K McNamara

The Marine Environment of Cockburn Sound

Strategic Environmental Advice

Advice to the Minister for the Environment from the Environmental Protection Authority (EPA) under Section 16(e) of the *Environmental Protection Act 1986*

(This is not an assessment of the Environmental Protection Authority under Part IV of the *Environmental Protection Act 1986*)

Environmental Protection Authority
Perth, Western Australia
Bulletin 907
October 1998

ISBN. 0 7309 8107 X
ISSN. 1030 - 0120

Contents

Figures

Appendix

1. Introduction

The purpose of this report is to provide the Environmental Protection Authority's (EPA) strategic environmental assessment and advice to the Minister for the Environment in relation to the cumulative impact of infrastructure proposals on Cockburn Sound. This advice is provided in accordance with Section 16(e) of the *Environmental Protection Act 1986.*

Cockburn Sound (Figure 1) is the most intensively used marine embayment in Western Australia. The Sound is highly valued by the community for recreation. It is used for commercial purposes, such as fisheries, aquaculture and tourism, which require a high level of marine quality. Cockburn Sound also provides a safe anchorage and maritime facilities near the State's major industrial complex.

The Sound receives waste inputs from point and diffuse sources. The development of industry and port facilities on the coastal strip and the intensification of land-uses in the surrounding catchments during the past fifty years have generated waste inputs to Cockburn Sound. By the late 1970's these wastes had degraded water quality which in turn had resulted in major habitat loss and contamination of biota, sediments and water in the Sound.

The Southern Metropolitan Coastal Waters Study (1991-1994) (SMCWS) arose from a need, identified by the EPA, for a better basis from which to manage existing and projected waste inputs to the marine environment of Perth. The SMCWS sought an improved understanding of the cumulative impacts of waste inputs and this has provided the impetus to work toward a comprehensive environmental quality management strategy for these waters, including Cockburn Sound.

The development of shipping and industrial infrastructure at the coast has diminished public access to the foreshore and beaches of the Sound. These coastal developments have also resulted in the loss or modification of marine habitat.

In late 1997, the northern breakwater extension for the Northern Harbour Precinct at Jervoise Bay was constructed. In recent years the State Government has announced a number of other development initiatives within Cockburn Sound. These include:

- a plan for a residential marina in Mangles Bay, Rockingham by the Department of Transport (DOT);
- a plan by the Fremantle Port Authority (FPA) to construct in the longer term a harbour at Naval Base/Kwinana;
- a call by the Department of Transport (DOT) for expressions of interest to construct and manage a private port in Cockburn Sound (Naval Base/Kwinana);
- a proposal by the Department of Commerce and Trade (DCT) for an Industrial Infrastructure and Harbour Development, Jervoise Bay; and
- a proposal for an additional berth at the FPA bulk cargo jetty.

2. Need for Strategic Environmental Advice

The EPA has statutory obligations to assess the potential environmental impacts of specific development proposals under Part IV of the *Environmental Protection Act 1986.*

However, from a broader perspective, the EPA holds the view that the marine environmental implications of potential developments, such as those listed above, cannot be considered in isolation, either from each other or from already existing pressures on the environment of Cockburn Sound.

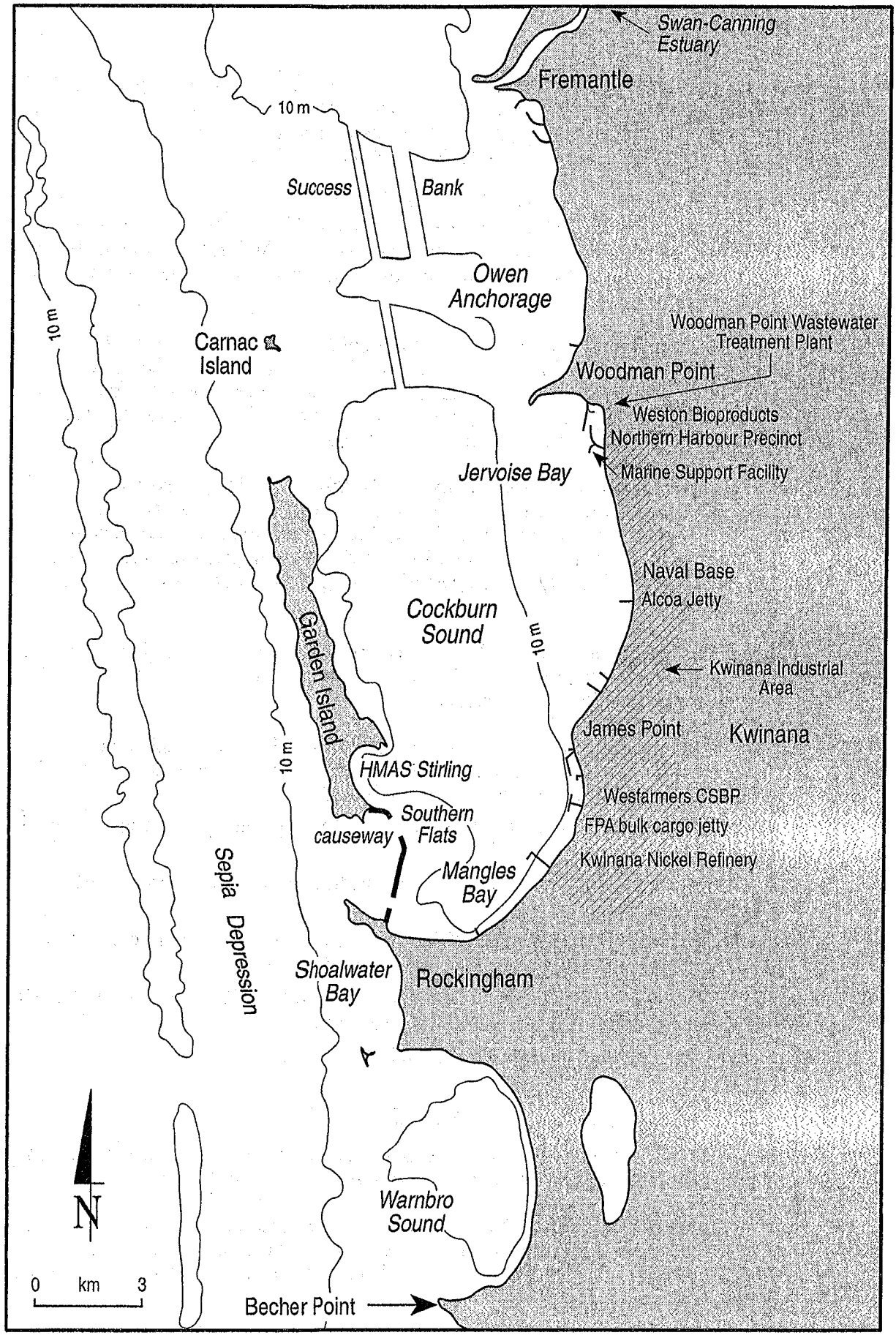


Figure 1. Cockburn Sound and adjacent areas.

A series of such developments along the shallow margins of the Sound would clearly result in extensive habitat modification, and together, they may have the potential to affect water circulation, water quality and ecological function over a broader portion of Cockburn Sound.

In addition, the recently completed Northern Precinct Harbour in Jervoise Bay has experienced algal blooms. Significant public concern was expressed in relation to water quality deterioration both within and beyond the harbour. The collapse of the original diatom bloom and its succession by a dinoflagellate bloom highlights the ecological instability which can occur when eutrophic waters are enclosed. Although the scale of this event is relatively small in comparison to the series of harbour proposals, it highlights what can occur as a result of additional development and exacerbation of existing conditions within Cockburn Sound.

There is also major community concern that the types of developments proposed would further restrict public access to beaches and coastal waters along the mainland coast of the Sound.

The EPA has therefore decided to prepare strategic environmental advice on the cumulative impact of infrastructure proposals on water quality and marine ecology in the Sound. This is consistent with its objectives of protecting or restoring a broad range of environmental values of Cockburn Sound and promoting uses that are ecologically sustainable.

To assist in preparing its strategic advice, the EPA convened a series of workshops, involving marine scientists, and representatives from Government agencies and industry, which culminated in a Statement of Advice to the EPA (see Appendix). The Statement of Advice, prepared by a core group of experienced marine scientists, focused on the marine ecological response that could arise from the cumulative effects of harbour infrastructure development initiatives in Cockburn Sound. Hence, the Statement considered issues of water circulation and flushing, water quality, sediment processes, nutrient cycling, benthic habitat and other environmental factors which may change as a result of infrastructure development scenarios over a time period of up to 30 years.

The EPA recognises that the Statement of Advice is a conceptual analysis based on currently available plans and proposals, and the scientific knowledge and expertise of the workshop participants. The intention of the EPA is that this strategic advice will provide timely guidance for decision makers, planners and proponents in relation to factors which need to be taken into account to ensure that the environmental quality of Cockburn Sound is protected and its community uses are maintained and enhanced. Furthermore, the EPA intends that this advice should encourage:

- careful review of strategic development plans for Cockburn Sound and its surrounds;
- broad stakeholder input and advocacy for the implementation of coordinated environmental management arrangements for Cockburn Sound and its surrounding catchments; and
- development of project alternatives, both in terms of siting and design, that avoid or minimise environmental impact and are consistent with the ecological sustainability and the long-term community vision for the Sound.

The EPA also considered that there was a need to set out accompanying advice on:

- its position on the protection of remaining seagrass meadows and potential seagrass habitat in Cockburn Sound;
- its programme to consultatively develop environmental values, environmental quality objectives and criteria against which predicted and monitored cumulative effects can be assessed, and hence environmental management decisions made;
- its views on the need for revised planning and environmental management mechanisms which would more fully incorporate environmental requirements; and
- the need for an ongoing programme of research and investigation to support decision making in relation to cumulative impact management.

The EPA is currently assessing the proposed Industrial Infrastructure and Harbour Development in Jervoise Bay, under Part IV of the Act. As part of this assessment, the EPA has required the proponent to undertake additional work and as a result of this additional work, a new breakwater design has been proposed. The EPA expects to complete its assessment of this modified proposal and report to the Minister for the Environment by the end of October 1998.

The proposal for an additional berth, for iron ore export, at the Fremantle Port Authority bulk cargo jetty was referred to the EPA and the level of assessment set at 'Not Assessed, to be managed under Part V of the Environmental Protection Act'. As a result of 21 appeals against this level of assessment, the Minister for the Environment, in her decision of 25 September 1998, has allowed the appeals on the grounds of visual, social and recreational amenity issues, as well as other environmental impact issues.

With regard to the Mangles Bay Marina, the EPA in 1992 rejected a proposal to construct a marina at Mangles Bay on the basis of unacceptable loss of seagrass. The Mangles Bay Steering Committee was established to investigate alternative design concepts which would meet environmental and other constraints for a marina in the area. As a result of these investigations and recommendations made by this committee, a new marina proposal is being considered by State Government. This new proposal has not yet been referred to the EPA for assessment.

Long-term port development plans for Naval Base/Kwinana are still at the conceptual design stage, and there have been no referrals to the EPA for project assessment.

3. Statement of Advice on Long-term Harbour Scenarios

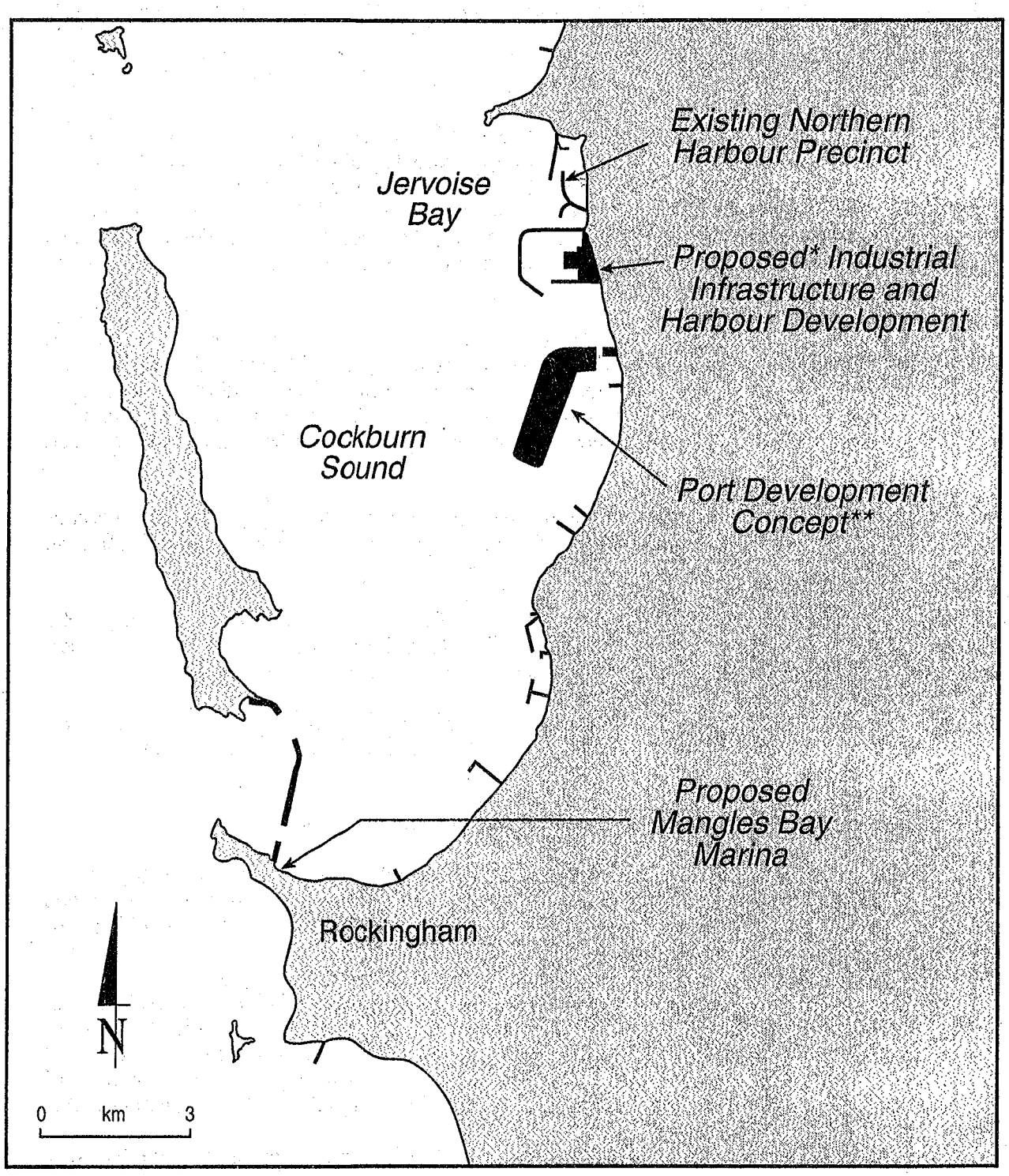
The Statement of Advice arising from the workshops (see Appendix) focuses on the likely response of the marine environment of Cockburn Sound to potential long-term harbour development scenarios, taking into account existing pressures on the marine environment from waste inputs and other activities.

