oil. A more specialised case has occurred in Owen Anchorage where a company attempting to hold live abalone and rock lobsters for export has had mass mortalities claimed to have been caused by their sea-water intake picking up toxic substances discharged through an adjacent effluent pipe.

(2) Reduction or degradation of specific habitats: Examples are the death of seagrass; bottom sediments turning anaerobic; dredging and reclamation. Some of these may be localised but specific sites should not be viewed in isolation as the impact upon fish production is cumulative.

(3) Accumulation of pollutants making fish resources less acceptable for human consumption: Examples can be seen in the elevated levels of certain metals, tainting by hydrocarbons, and filtering of pathogenic bacteria by shellfish.

(4) The impact of fishing itself: There is already some competition between the different forms of fishing. Net fishermen, both professional and amateur, have been accused by anglers of damaging stocks of juvenile fish. This aspect is being examined.

It has been suggested that some of the changes within the Sound may have been beneficial for fish production. Groynes, wharves and the causeway do afford sites for reef dwelling species and some structures provide amenity value for anglers. Another suggestion was that the increased impact may be elevating the productivity of these waters. While algal blooms represent a high production of organic material, it does not follow that edible fish resources are automatically enhanced. On the contrary, the recently observed depletion of dissolved oxygen during algal blooms serve as a warning that intensification of such blooms could lead to mass mortality of fish.

PRELIMINARY ASSESSMENT OF THE PRESENT STATE OF THE SOUND

In general, although the growth of port and industry has its attendant environmental problems, fish production does not appear to have been impaired greatly at this stage and a range of recreational activities are open to the public. Thus at present there are fair prospects for continued multipurpose use of the area.

However, because of the environmental pressures already placed on this resource, maintaining the objective is becoming increasingly difficult. Each new development proposed around the Sound must be weighed very carefully, not just against its own environmental impact, but against the sum of all the pressures on this environment. The resource (the Sound) is limited, not only spatially but also in its capacity to absorb additional pressures.

Better housekeeping will be essential, with greater care to improve the quality of effluents and to avoid spillages. Standards should be set for harmful constituents in effluents (e.g. nutrients, metals, hydrocarbons, bacteria, etc.).

Of the various substances being discharged, those posing the greatest potential hazard to water quality appear to be the nutrients. Algal blooms occurring during summer (when water exchange is low and the Sound is behaving like a lake) are at times approaching the critical point where de-oxygenation of the deeper water can occur. Without wishing to sound alarmist, such an event would have serious impact upon most users of the Sound. We would be failing in our responsibility if we did not draw attention to this danger.

EXPENDITURE

Direct expenditure by the Government on this Study is expected to total $613,000, distributed as set out in Table 1. In addition a number of departments and institutions are contributing in the form of staff time, loan of equipment, analytical and other services. Some of the major industries at Kwinana have met certain costs (for example, construction of observation bores on their property).

NEXT STEPS

The Cockburn Sound Study is presently in its most active phase of collecting and analysing data. If a particular problem is found to need immediate action, the necessary steps will be taken as soon as sufficient information has been assembled to demonstrate the extent of the problem and the action necessary. Any interim measures will then be incorporated in the final report of the Study.

While reports on some segments are expected to be completed during 1978, the overall report of the Study is to be completed by the end of June 1979.

Clearly the present policy of managing the Sound for multipurpose use requires careful planning of future use of land, foreshore and the water if we are to satisfy increasing demands for industry, recreational uses, and to safeguard fish resources.

Some of the problems which have been identified require concerted action if the quality of the environment is to be restored and maintained in a desirable state. This will not be achieved at once nor will it be of zero cost. As so little is known of acute toxicity levels of specific pollutants to local species, of sub-lethal effects on our flora and fauna, or the passage of substances through food webs in the ecosystem, the present short-term study represents only one step towards effective management of the Sound for multipurpose use.

TABLE 1

COCKBURN SOUND ENVIRONMENTAL STUDY

EXPENDITURE

	\$ 76/77	\$ 77/78	\$ 78/79 (budget)
Salaries	24,430	138,700	107,828
Operating costs -			
Core Group	48,854	21,000	15,600
Effluent Input	1,751	47,500	15,000
Effluent Impact	-	14,000	3,500
Water Circulation	26,215	25,000	6,000
Seagrass	24,391	4,100	6,000
Fish Production	3,027	6,000	4,000
Recreation	16,000	13,000	3,000
Eutrophication	360	19,500	3,100
Sediments	2,650	11,000	2,000
	147,678	299,800	166,028

TOTAL $613,506

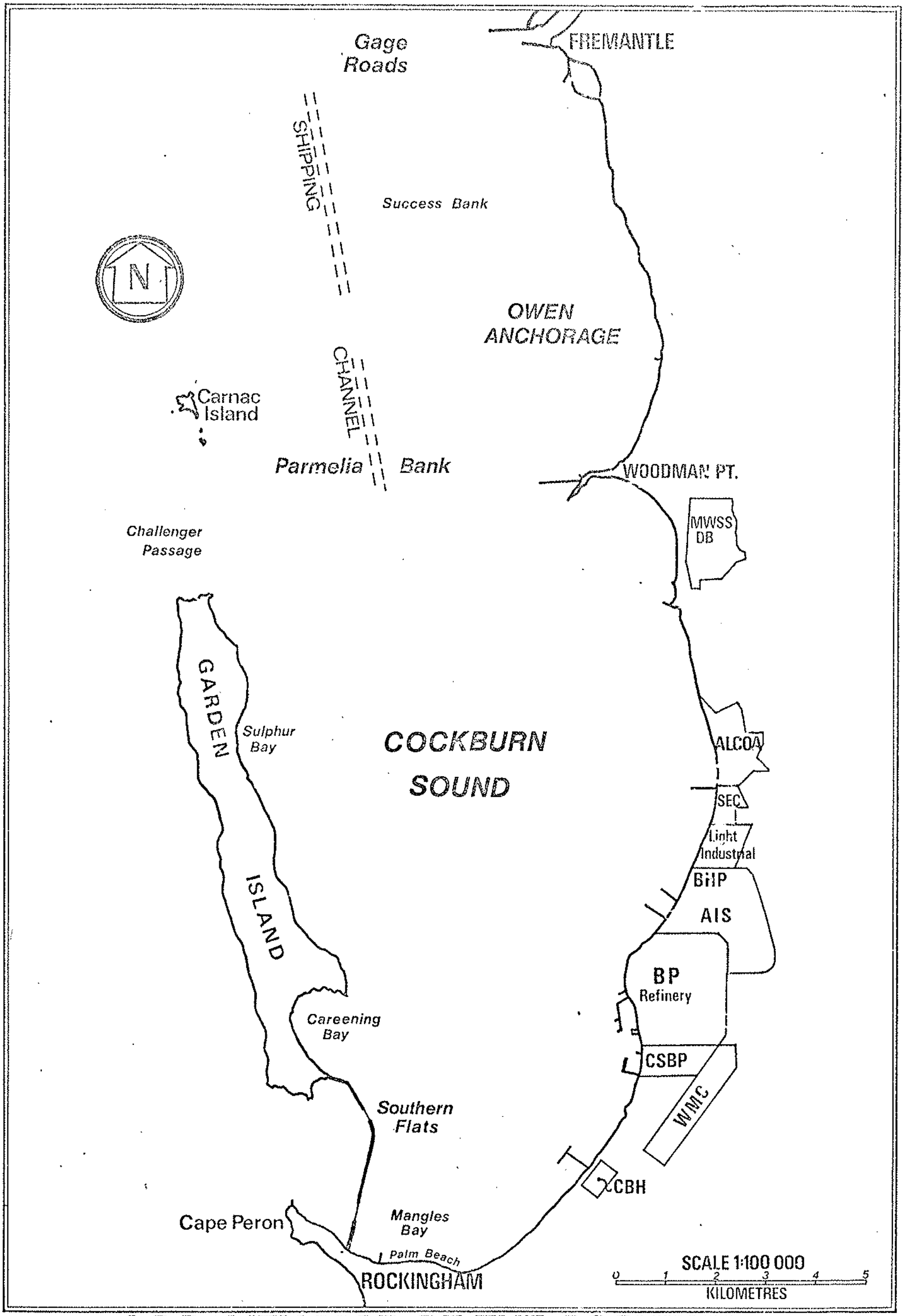


Figure 1. **LOCALITY MAP OF THE COCKBURN SOUND AREA**

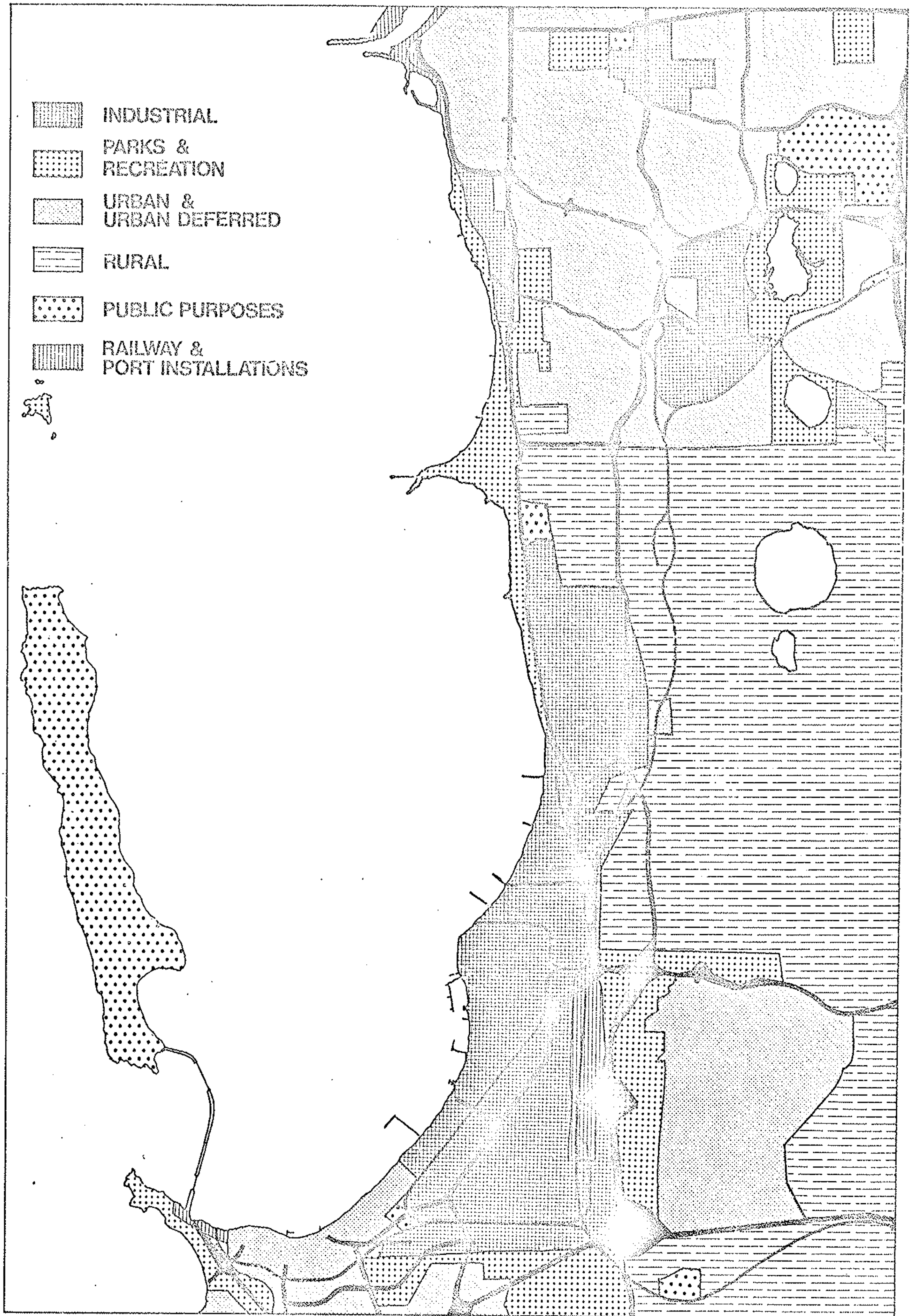


Figure 2. LAND USES IN THE VICINITY OF COCKBURN SOUND