The Statement advises on the qualitative nature and direction of ecological changes likely to occur as a result of a major developments scenario (Figure 2), including a proposal for an Industrial Infrastructure and Harbour Development in southern Jervoise Bay, a concept for a significant harbour development located off the Kwinana Industrial Area (between James Point and the Alcoa Jetty), and a proposed recreational marina facility entering Mangles Bay near Rockingham. This indicative major developments scenario was identified in consultation with representatives of relevant State and Commonwealth Government agencies and industry.

The Statement of Advice addresses the environmental issues which are predicted to arise as a result of prolonged periods (several years for each project) of construction, involving the construction of breakwaters and reclaimed areas, as well as the dredging of shipping channels and ship turning basins. It also deals with post-construction issues associated with increased shipping and the combined effects of the deepened areas and harbour breakwaters on water movement, sedimentation, light regime at the seabed, the dispersion and fate of nutrients and contaminants, and the consequences of these changes on water and sediment quality, as well as on marine plant and animal communities.

The potential for these environmental changes to occur were considered at three spatial scales:

- within harbours
- between harbours (along the eastern margin of Cockburn Sound), and
- broader Cockburn Sound.



* Harbour design from PER (Halpern Glick Maunsell, 1997). This design has been modified.
** Concept based on FPA and DOT advice (28 May 1998).

Figure 2. Long-term harbour developments scenario in Cockburn Sound.

In summary, for the major harbour developments scenario, the key findings in the Statement of Advice were:

(a) Within harbours

Existing breakwaters enclose an area of approximately 50 ha of sea bed. Under the major developments scenario there would be a total of approximately 550 ha of seabed either enclosed by breakwaters or covered by 'reclaimed' land. These areas represent approximately 2 % (existing development) and 20 % (major developments scenario) of the total area of the broad, relatively shallow eastern margin of Cockburn Sound between Woodman Point and James Point. There will be significant changes to ecological processes and major environmental alteration to these areas.

During prolonged construction periods (up to several years), breakwater placement and dredging will smother or remove marine life on the seabed and sediments will be disturbed, which may result in the release of nutrients, the mobilisation of toxicants and reduction in light regimes. Depending on the configuration, sequence and method of breakwater construction, water exchange between the harbour sites and surrounding areas may be significantly inhibited during this period.

After construction, water currents along the eastern margin will be obstructed by harbour developments of the type examined. This will increase the length of time required to flush these sites.

The deeper, calmer waters inside developments will lead to the accumulation of fine particle deposits and episodes of increased turbidity due to shipping movements. Under certain conditions, periods of reduced mixing between bottom and surface waters will occur.

Lengthened flushing times will magnify the impacts of local (within harbour) nutrient sources, resulting in accumulation of total nutrients, greater nutrient assimilation and more algal biomass within the breakwaters.

There will be an increase in the deposition of dead algae to the sediments.

Increased deposition of fine organic particles and decreased bottom light levels, as a result of greater depth and turbidity, will increase sediment respiration and the likelihood of oxygen depletion in bottom waters and sediments. Reduced mixing would reduce the likelihood of oxygen replenishment of bottom waters and marine sediments.

Under these conditions there is likely to be a shift in the processes of nitrogen recycling from the sediments. Firstly, there will be a reduced ability for the sediments to denitrify (and export biologically unavailable nitrogen gas to the atmosphere). Secondly, there will be an increased tendency for the release of ammonia. This may lead to an increase in the concentration of dissolved inorganic nitrogen, which is readily available for biological uptake and algal growth.

Density-stratified, turbid, nutrient-enriched waters tend to favour development of dinoflagellate blooms. It is possible for dinoflagellate cysts to accumulate in high concentrations in bottom sediments, and to seed more widespread blooms.

Organic enrichment of sediments and oxygen depletion in bottom waters could lead to loss of filter-feeding animal communities. This in turn would reduce phytoplankton loss rates and result in higher concentrations of phytoplankton in the water.

There will be a decrease in light levels at the sea bed in harbour areas that have been deepened by dredging, or where water turbidity has been increased. As a consequence of light reduction in these areas there will be a decrease in microscopic plant communities that dwell on the sea bed (microphytobenthos). Microphytobenthic production is presently likely to be high on the

eastern margin, and so reduction or loss of these communities may significantly affect sediment oxygenation, nutrient cycling and ecosystem function within the harbours.

With the projected growth in shipping there is an increased risk of toxic species introductions (for example from ballast water discharge). The risk that abundances of toxic species could build up to unacceptable levels would be exacerbated by an increase in the area of poorly flushed, turbid waters which could result from the projected developments.

Other pest species, such as the fan worm *Sabella cf. spallanzanii* or the algae *Caulerpa taxifolia* and *Codium fragile tomentosoides* are more likely to become established in disturbed areas. The projected harbours may therefore act as additional sites of introduction, both because of disturbed habitat and because of the frequent movement and servicing of ships that may carry these organisms in their hull fouling.

Much of the seagrass meadows that once covered the eastern margin have been lost. Construction of the harbours would result in further loss of remaining seagrass meadows and would also sacrifice the potential opportunity for re-establishment of seagrasses within these sites in areas where once they grew. Re-establishment of seagrasses across the eastern margin will require sustained reductions in nutrient inputs to achieve and maintain water quality and light climate conditions which would allow seagrass survival and growth. The availability of appropriate seagrass establishment technologies would also be required, and these are currently being researched.

The major toxicant of concern will continue to be tributyltin (TBT), which is leached into the water from antifouling paints on the hulls of vessels. An increase in the total number of ship-days in the harbours will increase this input. If hull cleaning and repainting of hulls is permitted in these harbours, the release of TBT will be further increased. TBT concentrations in waters and sediments are likely to have significant impacts on sensitive marine biota, particularly shellfish.

Concentrations of contaminants such as petroleum hydrocarbons and trace metals in biota which frequent or reside in the harbours are likely to be elevated, compared to species in the broader Sound. These contaminants may occur in industrial discharges and in runoff and inputs associated with harbour development infrastructure. Oils, greases and other hydrocarbons may lead to tainting of fish.

There is potential for chronic and accidental spills of nutrients and contaminants during loading and unloading of ships.

(b) Between harbours (on the eastern margin of Cockburn Sound)

The placement of several large-scale developments along the eastern margin will leave marine areas between the developments (or between developments and the coast) which are of similar size to the developments themselves. For the major developments scenario, the size of these inter-harbour areas is estimated to be 380 ha, ie. about 15 % of the eastern margin between James Point and Woodman Point. Environmental alterations and changes to ecological processes are likely to occur in these areas.

During construction, dredging of access channels will result in the removal of bottom-dwelling marine life from portions of the inter-harbour areas. There is potential for release of nutrients in sediment pore waters, toxicant mobilisation, siltation and light reduction arising from dredging these channels and from dispersion of waters while dredging within harbour confines. Both suspension feeders and photosynthetic organisms may be affected and there may be changes in species composition. The magnitude of these effects would depend upon the configuration of the inter-harbour areas, their flushing times and the length of the construction period.

Post-construction, the flushing times of these inter-harbour marine areas are likely to be significantly lengthened because of obstruction of flow by adjacent breakwaters.

The cumulative effect of a number of large-scale developments along the eastern margin is likely to be a reduction in the rate of exchange of water between the inner eastern margin and the remainder of the Sound.

Vertical mixing and bottom stress (from the action of wave-induced currents near the sea bed) will be reduced in more sheltered areas between or adjacent to harbours.

Lengthened flushing times, reduced mixing and reduced bottom stress, in conjunction with nutrient loads, will lead to changes in water quality, nutrient cycling and biological effects which are qualitatively similar to those predicted within harbours. There is also potential for exchange of water containing high nutrients, phytoplankton biomass, turbidity and depleted oxygen between harbours and adjacent regions.

To the extent that multiple harbours lead to low flushing over an extended region along the eastern shore, there is potential for trapping of nutrients originating outside this region, eg. the groundwater and industry nitrogen loads south of James Point.

If zones between harbours contain sufficient shallow habitat, there is potential for development of a high biomass of drift and attached macroalgae.

*(c) **Broader Cockburn Sound*** (beyond the harbour and inter-harbour areas).

In this assessment, the hydrodynamic analysis was limited to late summer, well-mixed water conditions with sea breezes and southerly winds. The flushing time of the Sound under these conditions appears to be quite long (a month or more) and the short model runs and limited analyses conducted do not permit comment at this stage on the effects of several major harbour developments on the flushing time of the broader Sound, or on the water residence times in regions of the Sound well away from the developments. The Sound is vertically stratified for much of the year, and it is not clear whether several developments along the eastern margin would affect density-driven flows in the Sound. More detailed modelling would be required to answer these questions.

It is likely that, under a range of meteorological conditions, water will be transported from the eastern margin into the broader Cockburn Sound. The eastern margin harbour developments may therefore represent sources of lower quality water to parts of the Sound which have long residence times.

It is possible that the developments could increase the proportion of the nitrogen load from the eastern margin of the Sound which is transferred to the deeper central basin. This could occur through a reduction in denitrification efficiency of the sediments on the eastern margin and an increase in the dissolved inorganic nitrogen released to the water column.

Nutrient and chlorophyll levels in some parts of Cockburn Sound may favour development of harmful or nuisance blooms. If harbours or adjacent areas act as a seed area for dinoflagellates, there is potential for these to spread to other nutrient-enriched parts of the Sound. This may impact commercial exploitation of filter-feeders (eg. mussels). Similarly, pest species such as macroalgae or worms, initially established in the harbours, may spread, with potential to alter the functioning of ecosystems in the Sound.

The proposed and projected harbour sites cover a substantial proportion of the seafloor within the Sound where light levels were once sufficient to support the growth and survival of perennial seagrass meadows. Harbour construction would permanently deepen these sites, thus significantly reducing the total area available for seagrass recolonisation.

During prolonged construction, there is likely to be movement of nutrients, toxicants and turbid waters from the vicinity of the harbour developments into areas of the broader Sound.

4. Other Infrastructure Issues

The EPA-convened workshops and the Statement of Advice focused on the cumulative environmental consequences of future harbour developments within Cockburn Sound. The EPA is of the view that there are additional infrastructure-related issues of relevance to the environmental management of Cockburn Sound which require further evaluation.

4.1 The Garden Island Causeway

Construction of a rock-fill causeway between Garden Island and the mainland (west of Rockingham) was completed in June 1974, providing vehicular access to the HMAS Stirling naval facility. The causeway traverses the southern entrance to Cockburn Sound, following the shallowest route between the land masses. Two bridge openings were incorporated into the causeway leaving a flow area of approximately one third of the original flow area along this section of the southern entrance to the Sound.

Between 1970 and 1976 a series of field studies was commissioned by the Commonwealth Government of Australia to assess the changes in flow which occurred as a result of the causeway construction. A complementary study by the Maritime Works Branch (1977a and b) used a two-dimensional hydrodynamic computer model which calculated the depth-averaged water circulation of Cockburn Sound. This study concluded that, as a result of the causeway: (i) water flow through the Sound's southern entrance had been reduced to about 40 % of what it was prior to causeway construction, (ii) the wind-driven water circulation patterns within Cockburn Sound had not been significantly affected, and (iii) water exchange across the southern and northern ends of the Sound were of a similar, low magnitude. Other hydrodynamic studies of the causeway by Steedman and Craig (1983) and Speedy (1994) also used depth-averaged models, and drew similar conclusions.

As part of the Southern Metropolitan Coastal Waters Study (DEP, 1996) a three-dimensional hydrodynamic model was used to examine for the first time the effects of the causeway under several conditions of density stratification. This Study concluded that exchange flows across the northern opening may have been underestimated by the previous two-dimensional modelling studies, and suggested that the most significant hydrodynamic changes due to the presence of the causeway occurred in the southern half of the Sound.

The EPA notes the previous investigations on the way in which the causeway affects circulation and flushing of the Sound. However, the Authority is of the view that further studies are required that would identify the effect of the causeway on the water quality and ecological status of Cockburn Sound. These studies should include simulations of the causeway with different sized openings to investigate the potential environmental benefits of structural modifications to the causeway.

4.2 Shipping Channels

An increase in the number and size of vessels entering Cockburn Sound will occur if the Sound remains as an important centre for port activities. Consequently, at some stage in the future, there may be a demand for widening, deepening or duplicating the main shipping channel that provides access into the Sound. There will be a range of environmental implications for Cockburn Sound, including loss of habitat on adjacent sand banks, and changes in water exchange, with associated implications for water quality and ecological function. The EPA is of the view that these environmental implications should be scoped and investigated at an early stage in the planning process.

5. Statement on Seagrass

Seagrasses have been significantly affected by development around Cockburn Sound. The dramatic and widespread loss of seagrasses in the Sound resulted primarily from poor water

quality conditions brought about by waste inputs containing nutrients. Direct loss of seagrass due to the construction of facilities (harbours, jetties, etc) and anchor damage has also occurred.

5.1 The Importance of Seagrass

Seagrasses not only have intrinsic value as marine flowering plants, but they also perform important ecological functions in the marine environment. One of the most important functions is that of primary production of organic matter as a food source for animals through the food chain, either directly, or after it has broken down into detritus.

As well as being a source of organic matter, seagrasses provide a habitat for small sedentary animals and provide shelter for juveniles and adults of larger animals during part of their life cycle. Seagrasses also play a part in sediment stability.