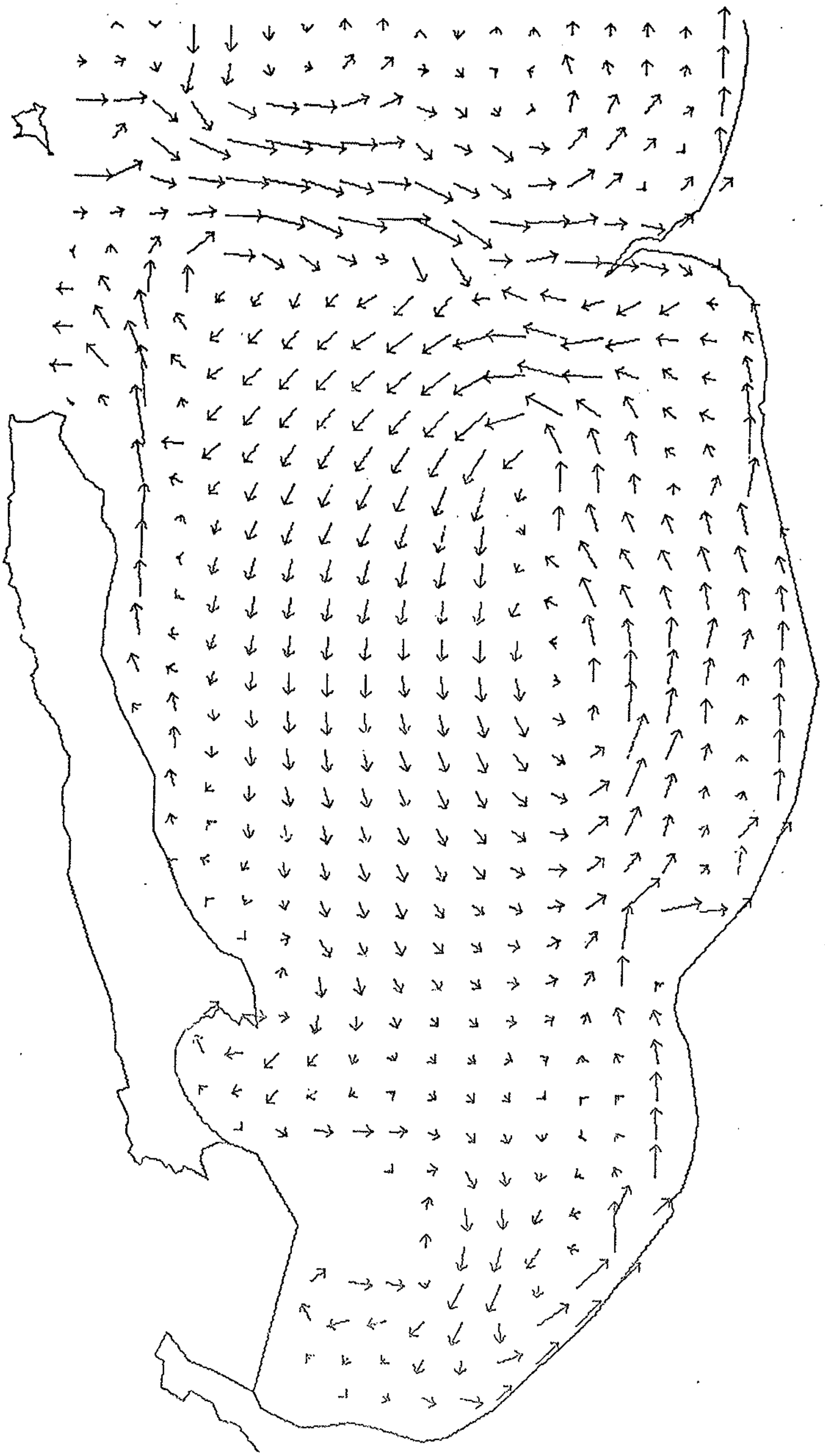


Figure 3.

Velocity vector simulation of the circulation in Cockburn Sound with wind from the south-west at 15 knots for 10 hr duration.