5.2 Seagrass in Cockburn Sound

Seagrass evolved in environments characterised by low nutrient levels and clear water. The area of seagrass meadows in Cockburn Sound before industrial activity commenced is estimated to have been about 3900 ha. By 1973, the area of seagrass in the Sound had been reduced to about 700 ha (a reduction of about 80 %). This loss was caused mainly by nutrient-rich waste inputs which stimulated the growth of marine algae, hence reducing the amount of light reaching the seagrass.

Recent surveys show that the current area of seagrass in Cockburn Sound is still in the order of 700 ha, indicating that there has been no significant recovery since the 1970's. Near optimal light conditions would need to be restored and maintained if Cockburn Sound is to provide an environment suitable for seagrass restoration and recovery. This would require improved management and the continued implementation of effective nutrient reduction strategies.

Seagrass and the associated issue of water quality is an important consideration for a number of proposals within Cockburn Sound. Clearly the area of seagrass in Cockburn Sound has been severely reduced. Accordingly, from an environmental perspective any further reduction in seagrass clearly adds to the 80 % or so loss which has already occurred.

Some harbour infrastructure proposals within Cockburn Sound would result in the further loss of seagrass. Whilst the area of seagrass meadow likely to be impacted (lost) by each of the proposals is relatively small compared with the area already lost, the impact needs to be viewed as a further reduction to an already significantly reduced resource.

The dredging of harbour basins and shipping channels in the shallow margins of the Sound, where seagrasses once flourished but have since been lost, would create deeper areas where bottom light levels would be greatly diminished. The construction of breakwaters and reclaimed areas would permanently cover additional areas of these shallow margins. Hence, if these developments were to proceed, they would sacrifice the opportunity to re-establish large areas of seagrasses at these sites.

In the EPA's Report and Recommendations on Cockburn Cement Limited's proposal for Medium Term Shellsand Dredging of Success Bank in Owen Anchorage (Bulletin 901), the EPA reinforced its position on seagrass in Cockburn Sound, stating that "development proposals should not adversely add to the gross changes that have already occurred. As seagrasses are the main biological element significantly impacted by the water quality change in Cockburn Sound it is paramount that there should not be any further losses."

The EPA (1998) further stated its dual objectives of "protecting the remaining seagrass meadows of Cockburn Sound and the need to conserve those areas where seagrasses are most likely to grow, for example sand banks and sandy sea floor." The establishment and maintenance in Cockburn Sound of environmental conditions that are consistent with the survival, growth, restoration and expansion of seagrass cover are key environmental outcomes for the EPA.

The EPA's consultative process to develop environmental quality objectives and criteria for the Perth coastal waters, including Cockburn Sound, is discussed in section 7. It is likely that this process will also address the goal of maintaining or restoring seagrass in Cockburn Sound.

5.3 Restoration of Seagrass

It may become possible to restore seagrasses to areas in Cockburn Sound where once they grew. Restoration of marine habitat is an active area of research in many parts of the world. Locally, research is being undertaken by Cockburn Cement into various aspects of seagrass on Success Bank, including the possibility of transplanting relatively large sods of seagrass from one area to another. Preliminary findings of the transplant work appear encouraging. However, transplanting seagrass is very time consuming and expensive in the short term, and causes significant impacts to, or loss of, the donor bed.

Other restoration approaches that cause minimal or no disruption to the donor bed have been tried elsewhere, with different types of seagrass. These include removal of small "plugs" of seagrass/sediment from donor beds and replanting in the rehabilitation site. This approach relies on growth and lateral expansion of the seagrass in the "plugs" to re-vegetate the new area and to repair any damage caused to the donor bed. Restoration using seeds, either planted directly in the restoration site or after they have germinated and grown into seedlings, is the least damaging method, but has yet to be trialed extensively for *Posidonia* seagrasses.

Restoration of temperate meadow-forming seagrasses in Western Australia remains unproven at this time, and no matter what technique is used, the degree of success of any restoration project attempted will not be known for many years.

As noted earlier, regardless of the restoration technique employed, improved light conditions at the seabed will need to be achieved and maintained if Cockburn Sound is to provide an environment suitable for seagrass restoration and recovery. This will require improved management aimed at (i) retaining the shallow sandy margins of the Sound where seagrass meadows once grew, and (ii) continuing to reduce nutrient inputs to the Sound.

5.4 Seagrass Protection Measures

(a) Reservation through the System of Marine Conservation Reserves

Most of the remaining seagrass meadow in Cockburn Sound is to be found on the western shallow margin of the Sound, just east of Garden Island, on the Southern Flats, and south into Mangles Bay. The Minister for the Environment, through her decision on the short-term dredging programme by Cockburn Cement in 1998, proposed that an extension of the Shoalwater Islands Marine Park should also include much of the remaining Cockburn Sound seagrass meadows (Figure 3).

(b) Policy Framework to Protect and Manage the Marine Environment

The EPA is committed to the objective of preserving, protecting and enhancing the environmental values of the State's marine waters, consistent with the principles of sustainable, multiple use. Hence, the Authority is developing a strategic policy framework to guide marine environmental protection, planning and management in the face of development pressures. The EPA has received public comment on a draft Environmental Protection (State Marine Waters) Policy document and is currently consulting with stakeholders and the general community to develop environmental quality objectives and criteria specifically applicable to the Perth coastal waters, including Cockburn Sound. These initiatives are discussed in greater detail in Section 7.

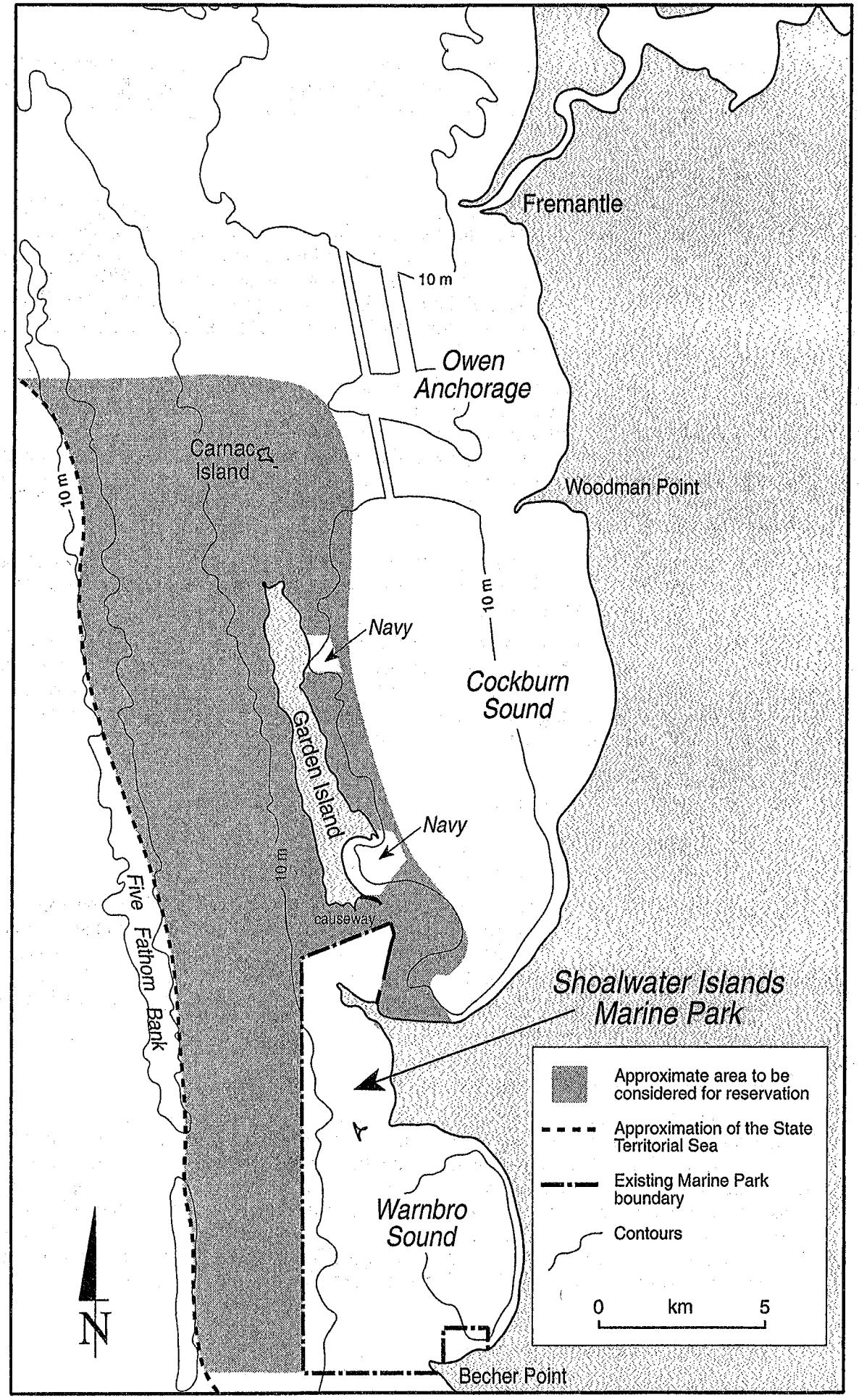


Figure 3. Approximate area proposed for inclusion into the Shoalwater Islands Marine Park.

(c) Pollution Management

Both the Government and industry have been taking strategic steps through environmental studies and pollution control mechanisms to remove or clean-up Cockburn Sound point source discharges. Further initiatives, following the SMCWS recommendations and strong community representation, include the reduction of both point and diffuse nutrient sources from the catchments. These wastes enter the Sound via estuarine, surface drainage or groundwater flows.

The availability of nitrogen is an important limiting factor on algal growth in marine waters and therefore affects the water clarity and light regime reaching benthic communities in Cockburn Sound. Therefore, reducing inputs of nitrogen to Cockburn Sound is a key pollution management strategy. The objective of this strategy is to restore environmental conditions that would ensure survival of remaining seagrass communities and allow for the possible re-establishment of seagrass in areas where once they grew.

The Department of Environmental Protection maintains and regularly updates an inventory of contaminant inputs to Perth's southern coastal waters, including Cockburn Sound and Owen Anchorage.

Nitrogen discharge to Cockburn Sound was low until about the mid-1960's when loadings from industrial and domestic waste outfalls increased rapidly. Peak nitrogen loadings occurred around 1978. Between 1978 and 1990, annual loads of nitrogen discharged to Cockburn Sound were estimated to decrease from about 2000 to 900 tonnes. By 1997 the annual nitrogen load was estimated to be about 421 tonnes, with an estimated 70 % entering in groundwater inflows, mainly in the form of discrete nitrogen-rich groundwater plumes originating from industrial premises. However, it must be realised that estimates of nutrient inputs to Cockburn Sound via groundwater are difficult to make and these estimates can only be considered to be indicative. Furthermore, once groundwater is contaminated, it may take years for the plume to transit from its source location on land to Cockburn Sound, so that there may be a time delay between nitrogen load reduction at source and reduction of groundwater nitrogen load entering Cockburn Sound. In addition, further detailed investigations of the recycling of nitrogen from the sediments of Cockburn Sound are required to better understand the role and significance of 'internal' nitrogen sources.

Water quality surveys over the past 20 years have recorded the phytoplankton concentration (measured as chlorophyll-*a*) and water clarity (light attenuation coefficient) of Cockburn Sound during the summer months (December- March). Since the 1970's, when the water quality of the Sound was at its poorest, and *Posidonia* seagrass meadows disappeared from the eastern margin, the mean summer chlorophyll-*a* concentration of Cockburn Sound reduced significantly in the early 1980's, then gradually increased during the mid-late 1980's and has remained relatively constant since the early 1990's. Similar trends have been observed in the mean light attenuation coefficient, although recently there have been some early signs of a possible improvement in water clarity. Hence, if further nutrient load reductions can be attained, there is a prospect of reaching and maintaining water quality conditions over the eastern margin that would be consistent with the restoration and survival of seagrass meadows.

Some recent, present and future actions which will result in further reductions in nitrogen inputs to Cockburn Sound are listed below.

Water Corporation

Water Corporation ceased the use of sludge drying beds at the Woodman Point Wastewater Treatment Plant in 1998, eliminating a source of nitrogen pollution of groundwater.

Water Corporation has committed to upgrading Woodman Point Wastewater Treatment Plant to advanced secondary standard by 2002. This will result in a major reduction in nitrogen loads to Sepia Depression, as well as significantly reducing biological oxygen demand (BOD), suspended solids and bacteria levels in the discharge.

Western Mining - Kwinana Nickel Refinery

In early 1998, Kwinana Nickel Refinery commenced recovery of a plume of ammonium sulfate-contaminated groundwater beneath their site. Prior to that, considerable capital works were carried out to eliminate sources of groundwater contamination. Following completion of the plume recovery, investigations will be carried out to determine if it is feasible to recover any contaminated groundwater which has travelled off-site and is moving toward Cockburn Sound.

Weston Bioproducts

Weston Bioproducts has been put on notice that continued discharge of nitrogen-laden wastewater to the shallow groundwater aquifer is not acceptable. The Department of Environmental Protection has requested that the company achieve a 95 % reduction in waste disposal to shallow groundwater by no later than April 2000, with a view to zero discharge in the long-term.

Wesfarmers CSBP

Wesfarmers CSBP has been steadily reducing the nitrogen and phosphorus loads to Cockburn Sound over the past three years, and is now aiming for a near zero discharge target to be achieved within five years.

6. Cumulative Impact Study Requirements

The EPA recognises that there is a need to obtain a better understanding of the relationships between changes in circulation and water quality and the impact on biota. These relationships therefore require further investigation if we are to make better decisions and to improve the management of the Sound.

The cumulative effect of a number of large scale developments along the eastern margin is likely to be a reduction in the rate of exchange of water between the inner eastern margin and the remainder of the Sound.

The spatial extent of changes will not be restricted to the areas enclosed by breakwaters but will also affect the inter-harbour marine areas and may possibly affect the broader Cockburn Sound.

In addition, the projected growth in shipping will increase the loading of tributyltin compounds to Cockburn Sound and also increase the risk of toxic species introductions from ballast water discharge and hull fouling.