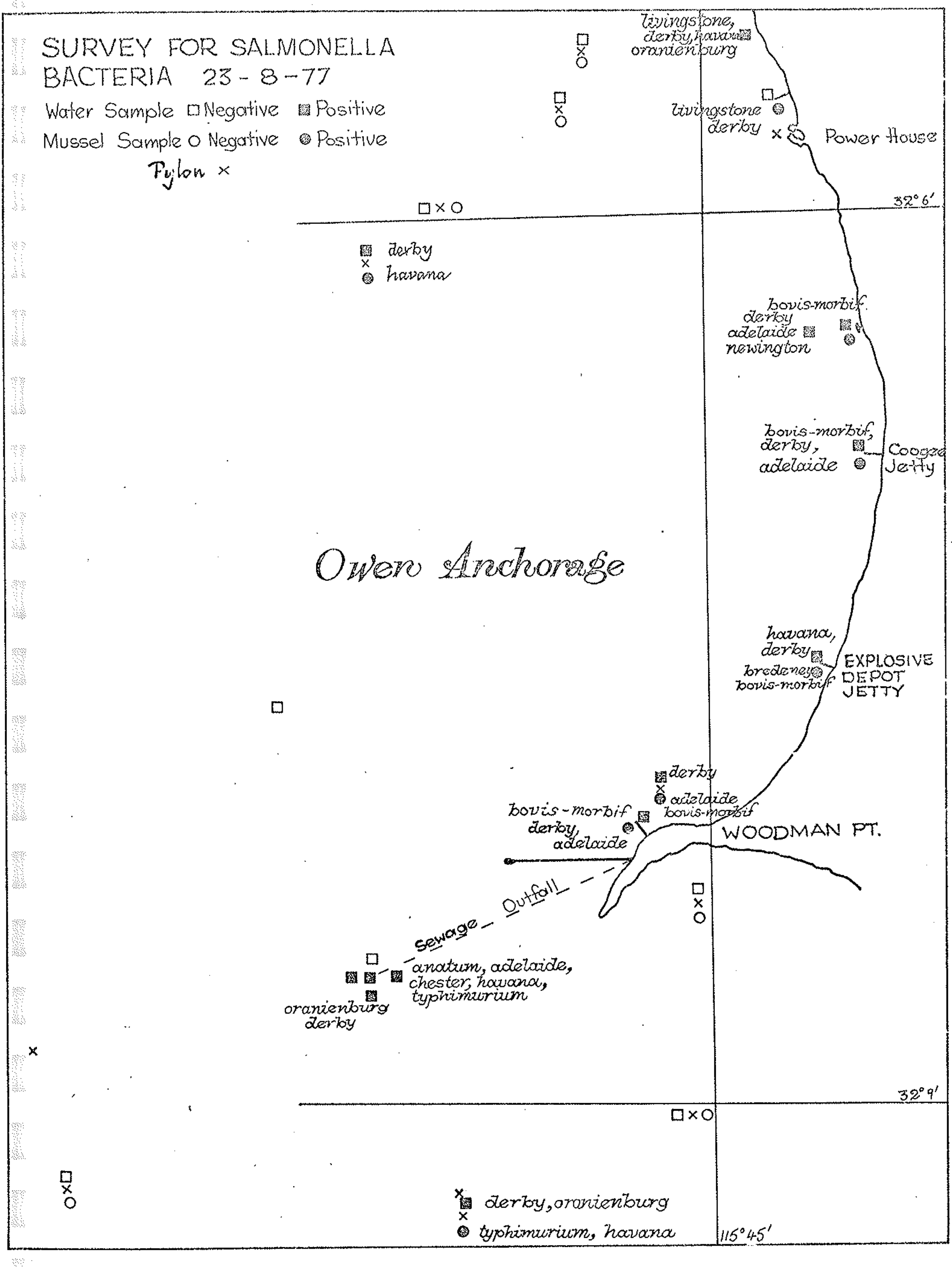

SURVEY FOR SALMONELLA BACTERIA 23 - 8 - 77
Water Sample □ Negative ▩ Positive
Mussel Sample ○ Negative ◉ Positive
Pylon ×
livingstone, derby, havana oranienburg
livingstone derby
Power House
32° 6'
derby havana
bovis-morbif. derby adelaide newington
bovis-morbif, derby, adelaide
Coogee Jetty
Owen Anchorage
havana, derby
bredeney bovis-morbif
EXPLOSIVE DEPOT JETTY
derby
adelaide bovis-morbif
bovis-morbif derby, adelaide
WOODMAN PT.
Sewage Outfall
anatum, adelaide, chester, havana, typhimurium
oranienburg derby
32° 9'
derby, oranienburg
typhimurium, havana
115° 45'

FIGURE 4

Figure 5.