6.1 Tributyltin

The use of tributyltin on vessels less than 25 m in length was banned in Western Australia in 1992. Since this ban on tributyltin use was implemented, tributyltin contamination has reduced slightly in areas used predominantly by small boats. Regulations controlling licensable activities were amended in September 1996 to include ship-building and ship-maintenance facilities which use or remove organo-tin compounds and to ensure that waste materials containing organo-tin are disposed of in an environmentally acceptable way.

However, tributyltin is still applied to larger commercial vessels and is carried on the hulls of most international ships visiting Western Australian ports, although there are legal limits on the leaching rate of tributyltin-based paints manufactured and used in Australia.

Until a commercially competitive alternative is available, it is unlikely further restrictions will be placed on the use of tributyltin in Australian waters. There is a proposal before the International Maritime Organisation that tributyltin be banned on all shipping by the year 2006. However, if this proposal is not adopted, tributyltin use may continue for the foreseeable future. Hence, marine communities in areas such as Cockburn Sound will continue to be exposed to the toxic effects of tributyltin, at least in the medium-term.

The projected growth in shipping associated with additional harbour developments would increase the loading to Cockburn Sound of organo-tin compounds leaching from the antifouling paint on the hulls of ships. This increased loading would offset to some degree the reductions achieved through regulating ship-building and ship-maintenance facilities and banning the use of TBT on small craft. One possible environmental benefit is that effective antifouling may reduce the risk of establishing exotic marine species in local waters, and lessen the impacts these exotic species can have on local species and local aquaculture.

6.2 Ballast water

There is potential for discharges of ballast water from ships to pollute Cockburn Sound waters. Locally, the discharge of ballast waters requires the approval of the Harbour Master who takes into consideration FPA regulations and the international and Australian ballast water guidelines, when refusing or granting permission. These guidelines encourage ships to exchange ballast water during passage at sea, but they are voluntary guidelines. The FPA regulations prohibit the discharge of oil, oily water, oil sludge, oily bilge water, sewage, poisons or scum into port waters.

There is currently no binding international requirement governing the discharge of ballast water. However the Marine Environmental Protection Committee of the International Maritime Organisation (IMO) has resolved to work toward completion of legally binding ballast water regulations as an Annex to the International Convention for the Prevention of Pollution from Ships (MARPOL) with a view to its adoption by IMO in the year 2000.

The likelihood of introductions of exotic species that may be dislodged from the hulls of ships or discharged in ballast water is likely to increase in proportion to shipping activity. Some naturally occurring or introduced species, such as certain dinoflagellate algae, are potentially very toxic to human consumers of shellfish collected from waters where these species occur in high concentrations. The risk that abundances of toxic species could build up to unacceptable levels will be exacerbated by the greater area of density-stratified, turbid waters which would result from the projected developments. The projected harbours may therefore act as additional sites of introduction, both because of the disturbed habitat and because of the frequent movement and servicing of ships that may carry these organisms in their hull fouling and ballast water.

6.3 Information requirements

Arising from the Statement of Advice

It was the EPA's intention that the attached Statement of Advice concerning potential environmental consequences for Cockburn Sound of future harbour developments (Appendix) should be provided within tight time constraints, based on available information and the marine scientific experience of the workshop participants. Within these constraints it was possible to identify the qualitative nature and direction of ecological changes that could occur in response to a major harbour developments scenario. However, further information and understanding would be required in order to estimate the magnitude of these changes. As requested by the EPA, the workshops identified a number of areas where improved understanding would be required. These information requirements are listed below:

- the effects of harbour developments on the circulation and mixing of contaminant under conditions of typical density stratification;
- hydrodynamic simulations for a wider range of meteorological and seasonal conditions assessed against appropriate field measurements over meaningful time frames;

- estimation of turbidity in the Sound based on the development of a sediment mobilisation and transport model, appropriately coupled to the hydrodynamic model;
- accurate projections of ship movements and hull areas;
- movement of suspended sediments;
- more accurate estimates of the groundwater nitrogen flux into Cockburn Sound (within harbours, between harbours and at a broader scale) and its seasonal variation;
- improved estimates of sediment, oxygen and nutrient fluxes (particularly denitrification) on the eastern margin (both inside and outside the existing Jervoise Bay Harbour development) and throughout Cockburn Sound. This should be coupled to an improved understanding and prediction of vertical mixing and the role that it plays in the dissolved oxygen budget;
- water quality models to predict algal biomass, oxygen depletion and light attenuation;
- the role of zooplankton and benthic filter feeders in controlling algal densities and distribution;
- conditions leading to the germination of dinoflagellate cyst distributions;
- data describing biological assemblages on the eastern margin both within and beyond existing harbour areas; and the relationships between these assemblages and local populations of fish, crabs and the connections between those local populations and the fisheries.

Additional information requirements

In addition to the above list, the EPA has identified other areas where it believes that further investigations should be carried out, in particular:

- the influence of the Rockingham - Garden Island Causeway on the environmental quality of the Sound, and the potential environmental benefits of modifying its design; and
- the environmental implications for Cockburn Sound of any future widening, deepening or duplication of the main shipping channel that provides access into the Sound.

7. Policy Framework for the Protection of State Marine Waters

(a) Draft Environmental Protection (State Marine Waters) Policy 1998

This draft policy seeks to provide a consistent regulatory framework to protect marine waters under Western Australia's jurisdiction from the cumulative effects of development pressures.

The policy provides for the declaration of environmental values of the State's marine waters and for their protection from human activities which may directly or indirectly threaten these values. The policy emphasises the links between catchments and the coastal waters and seeks not only to protect and enhance the quality of the State's marine waters, but also to encourage a waste management hierarchy of waste avoidance, minimisation, reuse, recycling and waste treatment to reduce potential degrading impacts and discharges, directly or indirectly, to marine waters.

In recognition of the variation in marine environments and the range of human activities along the Western Australian coast, the policy acknowledges the need to coordinate State, local and regional environmental protection plans and objectives. These local and regional objectives are more detailed and management-oriented.

The draft policy was released for public comment by the Minister for the Environment on 5 June 1998. The public comment period closed on 4 September 1998. Once the EPA has completed its consideration of public submissions it will prepare a revised draft of the policy for transmittal to the Minister for the Environment.

(b) Perth Coastal Waters Management and Consultative Process

The goal of the EPA's Perth Coastal Waters Management and Consultative Process is to develop an agreed set of environmental quality objectives, and criteria against which cumulative effects can be assessed or measured, and hence environmental management decisions made.

The EPA is coordinating an extensive stakeholder and community consultation process to help identify environmental values, environmental quality objectives and corresponding environmental quality criteria for Perth coastal waters, including Cockburn Sound. This will form the basis for a regulation under the Environmental Protection Policy. The regulation will contain more specific guidance for the protection and management of the Perth coastal waters. Environmental quality objectives are specific management goals that are set to help us achieve the level of environmental quality needed to protect our environmental values. Environmental quality criteria are the benchmarks used to compare with environmental quality monitoring data to determine whether our environmental quality objectives are being met. If this is not the case, then management action will be required to improve our understanding of the situation and to identify and address the cause of any environmental problem.

This framework will provide the setting not only for the assessment of port and harbour infrastructure development in Cockburn Sound, but for all assessments of development proposals affecting Perth's marine environment as well as for the regulation of waste discharges to these waters.

The consultation process in relation to environmental values, environmental quality objectives and the size of draft water quality management zones commenced in May 1998. An extensive round of stakeholder consultation has now been concluded and a Discussion Paper will be available for general public comment from mid October to mid December 1998. The EPA expects to receive the results of the consultation process by the end of January 1999, and shortly after that time the EPA will prepare its report on these issues.

The second phase of consultation will deal with the finalisation of environmental quality indicators and criteria. It is anticipated that this phase will be completed by the end of 1999.

8. Strategic Planning

A range of strategic and statutory land-use planning processes exists. However, these processes have often not given due recognition to environmental constraints, in particular the adverse effects of land-based activities on the quality of the marine environment. Furthermore, there is currently no clear mechanism for marine-use planning (beyond the State System of Marine Conservation Reserves) that takes into account multiple-use issues and environmental constraints.

The Fremantle-Rockingham region contains the major industrial area in Western Australia and has been experiencing significant residential and industrial development pressure over the past decade. Accordingly, the Fremantle Rockingham Industrial Area Regional Strategy (FRIARS) was initiated by the Western Australian Planning Commission to provide a framework to guide future planning and development in the region. Work on FRIARS began in March 1996, and a steering group was set up to manage the study with representation from key Government agencies, including the DEP, and is chaired by the Ministry for Planning.

The FRIARS main objective is to provide a framework to guide future planning and development in the region. However, when the FRIARS Discussion Paper was made available for public comment, it generated significant concern and confusion with respect to long-term

planning of Cockburn Sound and its hinterland. This was because the Discussion Paper essentially stopped at the coastline and made little or no mention of water quality and marine habitat constraints within Cockburn Sound, or the EPA's Coastal Waters Consultative Process to develop environmental quality objectives for these waters. In addition, the Discussion Paper did not consider social impact and social amenity issues relating to community uses of the Sound.

Given its relevance, it is important that FRIARS recognises and carefully considers the findings and draft recommendations of the SMCWS Final Report. Since the release of the Discussion Paper, the DEP has briefed the FRIARS Steering Committee on marine environmental implications and constraints. The DEP will continue to provide input on the full range of environmental issues during development of the draft strategy. The EPA expects that the FRIARS steering group will integrate protection measures into the strategy to protect Cockburn Sound.

There has been public concern expressed recently to the EPA during its assessment of several development proposals and the preparation of this advice about the consequences on public use of Cockburn Sound and its foreshore. Following discussions, the FRIARS committee has agreed that a social impact assessment will be commissioned as part of the FRIARS study, and that this assessment will involve all community sectors with an interest and involvement in the area.

It is likely that the EPA will provide advice to the Minister for the Environment on the FRIARS Report following its finalisation and publication.

9. Future Management of Cockburn Sound

Cockburn Sound provides a significant multiple-use resource to the Perth metropolitan area. The community has strong 'ownership' of Cockburn Sound, primarily derived from historical and current recreational use. Industrial and commercial activity is also a significant use of the Sound and its adjoining land. However there is no comprehensive statutory support for the multiple-use management of Cockburn Sound. Where statutory mechanisms exist, they are integrated into a larger multiple-use context.

One of the main recommendations of this report is that Government commit to the implementation of an overall planning and management strategy for the Sound that gives full consideration to the cumulative environmental implications of current activities and future development proposals. The SMCWS highlighted the need to reach an agreed set of environmental objectives and criteria to guide the range of uses of the Perth coastal waters and highlighted the problems which arise in the absence of clear objectives. The EPA considers that some form of statutory management body with coordinating control over Cockburn Sound and its catchments should be developed to oversee existing and future uses within a multiple-use framework, consistent with the agreed set of environmental objectives.

At present Cockburn Sound is managed by a number of agencies:

- the Fremantle Port Authority (FPA), which has primary management responsibility for much of Cockburn Sound, as it is within the FPA port boundary as defined under the Fremantle Port Authority Act 1902;
- the Commonwealth (Navy), in relation to navigation in 'Naval Waters' east of Garden Island;
- the Department of Conservation and Land Management, in relation to the Shoalwater Islands Marine Park, part of which is located west of the causeway and north of Cape Peron; and
- The Department of Commerce and Trade, in relation to a portion of Jervoise Bay.

In addition there are several State Agreement Acts that provide for rights within Cockburn Sound. These include:

- Broken Hill Proprietary Steel Industry Agreement Act 1952
- Cement Works (Cockburn Cement Limited) Agreement Act 1971
- Industrial Lands (Kwinana) Agreement Act 1964
- Oil Refinery (Kwinana) Agreement Act 1952

In terms of management, these agencies and legislation provide for the development of land, establishment of structures and use of waters for port purposes.

By virtue of the fact that the majority of Cockburn Sound is vested in it, the FPA has the major management presence in the Sound. However, its legislation does not provide for management responsibility outside of port-related activities. It is understood the current Ports Bill 1998 does not alter this. The management responsibilities for the adjoining foreshore and other land around Cockburn Sound are much clearer, with local authorities having a significant role through reserve vesting and planning controls. As a result of existing arrangements, the FPA is sometimes seen to have a defacto management role, however this is inconsistent with its more specific statutory role. There is no agency responsible for the management of the combined effects of diffuse source pollution, groundwater and drainage in this area.

The community also has strong 'ownership' of Cockburn Sound, primarily derived from historical use and presumed rights. However there is no statutory support for many of the multiple-use activities on Cockburn Sound. The recent expression by the public over the potential loss or restriction of existing uses resulting from proposed future developments highlights the conflict. An area of such significance to the State and the community cannot remain without a clear management presence which incorporates strategic planning for multiple-use management and ecologically sustainable development.

A comparable situation which now has a clear management presence is the Swan River. Prior to the establishment of the Swan River Management Authority under the Waterways Conservation Act, management responsibility for the river was dispersed and lacked coordination. The present Swan River Trust has dedicated legislation which provides for the integration of planning and management, consistent with a range of other statutory processes.

The State Government should examine and implement improved and coordinated management and planning over the waters of Cockburn Sound and its catchments. This may be expanded to incorporate Owen Anchorage, given the relationship and proximity of the two marine areas. It does not appear that existing legislation is adequate to provide for the required management presence in Cockburn Sound, or for proper coordination and implementation of management in the Sound and its catchments.

9.1 Catchment Management

It is recognised worldwide (GESAMP, 1990; Zann, 1995) that much of the deterioration in coastal water quality and loss of marine habitat that has occurred, can be attributed to waste inputs from land-based sources in the catchments. Hence, any initiative to manage the environmental quality of the coastal waters must be fully coordinated with land-based management of the catchments.

Australia has recognised the importance of this by becoming a signatory to the UNEP Global Program of Action for the Protection of the Marine Environment from Land-based Sources of Pollution (UNEP, 1995).

The Minister for the Environment has recently sought assistance from local Government in implementing a broad Government strategy to assist in the management of water quality and the retention of seagrasses in Perth's coastal waters.

The direct discharges of nutrients to the Sound are receiving management attention and have been reduced significantly compared with the late 1960's - early 1970's when major seagrass losses occurred. Groundwater inflows to the Sound deliver major nitrogen loads from point and diffuse sources in the catchments. Nutrients contained in outflows from the Swan-Canning and (to a lesser extent) the Peel-Harvey estuaries are also transported by water currents into Cockburn Sound.

Management of nutrient losses from catchments has largely been undertaken in an attempt to arrest the decline in the environmental quality of estuaries. Particular emphasis has been placed on reducing the export of phosphorus from these catchments, because it has been shown that excess phosphorus supply is a key factor which promotes algal growth and eutrophication in estuaries. However, it is essential to note that, in the marine coastal waters of the Perth region, including Cockburn Sound, it is nitrogen rather than phosphorus which is generally the nutrient of concern. The SMCWS highlighted the major contribution of catchment nutrients, via groundwater and estuarine outflows, to the nearshore coastal waters. Hence, it is critical that catchment management programmes identify protection of marine coastal waters (as well as estuaries) as a management objective, and explicitly target nitrogen reductions.

Reduction in loads from these sources are more difficult to achieve and will require a concerted and co-operative effort between State Government, local Government and the community. The Minister has therefore requested that relevant local authorities, together with the Water and Rivers Commission and the Water Corporation, develop nutrient reduction programmes for urban drainage into Cockburn Sound and Owen Anchorage. The Department of Environmental Protection needs to continue its efforts to progressively reduce the contributions of nutrients and other contaminants from point sources around Cockburn Sound.

It is envisaged that a broad set of management strategies, similar to the catchment management programme for Bayswater Main Drain (Klemm and Switzer, 1994) needs to be developed and implemented throughout the catchments draining toward Cockburn Sound/Owen Anchorage. The Water and Rivers Commission and the Department of Environmental Protection should continue their initiatives to reduce nutrient and other contaminant inputs to Cockburn Sound from point and diffuse sources.

10. Implications for Decision Making

It is the role of Government to make decisions, and it is the role of the EPA to provide the best environmental advice available as an input to the decision-making process.

Cockburn Sound is a special area combining recreational and industrial pursuits. Decisions taken today may determine the type of waterway Cockburn Sound becomes in the future and could either enhance or foreclose other current uses and future opportunities. Decisions can be guided by a knowledge of the state of the environment, the decision options available and their potential impacts on the environment, and the actions proposed so as to ameliorate, as best we can, any impacts which may arise from these decisions.

Western Australia has made formal commitments to the National Strategy for the Conservation of Australia's Biodiversity and the National Strategy for Ecologically Sustainable Development (ESD). ESD involves "...using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased." (Commonwealth of Australia, 1992).

To give effect to these commitments, there is a need for a workable and clear mechanism for marine-use planning and management (beyond the State System of Marine Conservation

Reserves) that is ecosystem-based and takes into account multiple-use and equity issues (among users and generations). Also, terrestrial planning needs to give adequate consideration to the links between land-based activities and the quality of near-shore marine waters. The need for adequate statutory management arrangements to address multiple-use and environmental issues affecting Perth's marine waters, particularly Cockburn Sound, has never been greater.

Cockburn Sound is the most intensively used marine system in the State. Its environmental status is increasingly being regarded by many in the community as a 'barometer' of how well the marine environment is being managed, as evidenced in the recent state of the environment report, entitled 'Environment Western Australia 1998' (Department of Environmental Protection, 1998).

Pressures and Responses 1950's - 1980's

Waste discharges to Cockburn Sound commenced in the mid-1950's. By the early 1970's most of the seagrass meadows in Cockburn Sound were severely degraded from nutrient enrichment, and water and biota were contaminated with toxicants and pathogens. In response, the Western Australian Government initiated the Cockburn Sound Environmental Study (1976-1979) to identify the causes of the problems and develop and evaluate solutions. The key recommendations centred on reducing waste discharges. These recommendations were implemented and marked improvements in environmental quality occurred in the early 1980's.

Pressures and Responses 1980's - 1990's

On-going monitoring during the 1980's showed a gradual decline in water quality associated with increasing nutrient loads. By 1990 the water quality had deteriorated to a level close to that of the late 1970's when it was at its poorest.

The EPA initiated the Southern Metropolitan Coastal Waters Study in 1991 to provide a clearer understanding of the present state of the coastal waters in relation to waste discharges and to identify, as far as possible, the long-term ecological consequences of projected future discharges. This re-focusing provided new impetus to arrest the decline and positive steps have been, and are being, taken to reduce waste inputs to Cockburn Sound. Monitoring is now showing that nutrient-related water quality has stopped deteriorating and that signs of a possible trend towards improvement are appearing.

Decision-making in the late 1990's

Positive steps are being taken to reduce waste inputs to Cockburn Sound, but further development of harbours or breakwaters in the Sound will, to some extent, mitigate the effects of these waste reduction strategies. There is insufficient scientific understanding at present to accurately predict the extent of the marine environmental impacts of further developments, but their potential to change water residence times and to permanently remove habitat is likely to reduce the environmental quality of the Sound. As a consequence of this, the range of community and other industry uses of the Sound may be further limited.

The EPA has a process in place to identify the environmental values and to develop environmental quality objectives and criteria for Cockburn Sound as an aid to management. This follows the work undertaken through the Southern Metropolitan Coastal Waters Study (1991-1994) and will lead to proposals for regulations pursuant to the draft Environmental Protection (State Marine Waters) Policy currently being progressed by the EPA. A clear and Government-endorsed set of environmental quality objectives would greatly assist the EPA in providing advice to Government to protect the environmental values of Cockburn Sound in the short and long term.

Decision-making about developments in the Sound from here on needs to take into account (i) the historical events which have affected water quality and marine habitat, (ii) the contempory community and Government views of the kind of waterway Cockburn Sound should be,

(iii) the potential impact of each development, both in isolation and cumulatively, and (iv) the response initiatives available and deliverable which can assist in ameliorating adverse environmental impacts.

The EPA is of the view that the Government response needs to consider the Sound as a whole, as well as at the project level. There is a need for a consolidated management structure to be developed for the Sound and its catchments. This structure should be sufficiently robust and resourced so as to enable on-going management initiatives to be taken in relation to the information needed, the planning necessary and the actions required to ensure that the multiple-uses of these waters are socially equitable and ecologically sustainable.

11. Conclusions

The following conclusions are made:

General

- The EPA will use the position statements and strategic advice provided in this report to assist in the assessment/evaluation of plans and project proposals which have a bearing on the Cockburn Sound environment.

Generic

- The community uses Cockburn Sound for multiple purposes, including recreation, tourism, commercial fishing (including aquaculture), shipping and industry.
- In accordance with the requirements of the *Environmental Protection Act 1986*, the EPA expects to see that plans, proposals and management undertaken in Cockburn Sound and its land catchment areas are consistent with the principles of ecologically sustainable development.
- An Environmental Protection (State Marine Waters) Policy which provides for the protection of marine environmental values is currently being developed in consultation with the community.
- The EPA is conducting a consultative process specifically for Perth coastal waters (including Cockburn Sound) to assist in developing the environmental values and marine quality objectives for the environmental management of the Perth region.

Cumulative Environmental Effects

- A series of further breakwater and harbour developments in Cockburn Sound will reduce flushing of water enclosed within the harbours or between neighbouring harbour developments. Reduced water flushing has implications for degradation of water quality and marine ecosystems, such as increased risk of algal blooms and reduced primary productivity.
- Approximately 80 % of the seagrasses in Cockburn Sound have been lost, either from water quality change or direct physical impact. The EPA considers that it is paramount that any further loss of seagrasses in the Sound be avoided. Protection of the remaining seagrass meadows of Cockburn Sound is an objective of the EPA.
- Most of the remaining seagrass meadows in Cockburn Sound border the east coast of Garden Island, or are found on the Southern Flats and in Mangles Bay. The EPA is aware that the Marine Parks and Reserves Authority has been requested by the Minister for the Environment to consider including these areas in the Statewide System of Marine Conservation Reserves.

- The EPA considers that it is important to retain the sand banks and sandy margins of Cockburn Sound, where seagrass meadows once grew, so as not to lose future opportunities for seagrass re-establishment in the Sound.
- The EPA expects that proponents developing proposals which have the potential to affect the marine environment of Cockburn Sound, should consider the cumulative environmental implications on the Sound, taking into account the relationship between the proposal and the existing and planned future uses in Cockburn Sound.
- The EPA considers that there is need to encourage better management and a further reduction of contaminant inputs from direct and indirect sources, with the goal of achieving and maintaining agreed environmental quality objectives for Cockburn Sound.
- The EPA considers that public access to the mainland foreshores and beaches of Cockburn Sound has been severely restricted.

Management-related

- The EPA has identified the need to establish a statutory management structure to coordinate management within Perth's marine waters, especially Cockburn Sound, and between these waters and their land catchments.

- The EPA has identified the following issues which need to be addressed through coordinated management action:
  - continued reductions of waste inputs from point sources direct to the Sound;
  - reduction in catchment point sources which have the potential to reach Cockburn Sound via groundwater outflow or surface drainage;
  - improvements in catchment land-use to reduce diffuse catchment sources, bearing in mind (i) the direct inflow of surface drainage and groundwater to the Sound, and (ii) the movement of nutrient-rich outflows from the Swan-Canning and Peel-Harvey estuaries into Cockburn Sound;
  - the need to incorporate marine environmental constraints in planning and management, including planning conditions for no discharge either via groundwater or directly to the Sound;
  - improved measures to prevent waste inputs from ship-related activities; and
  - the need for an ongoing programme of research, investigation and monitoring of the ecological response of Cockburn Sound to human-use pressures, developments and natural variation, in order to assist in broad decision making and to provide the basis for implementing management action to maintain and enhance the values and uses of the Sound.

Research and Monitoring to support Decision-making

- In the short time frame available, the Statement of Advice (Appendix) provided a qualitative assessment of the likely cumulative impacts of infrastructure developments in Cockburn Sound. The EPA stresses that a continuing programme of research and investigation is required in order to provide more quantitative information to support planning and management of the Sound. Section 7.3 of the Statement of Advice lists specific information requirements and needs to improve the understanding of key ecological processes in Cockburn Sound. Unless these needs are addressed, it will not be possible to accurately assess the cumulative environmental impacts of development proposals, and management of the Sound as a whole will be compromised.

- As part of a continuing management-oriented research and investigation programme for Cockburn Sound, the EPA considers that further work should be conducted:
  - to improve the understanding of, and ability to predict, the extent to which development proposals and other human-use pressures affect the ecological health and social amenity of Cockburn Sound. This understanding will be used to support decision-making. It will require further studies and modelling of the hydrodynamic movement and mixing of contaminants and nutrients, nutrient cycling processes, and ecosystem response to water and sediment quality changes;
  - to develop and track key environmental performance indicators, including chlorophyll-*a* and light attenuation;
  - to assess the influence of the Rockingham - Garden Island Causeway on the environmental quality of Cockburn Sound, and the potential environmental benefits of modifying its design; and
  - to evaluate the influence of widening, deepening or duplicating shipping access channels into Cockburn Sound on the flushing characteristics and environmental quality of the Sound

12. Recommendations

The EPA recommends to the Minister for the Environment that:

1. The Minister notes that this report has been prepared to assist decision-making for the long-term planning and management for the sustainable use of Cockburn Sound.

2. The Minister endorses the strategic environmental advice set out in this report and encourages both government and proponents of development proposals to adopt the advice as a guide for considering cumulative impact issues in the marine environment of Cockburn Sound.

3. The Minister agrees that the issues raised in this report should be addressed by proponents during the planning and design of their proposals and by government during the decision-making process, taking into account the interactions of each proposal with existing and planned facilities.

4. The Minister recommends to Government that it provide a commitment to an ongoing programme of research and investigation in Cockburn Sound to assist in broad decision-making, and as a basis for the consideration of management action over time aimed at ameliorating the cumulative impacts on the marine environment arising from existing and future developments.

5. With respect to Recommendation 4, the Minister requests the EPA to provide a report outlining an ongoing programme of management-oriented research and investigation, taking into account the information requirements identified in Section 6, the proposed co-ordination arrangements for that research, and the benefits in terms of management action which could result from the research undertaken.

6. The Minister recommends to Government that it establish a management structure, including representatives of Government and community sectors, to coordinate environmental management within Perth's marine coastal waters, including Cockburn Sound, and between these waters and their land catchments.

13. References

Department of Environmental Protection (1996). *Southern Metropolitan Coastal Waters Study (1991-1994). Final Report.* (Department of Environmental Protection, Perth, Western Australia, 6000). Report 17.

ERM Mitchell McCotter (1998). *Fremantle Rockingham Industrial Area Regional Strategy, Draft 3.* Report prepared for the Ministry for Planning. ERM Mitchell McCotter, Western Australia.

Department of Environmental Protection (1998). *Environment Western Australia 1998: State of the Environment Report.* (Department of Environmental Protection, Perth, Western Australia).

Environmental Protection Authority (1998). *Medium-term Shellsand Dredging, Success Bank, Owen Anchorage.* Report and Recommendations of the Environmental Protection Authority, Bulletin 901, Western Australia.

Environmental Protection Authority (1998). *Draft Environmental Protection (State Marine Waters) Policy.* Environmental Protection Authority, Western Australia.

GESAMP (1990). *The State of the Marine Environment.* (Joint Group of Experts on the Scientific Aspects of Marine Pollution). United Nations Regional Seas Reports and Studies, No. 39.

Klemm VV and Switzer CJ, editors (1994). *Recreating the Catchment: Bayswater Main Drain Catchment Management Strategy.* Report for the Bayswater Integrated Catchment Management Steering Committee.

Maritime Works Branch (1977a). *Western Australia Naval Support Facility. Water Movements Cockburn Sound.* (Maritime Works Branch, Australian Department of Construction, Perth, Western Australia, 6000). Report MW77.

Maritime Works Branch (1977b). *The Environmental Significance of the Garden Island Causeway, Cockburn Sound, Western Australia.* (Maritime Works Branch, Australian Department of Construction, Perth, Western Australia, 6000). Report MW80.

Speedy V (1994). *A Numerical Model of the Effects of the Garden Island Causeway on the Flushing of Cockburn Sound, Western Australia.* Unpublished Honours Thesis. (Department of Geography and Oceanography, University College, University of New South Wales, Australian Defence Force Academy, Australian Capital Territory, 2600).