Sediment core taken in Cockburn Sound

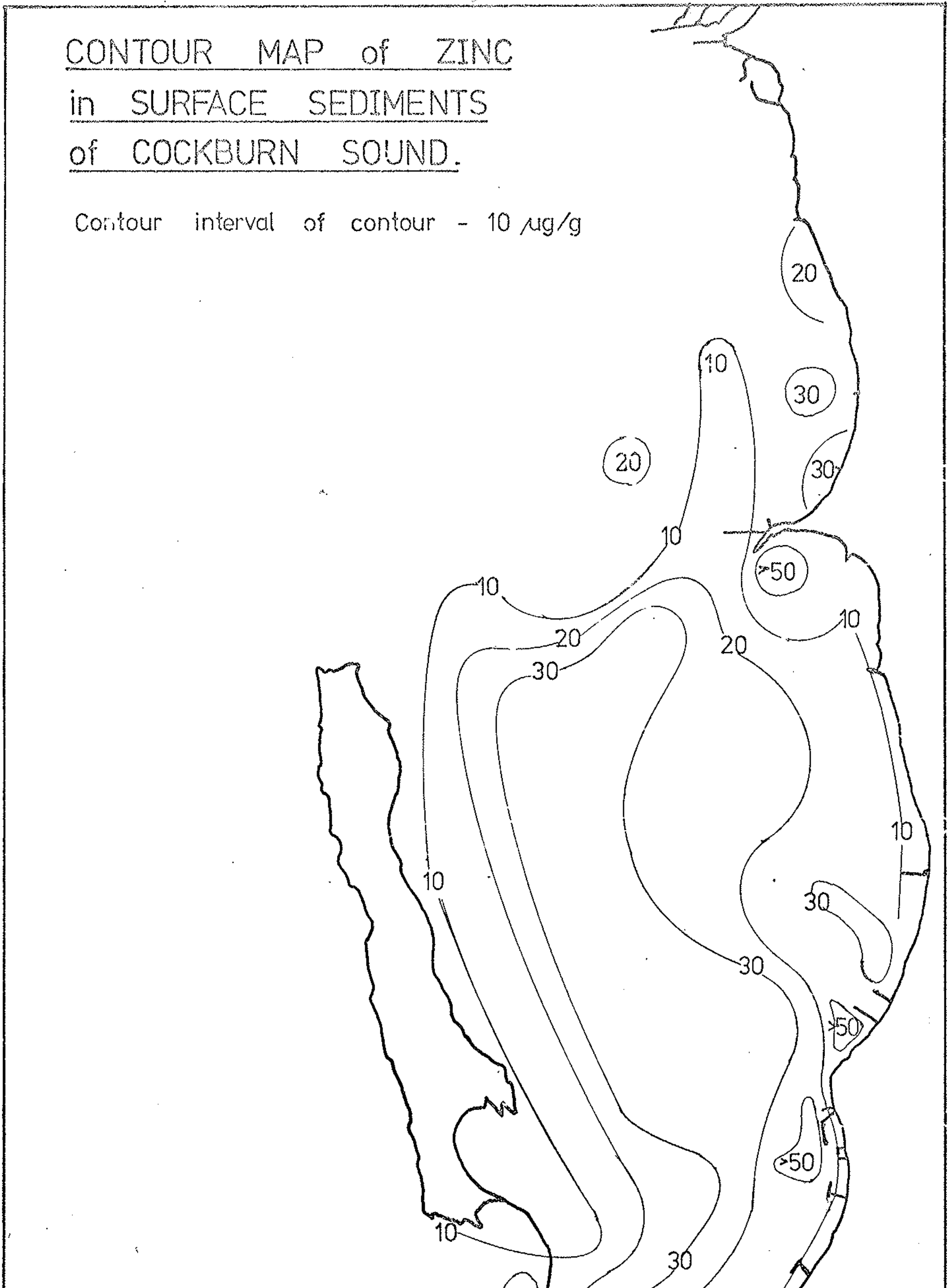

CONTOUR MAP of ZINC
in SURFACE SEDIMENTS
of COCKBURN SOUND.
Contour interval of contour - 10 µg/g
20
10
30
20
30
10
>50
10
20
10
20
30
10
10
30
30
>50
>50
10
30
20
10
20

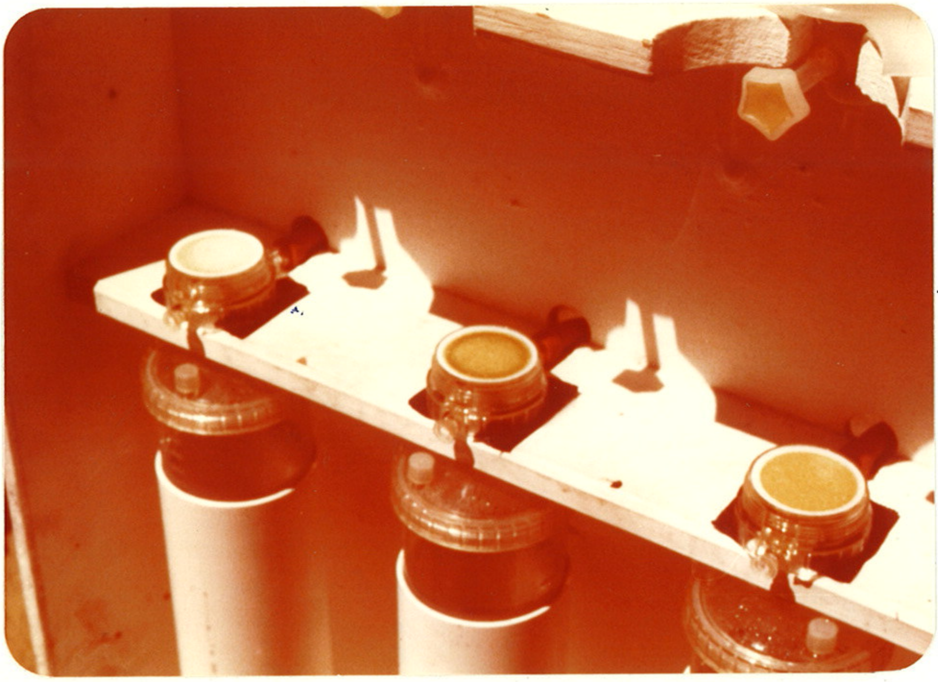
Figure 6.

Figure 7.

Sediment raised from seabed during ship berthing in Cockburn Sound.
11 January 1978

Figure 8.

Sediment lifted from Parmelia Bank during dredging for lime sands.
25 January 1978



bottom sample | middle sample | surface sample

Figure 9.

Phytoplankton filtered from three water samples collected at different depths of water off the Co-operative Bulk Handling jetty at 1400 hours on 6 January 1978.

Chlorophyll a concentrations determined for the bottom sample (depth of 15 m), middle sample (depth of 8 m) and surface sample (depth of 0 m) were 2 g/l, 13 g/l and 8 g/l respectively.