Steedman RK and Craig PD (1983). *Wind-driven Circulation of Cockburn Sound.* Aust. J. Mar. Freshwater Res. **34**:187-212.

United Nations Environment Program (1995) *Global Program of Action for the Protection of the Marine Environment from Land-based Activities.* UNEP(OCA)/LBA/IG. 2/7.

Zann LP (1995). *Our Sea, Our Future; Major Findings of the State of the Marine Environment Report for Australia.* (Ocean Rescue 2000, Department of Environment, Sport and Territories, Canberra, Australian Capital Territory, 2601).

APPENDIX

STATEMENT OF ADVICE

STATEMENT OF ADVICE

AN APPRAISAL OF POTENTIAL ENVIRONMENTAL CONSEQUENCES FOR COCKBURN SOUND OF FUTURE HARBOUR DEVELOPMENTS

Report to the Environmental Protection Authority

August 1998

Acknowledgements

Many people facilitated or were involved in the technical workshops and the preparation of this Statement of Advice. Their contributions are gratefully acknowledged.

Dr Nan Bray, Chief of the CSIRO Division of Marine Research, kindly made available senior scientific staff from the Division. Dr Chris Fandry acted as Chairman, and Dr Don Hancock as Rapporteur, for the technical workshops.

Port and Harbour Development Scenarios Workshop Participants

Dr Chris Fandry (DEP - Workshop Chairman); Dr Don Hancock (Workshop Rapporteur); Mr Patrick Dick and Mr Mike Williams (Department of Transport); Mr Bruce Sutherland (Department of Commerce and Trade); Mr John Barraclough (Fremantle Port Authority); Mr Tom Grigson (Department of Resources Development); Lieutenant Commodore Ian Jempson and Dr Boyd Wykes (HMAS Stirling); Dr Rod Lukatelich (Kwinana Industries Council); Dr Alan Butler, Dr Stephen Walker (CSIRO Division of Marine Research); Dr Paul Lavery (Edith Cowan University); Ms Susan Ingram (Environment Australia); Mr Paul Byrnes, Ms Juliet Cole and Dr Des Mills (DEP).

Hydrodynamic Response Workshop Participants

Dr Chris Fandry (DEP - Workshop Chairman); Dr Don Hancock (Workshop Rapporteur); Dr Stephen Walker (CSIRO Division of Marine Research); Mr Nick D'Adamo (CALM); Dr Kresimir Zic (Kinhill); Ms Susan Ingram (Environment Australia); Ms Juliet Cole and Dr Des Mills (DEP).

Ecological Response Workshop Participants

Dr Chris Fandry (DEP - Workshop Chairman); Dr Don Hancock (Workshop Rapporteur); Mr Bernard Bowen (EPA Chairman); Dr Bryan Jenkins (Chief Executive Officer, DEP); Dr Graeme Batley (CSIRO Centre for Advanced Analytical Chemistry); Dr Alan Butler, Dr Peter Craig, Dr John Parslow, Dr Stephen Walker (CSIRO Division of Marine Research); Dr David Hamilton (UWA Centre for Water Research); Dr Kresimir Zic (Kinhill); Mr Mark Bailey, Mr Craig Schluter (Halpern Glick and Maunsell); Mr Steve Appleyard, Dr Jane Latchford (Water and Rivers Commission); Mr Nick D'Adamo (CALM Marine Conservation Branch); Dr Rod Lenanton (Fisheries WA Marine Research Laboratories); Ms Susan Ingram (Environment Australia); Dr Rod Lukatelich (Kwinana Industries Council Environmental Committee); Ms Juliet Cole, Mr Philip Hine, Mr Colin Murray and Dr Des Mills (DEP).

Preparation of the Statement of Advice

The following group of marine scientists prepared the Statement of Advice, based on the information provided at the series of technical workshops:
Dr Graeme Batley (CSIRO Centre for Advanced Analytical Chemistry); Dr Alan Butler, Dr Peter Craig, Dr John Parslow, Dr Stephen Walker (CSIRO Division of Marine Research); Dr Paul Lavery (Edith Cowan University); Dr Kresimir Zic (Kinhill); Mr Philip Hine (DEP); Dr Don Hancock (Workshops Rapporteur); Dr Des Mills (DEP - Statement Editor).

Executive Summary

Background

The sheltered waters of Cockburn Sound are used for recreation, tourism, commercial fishing (including aquaculture), shipping and industry. Major losses of seagrass habitat and contamination of marine life, sediments and waters had occurred by the late 1960's and early 1970's. In response to these problems, industry and Government have achieved significant reductions in the quantities of toxicants and nutrients discharged from point sources directly to the Sound, and further reductions in these loads are projected. Diffuse sources (e.g. nutrients in groundwater outflows) and ship-related sources (e.g. release of tributyltin in antifouling paints) are also a major concern. Other pressures on the Sound include the disturbance to marine habitats through anchor damage from recreational boats, the dredging of shipping channels and the construction of berths and harbours. As a result of these combined pressures the Sound remains in a delicate state of ecological balance.

During the last two years the State Government announced infrastructure development plans for several commercial harbours on the eastern margin of Cockburn Sound and a residential marina in Mangles Bay, at the southern end of the Sound.

Strategic Environmental Assessment

The Environmental Protection Authority (EPA) is of the view that the marine environmental effects of these potential developments should not be considered in isolation, either from each other, or from already existing activities and environmental concerns in Cockburn Sound. The EPA therefore decided to prepare a strategic environmental assessment of the cumulative effects of anticipated harbour developments in Cockburn Sound over the next 20-30 years. The strategic environmental assessment was to be based on currently available plans and proposals. The EPA requested that a series of technical workshops be convened, culminating in the preparation of a Statement of Advice from a group of experienced marine scientists. This will be part of the EPA's Strategic Environmental Assessment which will take the form of a public report to the Minister for the Environment.

Purpose and Scope of the Statement of Advice

The focus of the Statement of Advice is on the response of the marine environment of Cockburn Sound to potential long-term harbour development scenarios, taking into account existing pressures on the marine environment from waste inputs and other activities. Given the short time frame that was made available to prepare the Statement, it must be considered as initial advice in relation to the issues considered. In particular, it is stressed that the workshop participants were considering the possible consequences of a long-term 'major developments' scenario. Further, it must be emphasised that, while this Statement advises on the qualitative nature and direction of ecological changes likely to occur, further scientific investigations would be required to determine, with reasonable certainty, the magnitude of these changes. Nonetheless, it is intended that this Statement should highlight key environmental issues that need to be resolved through sound planning, management and decision making, supported where necessary by continuing research.

The anticipated effects of a 'major developments' scenario were referenced against a 'baseline' scenario (existing situation). The baseline scenario includes the existing Northern Precinct harbour and the adjoining Marine Support Facility, Jervoise Bay, in the northeast corner of Cockburn Sound. In addition to existing structures, the major developments scenario also includes the proposed Industrial Infrastructure and Harbour Development (Jervoise Bay), a concept for a significant harbour development located off the Kwinana industrial area (between James Point and the Alcoa Jetty), and a proposed recreational marina off Mangles Bay (near Rockingham).

The Statement of Advice addresses the environmental issues which could be expected to arise as a result of prolonged periods (several years per project) of construction, involving the building of breakwaters and reclaimed areas, as well as the dredging of shipping channels and ship turning basins. It also deals with post-construction issues associated with increased shipping and the combined effects of the harbours on water movement, sedimentation, the dispersion and fate of nutrients and contaminants, and the consequences of these changes for water quality and the marine plant and animal communities.

The potential for these environmental changes to occur has been considered at three spatial scales:

- within harbours
- between harbours (eastern margin of Cockburn Sound)
- broader Cockburn Sound.

Summary of the Statement of Advice

(a) Within harbours

Existing breakwaters enclose an area of approximately 50 ha of sea bed. Under the major developments scenario there would be a total of approximately 550 ha of sea bed either enclosed by breakwaters or covered by 'reclaimed' land. These areas represent approximately 2 % (existing development) and 20 % (major developments scenario) of the total area of the broad, relatively shallow eastern margin of Cockburn Sound between Woodman Point and James Point. There will be significant changes to ecological processes and major environmental alteration to these areas.

During prolonged construction periods (up to several years), breakwater placement and dredging will smother or remove marine life on the sea bed, and sediments will be disturbed, and may result in the release of nutrients, the mobilisation of toxicants and reduction in light regimes. Depending on the configuration, sequence and method of breakwater construction, water exchange between the harbour site and surrounding areas may be significantly inhibited during this period.

After construction, water currents along the eastern margin will be obstructed by harbour developments of the type examined and the length of time required to flush these sites will be increased.

The deeper, calmer waters inside developments will encourage accumulation of fine particle deposits and episodes of increased turbidity due to shipping movements. Under certain conditions, these areas will experience periods of reduced mixing between bottom and surface waters.

Lengthened flushing times will magnify the impacts of local (within harbour) nutrient sources, resulting in accumulation of total nutrients, greater nutrient assimilation and more algal biomass within the breakwaters.

There will be an increase in the deposition of dead algae to the sediments.

Increased deposition of fine organic particles and decreased bottom light levels, due to greater depth and turbidity, will increase sediment respiration and the likelihood of oxygen depletion in bottom waters and sediments. Reduced mixing would reduce the likelihood of oxygen replenishment of bottom waters and marine sediments.

Under these conditions there is likely to be a shift in the processes of nitrogen recycling from the sediments, with a reduced ability for the sediments to denitrify (and export biologically unavailable nitrogen gas to the atmosphere) and an increased tendency for the release of

ammonia and the build-up of dissolved inorganic nitrogen, which is readily available for biological uptake and algal growth.

Density-stratified, turbid, nutrient-enriched waters tend to favour development of dinoflagellate blooms. It is possible for dinoflagellate cysts to accumulate in high concentrations in bottom sediments and to act as seed populations for more widespread blooms.

Changes in bottom sediment type and oxygen depletion in bottom waters could lead to loss of filter-feeding animal communities, reducing phytoplankton loss rates and thus resulting in higher concentrations of phytoplankton in the water.

Decreases in light levels at the sea bed, due to increased depth and enhanced water turbidity, will lead to decreases in microscopic plant communities that dwell on the sea bed (microphytobenthos). Microphytobenthic production is presently likely to be high on the eastern margin, and so reduction or loss of these communities may significantly affect sediment oxygenation, nutrient cycling and ecosystem function within the harbours.

With the projected growth in shipping there is an increased risk of toxic species introductions (for example from ballast water discharge). The risk that abundances of toxic species could build up to unacceptable levels would be exacerbated by an increase in the area of poorly flushed, turbid waters which could result from the projected developments.

Other pest species, such as the fan worm *Sabella cf. spallanzanii* or the algae *Caulerpa taxifolia* and *Codium fragile tomentosoides* are more likely to become established in disturbed areas. The projected harbours may therefore act as additional sites of introduction, both because of disturbed habitat and because of the frequent movement and servicing of ships that may carry these organisms in their hull fouling.

Much of the seagrass meadows that once covered the eastern margin have been lost. Construction of the harbours would result in further loss of remaining seagrass habitats and would also sacrifice the potential opportunity for re-establishment of seagrasses in these areas. Re-establishment of seagrasses across the eastern margin will require sustained reductions in nutrient inputs to achieve and maintain water quality and light climate conditions which would allow seagrass survival and growth. The availability of appropriate seagrass establishment technologies would also be required, and these are currently being researched.

The major toxicant of concern will continue to be tributyltin (TBT), which is leached into the water from antifouling paints on the hulls of vessels. An increase in the total number of ship-days in the harbours will increase this input. If hull cleaning and repainting of hulls is permitted in these harbours, the release of TBT will be further increased. TBT concentrations in waters and sediments are likely to have significant impacts on sensitive marine biota, particularly shellfish.

Concentrations of contaminants such as petroleum hydrocarbons and trace metals in biota which frequent or are resident in the harbours are likely to be elevated, compared to species in the broader Sound. These contaminants occur in industrial discharges and in runoff and inputs associated with harbour development infrastructure. Oils, greases and other hydrocarbons may lead to tainting of fish.

There is potential for chronic and accidental spills of nutrients and contaminants during loading and unloading of ships.

(b) Between harbours (on the eastern margin of Cockburn Sound)

The placement of several large-scale developments along the eastern margin will leave marine areas between the developments (or between developments and the coast) which are of similar size to the developments themselves. For the major developments scenario, the size of these

inter-harbour areas is estimated to be 380 ha, i.e. about 15 % of the eastern margin between James Point and Woodman Point. Environmental alterations and changes to ecological processes are likely to occur in these areas.

During construction, dredging of access channels will result in the removal of bottom-dwelling marine life from portions of the inter-harbour areas. There is potential for release of nutrients in sediment pore waters, toxicant mobilisation, siltation and light reduction arising from dredging these channels and from dispersion of waters while dredging within harbour confines. Both suspension feeders and photosynthetic organisms may be affected and there may be changes in species composition. The magnitude of these effects would depend upon the configuration of the inter-harbour areas, their flushing times and the length of the construction period.

Post-construction, the flushing times of these inter-harbour marine areas are likely to be significantly lengthened because of obstruction of flow by adjacent breakwaters.

The cumulative effect of a number of large-scale developments along the eastern margin is likely to be a reduction in the rate of exchange of water between the inner eastern margin and the remainder of the Sound.

Vertical mixing and bottom stress (from the action of wave-induced currents near the sea bed) will be reduced in regions between or adjacent to harbours.

Lengthened flushing times, reduced mixing and reduced bottom stress in conjunction with nutrient loads will lead to changes in water quality, nutrient cycling and biological effects which are qualitatively similar to those predicted within harbours. There is also potential for exchange of water containing high nutrients, phytoplankton biomass, turbidity and depleted oxygen between harbours and adjacent regions.

To the extent that multiple harbours lead to low flushing over an extended region along the eastern shore, there is potential for trapping of nutrients originating outside this region, e.g. the groundwater and industry nitrogen loads south of James Point.

If zones between harbours contain sufficient shallow habitat, there is potential for development of a high biomass of drift and attached macroalgae.

Increased inputs or delayed flushing of contaminants, including TBT, may affect sensitive marine biota, particularly shellfish, and prejudice their suitability for commercial use.

*(c) **Broader Cockburn Sound*** - beyond the harbour and inter-harbour areas.