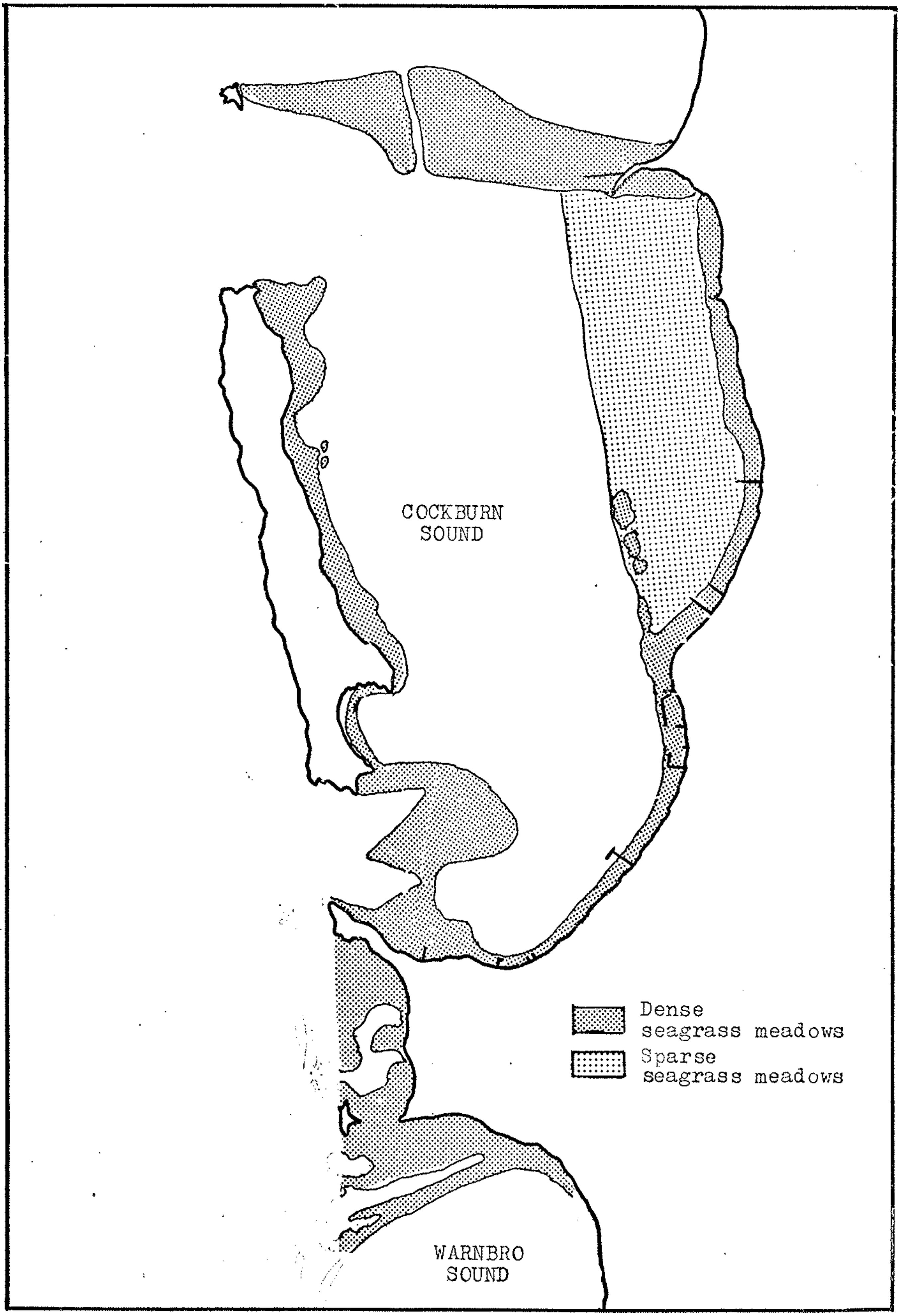


Figure 10a

Seagrass distribution 25 years ago

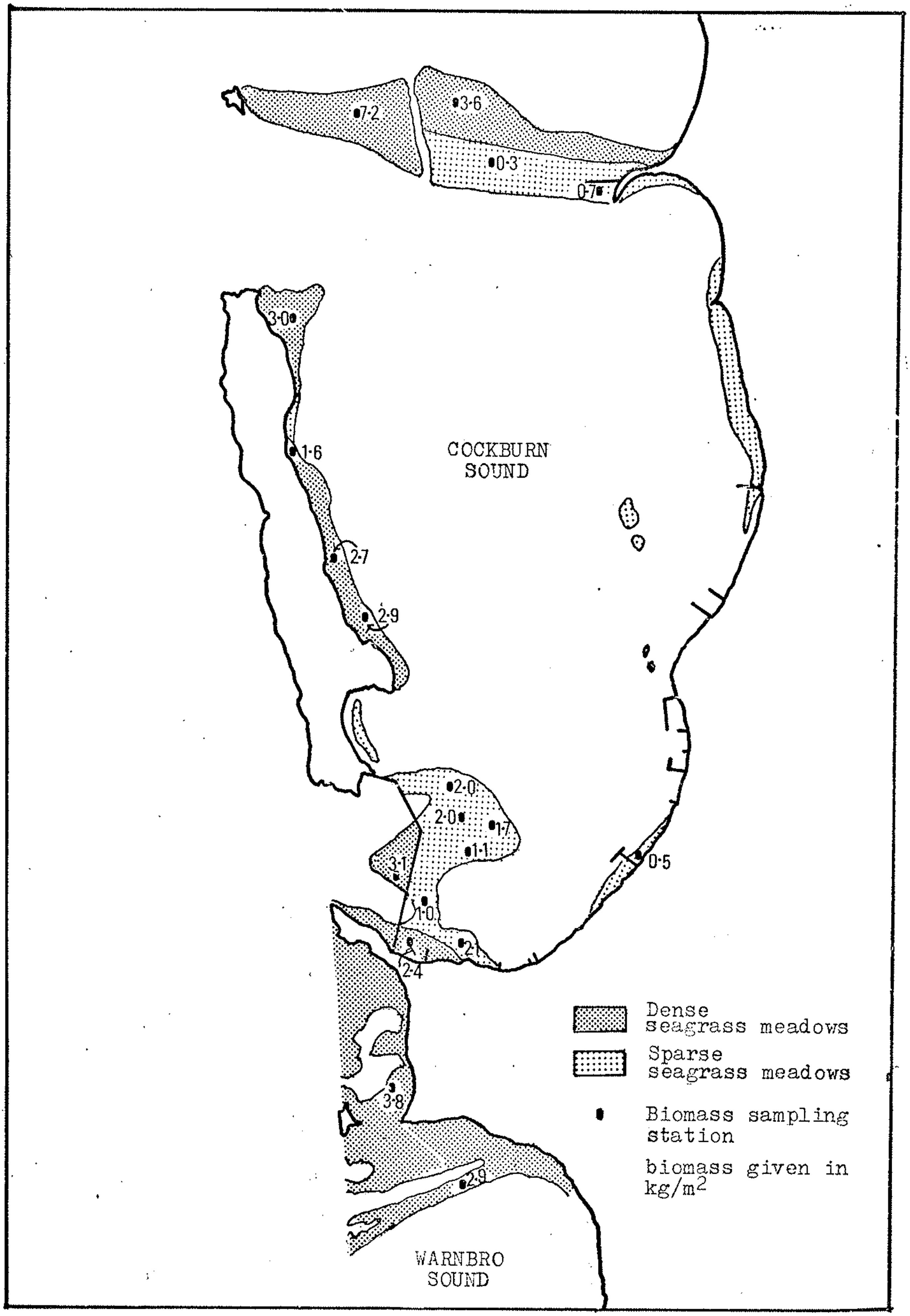


Figure 10b

Present seagrass distribution

Figure 11.
Underwater measurement of seagrass meadows

Figure 12.
Shore sediment trapped by BP intake flume, James Point (3 September 1977).

Figure 13.

Beach erosion cutting into vegetation on north side of James Point (8 April 1978).

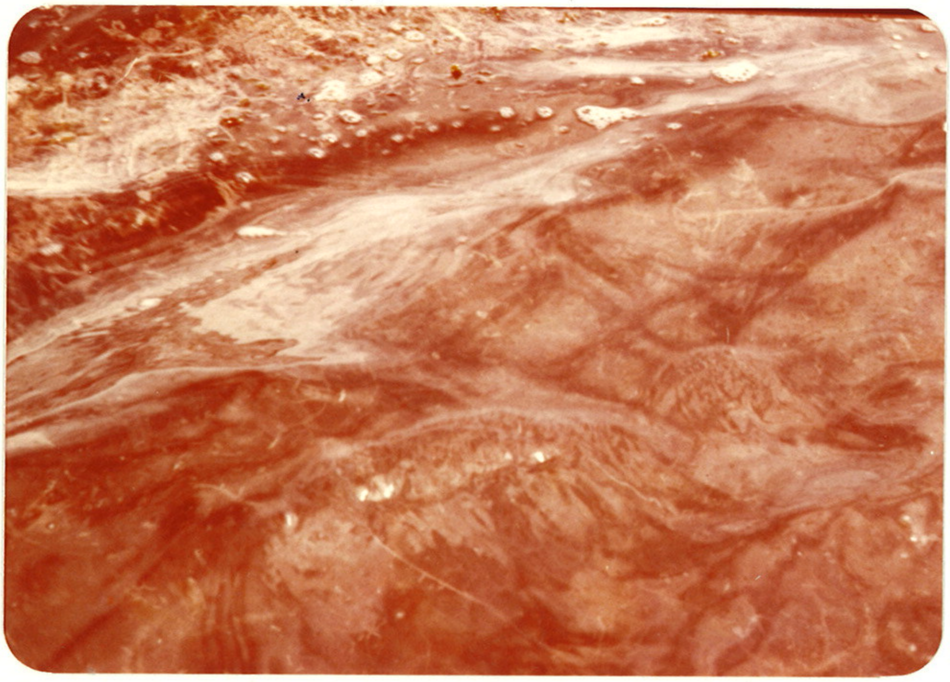


Figure 14.

Oil bearing sludge and algae floating off James Point on 7 November 1977.

REFERENCES

Aaronson, S. (1970). Experimental microbial ecology. Academic Press. 236p.

Connell, D.W. (1974). A kerosene-like taint in the sea mullet, Mugil cephalus (Linnaeus). I. Composition and environmental occurrence of the tainting substance. Aust. J. Mar. Freshw. Res. 25:7-24

Côté, R.P. (1976). The effects of petroleum refinery wastes on aquatic life, with special emphasis on the Canadian environment. Nat. Res. Council Canada. Publ. of the Envir. Secretariat No. 15021.

D'Agostino, A. & Finney, C. (1974). The effect of copper and cadmium on the development of Tigriopus japonicus. In; Vernberg, F.J. & W.B. (Eds.) Pollution and physiology of marine organisms. Academic Press: 445-63.

DiSalvo, L.H., Goard, H.E. and Try, K. (1976). Comparative hydrocarbon content of algae from a San Francisco Bay wharf and a California coastal inlet. Phycologia 15(2):245-7

Evans, G.W., Lyes, M. & Lockwood, A.P.M. (1977). Some effects of oil dispersants on the feeding behaviour of the brown shrimp, Crangon crangon. Mar. Behav. Physiol. 4:171-81

Fall, V.G. (1972). The sea and the forest. University of W.A. Press. 213pp.

Fremantle Port Authority, Western Australia. Annual Report 1976-1977.

Goldman, J.C. & Davidson, J.A. (1977). Physical model of marine phytoplankton chlorination at coastal power plants. Environmental Science and Technology. 11(a): 908-13.