During prolonged construction, there is likely to be movement of nutrients, toxicants and turbid waters from the vicinity of the harbour developments into areas of the broader Sound.

The short model runs and limited analyses conducted in the period between the technical workshops do not permit comment at this stage on the effects of several major harbour developments on the flushing time of the broader Sound, or on the water residence times in regions of the Sound well away from the developments.

It is likely that, under a range of meteorological conditions, water will be transported from the eastern margin into the broader Cockburn Sound. The eastern margin harbour developments may therefore represent sources of lower quality water to parts of the Sound which have long residence times.

It is possible that the developments could increase the proportion of the nitrogen load from the eastern margin of the Sound which is transferred to the deeper central basin. This could occur through a reduction in denitrification efficiency of the sediments on the eastern margin and an increase in the dissolved inorganic nitrogen released to the water column.

Nutrient and chlorophyll levels in some parts of Cockburn Sound may favour development of harmful or nuisance blooms. If harbours or adjacent areas act as a seed area for dinoflagellates, there is potential for these to spread to other nutrient-enriched parts of the Sound. This may impact commercial exploitation of filter-feeders (e.g. mussels). Similarly, pest species such as macroalgae or worms, initially established in the harbours, may spread, with potential to alter the functioning of ecosystems in the Sound.

The proposed and projected harbour sites cover a substantial proportion of the seafloor within the Sound where light levels were once sufficient to support the growth and survival of perennial seagrass meadows. Harbour construction would permanently deepen these sites, thus significantly reducing the total area available for benthic photosynthesis.

Information Requirements

It was the EPA's intention that this Statement of Advice should be provided within tight time constraints, based on available information and the marine scientific experience of the workshop participants. The workshops were expected to identify a number of areas where improved knowledge and understanding would be needed if the Government and the EPA were to seek more detailed and quantitative advice on the ecological response of Cockburn Sound to harbour development scenarios. While acknowledging that much environmental data exists for this region, the workshops nonetheless identified a number of critical areas where further information would definitely be required. These critical information requirements are detailed in section 7.3. It is strongly recommended that a programme to carry out the necessary investigations be prepared and supported.

Contents

Figures

1. Introduction

Cockburn Sound (Figure 1) is the most intensively and multiply-used marine embayment in Western Australia. The Sound is highly valued by the community for water-based recreation and is used for commercial purposes, for example fisheries (including aquaculture) and tourism, which require a high level of marine quality. The Sound also provides a safe anchorage next to the State's major industrial complex and it receives waste inputs from point and diffuse sources. The development of industrial and naval facilities and the intensification of land-uses in the surrounding catchments during the past fifty years have together contributed to major losses of seagrass meadow habitats in Cockburn Sound and the contamination of biota, sediments and water. There have been reductions in the quantities of wastes discharged from point sources since the late 1970's, and further reductions in these loads are projected. Diffuse sources (e.g. nutrients in groundwater outflows) and ship-related sources (e.g. release of tributyltin in antifouling paints) are also a major concern. As a result, the Sound remains in a delicate state of ecological balance.

Recently, the State Government of Western Australia announced several infrastructure development initiatives within Cockburn Sound. These include:

- a plan for a residential marina in Mangles Bay, Rockingham;
- a plan by the Fremantle Port Authority to construct a harbour at Naval Base;
- a call by the Department of Transport for expressions of interest to construct and manage a private port in Cockburn Sound (also at Naval Base/Kwinana); and
- a proposal by Department of Commerce and Trade for an Industrial Infrastructure and Harbour Development, Jervoise Bay.

Furthermore, in 1997, the northern breakwater for the Northern Harbour Precinct at Jervoise Bay was constructed.

2. Need for a Strategic Environmental Assessment

The Environmental Protection Authority (EPA) is of the view that the marine environmental effects of these potential developments should not be considered in isolation, either from each other, or from already existing activities and environmental concerns in Cockburn Sound. The EPA has therefore decided to prepare a strategic assessment of the marine ecological response that could arise from the cumulative effects of a series of harbour developments in Cockburn Sound over the next 20-30 years. The EPA's assessment will take the form of a public report to the Minister for the Environment in accordance with the provisions of Section 16 (e) of the *Environmental Protection Act, 1986.*

It is intended that the Section 16 (e) report will provide constructive, timely advice for decision makers, planners, proponents and the public in relation to the issue of long-term harbour developments in Cockburn Sound. It is also intended that the report will highlight the information gaps and further environmental research that will be required to more fully assess and manage the environmental quality of the Sound in the face of potential harbour and other development pressures.

3. Preparation of the Statement of Advice

The EPA requested that a series of technical workshops be convened, culminating in the preparation of a Statement of Advice to the EPA from a group of experienced marine scientists. This Statement, together with accompanying advice from the EPA, will be included in the Section 16(e) Strategic Environmental Assessment report.

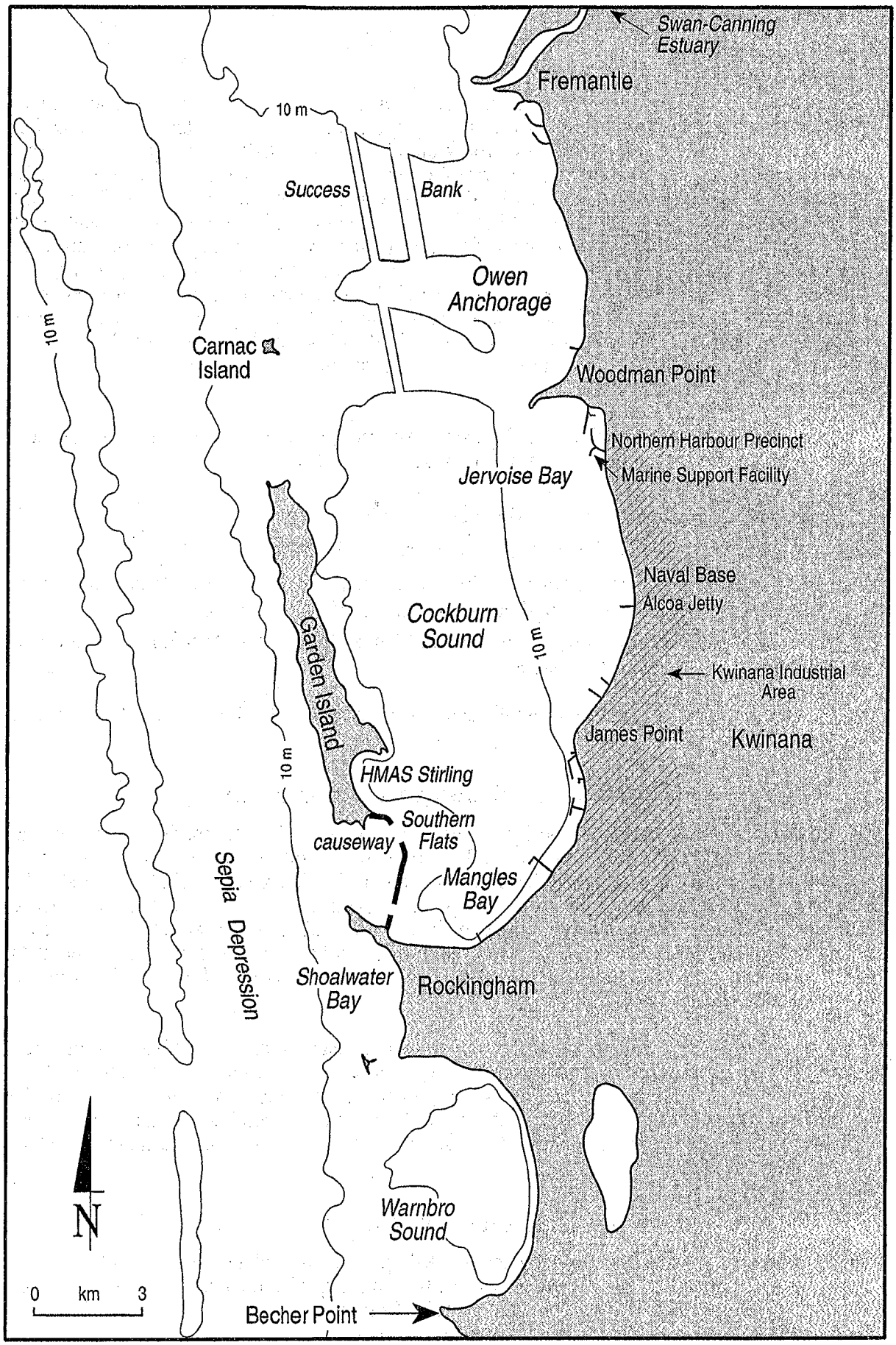


Figure 1. Cockburn Sound and adjacent areas.

The workshops convened were as follows:

- **Harbour Development Scenarios Workshop (28 May 1998)**

The primary purpose of this half-day workshop was to assist in identifying development scenarios over a 20-30 year time horizon to provide a basis for the EPA's strategic environmental assessment. Representatives from industry, the Navy, and from State agencies involved with port planning, were invited to contribute up-to-date information on their current and anticipated usage of Cockburn Sound.

- **Hydrodynamic Response Workshop (28 May 1998)**

This second half-day workshop discussed key aspects of the hydrodynamic response of Cockburn Sound to long-term harbour development scenarios identified from the first workshop. Oceanographers and numerical modellers were invited to conduct a short-term, preliminary appraisal of the hydrodynamic response and to present their findings at the third in this series of workshops. In particular, the consultants Kinhill (1998a and b) were requested to prepare a report on the findings of their hydrodynamic modelling investigations.

- **Ecological Response Workshop (24 June 1998)**

This one-day workshop addressed the potential ecological responses to the long-term harbour development scenarios previously identified. The workshop considered the consequences of predicted hydrodynamic changes and also addressed other potential direct and indirect ecological effects which could be associated with such developments. Core representatives from the first two workshops were joined by nationally and locally experienced marine ecologists from CSIRO, tertiary institutions, Government agencies and industry.

- **Preparation of Statement of Advice (25 June 1998)**

A core scientific group of CSIRO and local marine scientists was convened to prepare the basis of a summary Statement of Advice which synthesises the outcomes of the three workshops. The finalised Statement arising out of the workshops (this document) will be submitted to the EPA.

4. Scope of the Statement of Advice

The focus of the Statement of Advice is on the response of the marine environment of Cockburn Sound to potential long-term harbour development scenarios, taking into account existing pressures on the marine environment from waste inputs and other activities. Based on information provided at the first workshop, these scenarios represent in general terms feasible sizes, locations and number of projected developments over a time scale of up to 30 years. It is obviously not possible to define future development scenarios with certainty, nor to anticipate the detailed design features of future proposals. Therefore, this Statement advises only on the likely direction (or qualitative nature) of ecological changes which may occur if major harbour developments proceed in Cockburn Sound over the long-term. It must be stressed that further scientific investigations would be required to determine, with reasonable certainty, the magnitude of these changes for any given harbour developments scenario. Hence, the purpose of this Statement is to focus attention on key marine environmental issues that need to be resolved by sound planning, management and decision making, supported by existing knowledge and continuing environmental research. This Statement is strategic in nature, and does not seek to provide a detailed environmental assessment of specific proposals.

The Statement of Advice has assumed the ongoing presence of existing infrastructure. It has not attempted to assess the marine environmental effects of altering existing structures.

While it would be appropriate to consider cumulative environmental effects which may occur on land, and other issues of community concern, such as reduced public access to the beaches surrounding Cockburn Sound, these matters are not within the scope of this Statement.

The technical workshops were held within tight time constraints and used readily available information and data. Given the short time frame available to prepare the Statement, it must be considered as initial advice in relation to the issues considered. While acknowledging that much environmental data exists for this region, the workshops nonetheless identified a number of critical areas where further information would be required to provide more accurate advice concerning the environmental implications of harbour developments. These critical information and knowledge requirements are detailed in section 7.3. It is strongly recommended that a programme to carry out the necessary investigations be prepared and supported.