Hart, B.T. (1974). A compilation of Australian water quality criteria. Australian Water Resources Council. Tech. Pap. No. 7

Hoese, D.F. (1973). The introduction of the Gobiid fishes Acanthogobiis flavimanus and Tridentiger trigonocephalus into Australia. Koolewong, 2(3):3-5.

Mironov, O.G. (1975). Biological aspects of marine hydrocarbon pollution. In; Pearson, E.A. & Fraja Frangipane, E.de (Eds.) Marine Pollution and Marine Waste Disposal. Proc. 2nd Int. Congress, San Remo, Dec. 17-21, 1973:175-82.

Neff, J.M., Cox, B.A., Dixit, D. & Anderson, J.W. (1976). Accumulation and release of petroleum-derived aromatic hydrocarbons by four species of marine animals. Mar. Biol.: 38:279-89

Parsons, T.R., Li, W.K.W. & Waters, R. (1976). Some preliminary observations on the enhancement of phytoplankton growth by low levels of mineral hydrocarbons. Hydrobiologia, 51:85-9

Percy, J.A. (1977). Responses of Arctic marine benthic crustaceans to sediments contaminated with crude oil. Envir. pollution, 13:1-10

Reynolds, J.H., et al (1975). Effects of temperature on oil refinery waste toxicity. J. Water Poll. Control Fed. 47(11):2674-93

Scott, W.D. & Co. Pty. Ltd. (1976). A review of the environmental consequences of industrial development in Cockburn Sound for Environmental Protection Authority Western Australia.

Sidhu, G.S., Vale G.L., Shipton J. & Murray, K.E. (1970) A kerosene-like taint in Mullet (Mugil cephalus) Marine Pollution and Sea Life (Fishing News, Books: London):546-50

Suess, M.J. (1976). The environmental load and cycle of polycyclic aromatic hydrocarbons. Sci. Total Environ. 6(3):239-50

Takahashi, F.T. & Kittredge, J.S. (1973). Sub-lethal effects of the water soluble component of oil: chemical communication in the marine environment. The Microbial Degradation of Oil Pollutants. Lousiana State University, Centre of Wetland Resources. Publ, LSU-SG-73-01; 259-64.

Tanacredi, J.T. (1977). Petroleum hydrocarbons from effluents: detection in marine environments. J. Water Pollution Control Federation 49(2):216-26

Tokuda, H. (1977). Fundamental studies on the influence of oil pollution upon marine organisms. II Lethal concentrations of oil-spill emulsifier components for marine phytoplankton. Bull. Jap. Soc. Fish. 43(1):103-6

U.S. EPA (1976) Disinfection of wastewater. EPA Task Force Report 430/9-75-012.

Vandermeulen, J.H. & Ahern, T.P. (1976). Effects of petroleum hydrocarbons on algal physiology: a review and progress report. In; Lockwood, A.P.M. (Ed.) Effects of Pollutants on Aquatic Organisms. Cambridge University Press. 107-25

Vetter, R.C. (1971). Marine Environmental Quality. National Academy of Sciences, Washington, D.C. 107p.

Wakeman, T.H. (1977). Release of trace constituents from sediments resuspended during dredging operations. In; Yen, T.F. (Ed.) Chemistry of marine sediments. Ann Arbor Science 173-180.

Winters, K., Batterton, J.C. & van Baalen, C. (1977) Phenalen-1-one; occurrence in a fuel oil and toxicity to microalgae. Envir. Sci. & Tech. 11(3):270-2

APPENDICES

Membership of Steering Committee

Mr. C.F. Porter	Department of Conservation and Environment (Chairman)
Mr. E.R. Gorham	Department of Industrial Development
Dr. D.A. Hancock	Department of Fisheries and Wildlife
Captain B.L. Noble	Fremantle Port Authority
Mr. L.F. Ogden	B.P. Refinery (Kwinana) Pty. Ltd.
Mr. F.W. Statham	Commonwealth Department of Construction

Membership of Study Group

Dr. R.G. Chittleborough	Department of Conservation and Environment (Project Leader)
Mrs. E. Moore	Department of Conservation and Environment (Technical Secretary)
Miss D.A. Totterdell	Department of Conservation and Environment (Secretary)
Mr. T.E. Brown	Department of Conservation and Environment (Impact of Pollutants)
Miss M.L. Cambridge	Department of Botany, University of Western Australia (Seagrass)
Mr. A.W. Chiffings	Department of Conservation and Environment (Eutrophication)
Mr. R.E. Dybdahl	Department of Conservation and Environment (Fish Production)
Mr. R.E. France	Department of Geology, University of Western Australia (Sediments)
Mr. J.A.G. Griffiths	Feilman Planning Consultants Pty. Ltd. (Recreation Survey)
Dr. P.J. Murphy	Department of Industrial Development (Industrial Effluents)
Dr. R.K. Steedman	R.K. Steedman & Associates (Physical Oceanography)
Mr. W. Aeschlimann	Department of Conservation and Environment (Technician)
Mr. R.E. Biddiscombe	Department of Conservation and Environment (Technician)
Mr. D.V. Koontz	Department of Conservation and Environment (Technician)
Mr. M.J. Thompson	Department of Conservation and Environment (Technician)

Departments and Institutions associated with the Study

(In addition to those given above)

Community Recreation Council
Department of Botany, University of Western Australia
Government Chemical Laboratories
Harbours and Rivers Branch: Public Works Department
Metropolitan Water Supply, Sewerage and Drainage Board
Murdoch University
Soil Conservation Service: Department of Agriculture
Western Australian Department of Fisheries and Wildlife
Western Australian Institite of Technology
Western Australian Museum