5. Description of the area

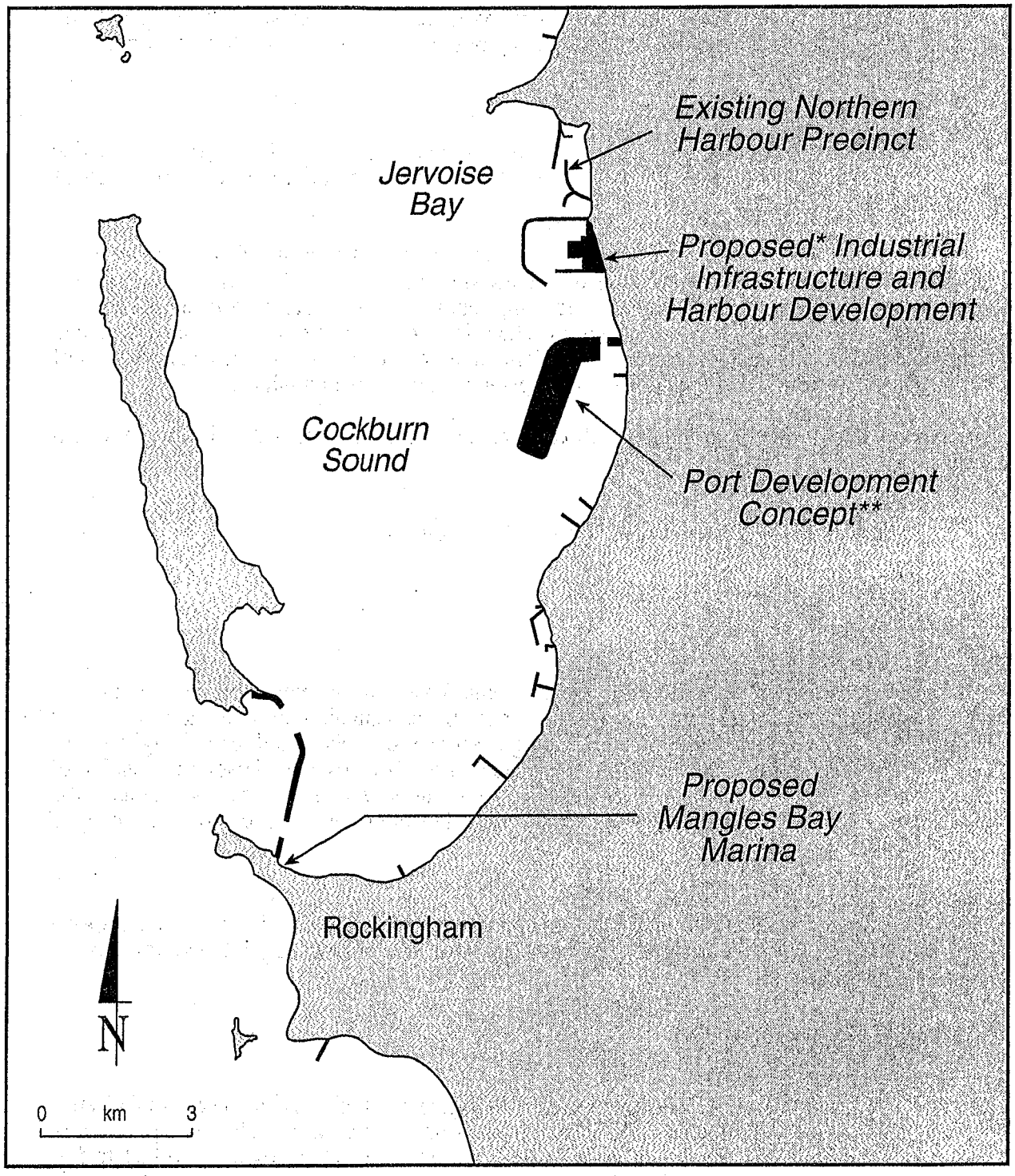
Cockburn Sound is situated on the southwest coast of Western Australia, next to southern metropolitan Perth, and extends from about 10 km to 26 km south of the Swan-Canning Estuary mouth at Fremantle. The western side of the Sound is bordered by Garden Island. Cockburn Sound has a relatively large, deep basin (approximately 14 km long, 5 km wide and up to 21 m deep) which is surrounded by shallower margins. An eastern margin, adjacent to the mainland coast between James Point and Woodman Point, is generally less than 10 m deep and up to 4 km wide. A much narrower western margin borders the coast of Garden Island. The 10 km broad northern opening of the Sound is generally restricted to a depth of about 5 m by a transverse sand bank through which a 15 m deep shipping access channel has been dredged. In the early 1970's a rock fill causeway with two small bridge openings was built across the Southern Flats at the shallow southern entrance to the Sound between Garden Island and the mainland.

In 1973 approximately 700 ha of the original 3,900 ha of seagrass meadow were estimated to be remaining in Cockburn Sound (excluding Parmelia Bank). This figure is in reasonable agreement with the 750 ha identified in the same area from high resolution digital images obtained in 1993. Hence the decline in seagrass meadows in Cockburn Sound has slowed considerably since the rapid, widespread losses that occurred in the late 1960's to early 1970's, but there has been no appreciable gain in seagrass meadow area in the Sound since then. The estimated area of seagrass on the eastern margin of Cockburn Sound was 29 ha in 1995, compared to 153 ha in 1971. The majority of remaining seagrass meadows in Cockburn Sound are located on the western margin, adjacent Garden Island, on the Southern Flats and in Mangles Bay.

6. Scenarios considered

This appraisal focused mainly on the implications of a 'major developments' scenario, as defined at the first technical workshop, comprising existing infrastructure, a current harbour proposal and preferred planning options for additional harbour facilities. The anticipated effects of this scenario were referenced against the 'baseline' scenario, which includes only existing harbour infrastructure. Consideration was also given to the effects of intermediate levels of development. Some additional work was done to assist in understanding how different locations, orientations and sizes of structures may affect the water circulation and ecological response of Cockburn Sound.

The baseline scenario includes the existing Northern Precinct harbour and the adjoining Marine Support Facility, Jervoise Bay, in the northeast corner of Cockburn Sound. In addition to the existing facilities, the major developments scenario (Figure 2) also included the proposed Industrial Infrastructure and Harbour Development (Jervoise Bay), a concept for a significant



* Harbour design from PER (Halpern Glick Maunsell, 1997). This design has been modified.
** Concept based on FPA and DOT advice (28 May 1998).

Figure 2. Major developments scenario.

harbour development to be located off the Kwinana industrial area (between James Point and the Alcoa Jetty), and a recreational marina opening onto Mangles Bay (near Rockingham).

7. Statement of Advice

This Statement of Advice to the EPA provides an initial appraisal of the potential marine environmental consequences for Cockburn Sound of combined harbour development scenarios over the next 20-30 years.

The Statement addresses the environmental issues which arise as a result of prolonged periods of construction, involving the building of breakwaters and reclaimed areas, as well as the dredging of shipping channels and ship turning basins. It also deals with post-construction issues associated with increased shipping and the effects of the harbours on water movement, sedimentation, the dispersion and fate of nutrients and contaminants, and the consequences of these changes for water quality and the marine plant and animal communities.

The potential for these environmental changes to occur has been considered at three spatial scales:

- within harbours
- between harbours (eastern margin of Cockburn Sound)
- broader Cockburn Sound.

7.1 During construction

Effects

The overall construction period for individual harbour developments may be up to three or four years. The major developments scenario includes the construction of two harbours and a marina. Dredging will disturb sediments, leading to increased turbidity and reduced light levels, and may result in nutrient release from sediments and localised oxygen depletion. Creation of new, 'reclaimed' land areas and placement of breakwaters will remove marine habitat. The magnitude of these environmental effects may vary depending on the method and timing of construction.

Consequences

The likely consequences of these harbour construction effects were considered at several spatial scales, namely (a) within harbour, (b) between harbour (eastern margin) and (c) broader Cockburn Sound.

Consequences within harbours

Toxicants

The major potential effect of construction and dredging on toxicants is their remobilisation during disturbance of sediments. TBT is the toxicant of major concern. The toxic potential of TBT, once remobilised, depends on whether it is present as paint flakes or adsorbed to fine sediments. Solubilisation of TBT will increase the opportunity for biological impact, but will also allow quicker degradation to less toxic forms. (Significant TBT degradation occurs within days in water, but may take years in sediments). Surveys of TBT contamination of the marine sediments off metropolitan Perth indicate that TBT concentrations are already significantly elevated at locations along the eastern margin of Cockburn Sound where harbour developments are planned.

Nutrient cycling and algal blooms

Increases in light attenuation will lower phytoplankton growth rates while increases in nutrients will stimulate growth The net effect on phytoplankton biomass will depend on water column stratification, local flushing rates, and the season and method of construction.

Ecological
Creation of breakwaters, turning basins and 'reclaimed' areas will result in the direct removal of existing assemblages, including soft-sediment communities, low-relief limestone pavement communities and residual seagrass beds, which are generally dominated by the species *Posidonia sinuosa.*

Consequences between harbours (eastern margin)

Toxicants
The qualitative effects of toxicants in areas between harbour developments are likely to be similar to effects within harbours, but their significance will depend on the extent of contaminated sediment mobilisation from dredging, both of the shipping channels crossing the eastern margin between harbours, and of harbour basins themselves.

Nutrient cycling and algal blooms
The nutrient-related effects in inter-harbour development areas are likely to be qualitatively similar, but their magnitude will depend strongly on water circulation. Once significant developments have occurred, flushing rates may be low, and potential for stimulation of algal blooms may increase. Then, low flushing rates, combined with altered light regimes and stratification, may favour dinoflagellate blooms.

Ecological
Turbidity levels will be raised for a substantial period by dredging and construction, and reduced light levels and siltation may extend over considerable areas beyond the harbours. This will directly affect suspension feeders and photosynthetic organisms and may therefore lead to changes in species composition and functioning of bottom dwelling organisms.

Broader Cockburn Sound Consequences

Toxicants
Contaminants attached to particles mobilised during harbour construction will tend to settle into the adjacent, deeper central basin of Cockburn Sound. This basin will also receive particulates from other sources, such as the Swan-Canning Estuary outflow.

Nutrients
Effects will be dominated by flushing and transport of nutrients, sediments or low-oxygen waters by currents. Under some wind regimes, sediment and nutrient plumes generated during development will be moved by currents into the southern, central and western areas of Cockburn Sound.

Ecological
There would be physical loss of habitat due to the dredging and construction of channels outside the harbours themselves. There is potential for increased levels of turbidity and siltation, lasting up to several years for each major construction project.

7.2 Post-construction

Effects

The major developments scenario in Cockburn Sound would result in:

- additional breakwaters;
- changed water depths due to shipping channels and turning basins;
- changes to wave, water circulation, water mixing and sedimentation conditions; and
- increased harbour-related and maritime activity with increased risk of contaminant inputs.

Consequences

The likely consequences of these effects were considered at several spatial scales, namely (a) within harbour, (b) between harbour (eastern margin) and (c) broader Cockburn Sound.

Consequences within harbours

Existing breakwaters enclose an area of approximately 50 ha of sea bed. Under the major developments scenario there would be a total of approximately 550 ha of seabed either enclosed by breakwaters or covered by 'reclaimed' land. These areas represent approximately 2 % (existing development) and 20 % (major developments scenario) of the total area of the broad, relatively shallow eastern margin of Cockburn Sound between Woodman Point and James Point.

Hydrodynamic

- Developments of the type examined would obstruct currents along the eastern margin and flushing times would be lengthened.

- The harbour developments, designed to limit water motions (e.g. waves), would result in deeper, lower energy environments and, as a result:
  - the quiescent environment inside developments would lead to the build-up of fine particle deposits, which will be periodically disturbed by shippingmovements, promoting resuspension and increased turbidity levels, and
  - mixing between bottom and surface waters would be reduced and density differences between bottom and surface waters would occur more frequently.

Toxicants

- The major toxicant of concern will continue to be tributyltin (TBT), which is contained in antifouling paints on the hulls of vessels. Commercially-viable alternatives to TBT-based antifouling paints are being sought. There is a proposal before the International Maritime Organisation that TBT be banned on all shipping by the year 2006. However, if this proposal is not adopted, TBT use may continue for the forseeable future. TBT leaches directly into the water from the hulls of vessels and an increase in the total number of ship-days in the harbours will increase this input. The release of TBT will be further increased if hull cleaning and repainting of hulls is permitted. TBT concentrations in waters and sediments are likely to have significant impacts on sensitive marine biota, particularly shellfish.

- As already found in existing harbour areas, concentrations of contaminants such as petroleum hydrocarbons and trace metals in biota are likely to be elevated compared to levels found in the same species throughout the broader Sound. Concentrations may approach guidelines for human consumption. These contaminants occur in industrial discharges and in runoff and inputs associated with harbour development infrastructure. Oils, greases and other hydrocarbons may lead to tainting of fish.

- Accidental spills generally within the breakwaters represent a potential source of contaminants. The potential for spills to occur during loading and unloading of ships is relatively high.

Nutrient cycling and algal blooms

- Lengthened flushing times will magnify the impacts of local (within harbour) nutrient loads, resulting in greater nutrient accumulation, increased nutrient assimilation, and more algal biomass within the breakwaters. Consequently, there will be an increase in the deposition of dead algae to the sediments.

- Reduced mixing and increased density stratification within a deepened harbour would increase the likelihood of oxygen depletion in bottom waters and marine sediments. In terms of nitrogen efflux from the sediments, oxygen depletion, should it occur, would reduce denitrification (the release of inert nitrogen which is lost to the atmosphere) and increase the release to the harbour waters of ammonia, which is readily available to promote algal growth.

- Reduced movement and reduced water stress on the sea bed will lead to accumulation of fine sediments, which will modify sediment biogeochemistry, again increasing the potential for both ammonia release and burial of organic matter. The presence of fine sediments together with occasional resuspension by shipping activity may lead to significant increase in turbidity and light attenuation.

- Density-stratified, turbid, nutrient-enriched waters tend to favour development of dinoflagellate blooms. In some similar Australian environments dinoflagellate cysts are known to accumulate in high concentrations in bottom sediments, and these act as seed populations for more widespread blooms.

- Changes in bottom sediment type and oxygen depletion in bottom waters could lead to loss of filter feeding animal communities, reducing phytoplankton loss rates and thus resulting in higher concentrations of phytoplankton in the water.

- Decreases in light levels at the sea bed due to increased depth and enhanced water turbidity will lead to decreases in microscopic plant communities that dwell on the sea bed (microphytobenthos). It is likely that microphytobenthic production is currently high on the eastern margin, and so reduction or loss of these communities may significantly affect primary production, sediment oxygenation and benthic communities within the harbours.

Ecological
Several ecological effects have been referred to in the 'nutrient cycling and algal blooms' section above. In addition to these:-

- there is an increased risk of introduction of toxic species from elsewhere in Australia or from overseas (for example from ballast water discharge), given the projected increase in shipping movements. The risk that abundances of toxic species could build up to unacceptable levels will be exacerbated by the greater area of semi-enclosed, turbid, nutrient-enriched waters;

- other pest species, such as the fan worm *Sabella* cf. *spallanzanii* or the algae *Caulerpa taxifolia* and *Codium fragile tomentosoides* are considered more likely to become established in disturbed areas. The harbours may therefore act as sites of introduction, both because of disturbed habitat and because of the frequent movement and servicing of ships that may carry these organisms in their hull fouling; and

- the seagrass meadows that once covered the eastern margin have been largely lost. Construction of the harbours would result in further loss of remaining seagrass habitats and would also sacrifice the opportunity for re-establishment of large areas (hundreds of hectares) of seagrasses. Re-establishment of seagrasses across the eastern margin would require reductions in nutrient inputs to achieve water quality and light climate conditions which would allow seagrass survival and growth. The availability of appropriate seagrass re-establishment technologies would also be required, and these are currently being researched.

Consequences between harbours (eastern margin)

The placement of several large-scale developments along the eastern margin would create marine areas between the developments (or between developments and the coast) which are of similar size to the developments themselves. For the major developments scenario, the size of these inter-harbour areas is estimated to be 380 ha, i.e. 15 % of the eastern margin between James Point and Woodman Point.

Hydrodynamic

- Flushing times of these intermediate marine areas are likely to be significantly lengthened due to the obstruction of circulation in the area by adjacent breakwaters. Flushing characteristics of these areas will depend greatly on the particular location and configuration of the developments.

- The cumulative effect of a number of large-scale developments along the eastern margin is likely to be a reduction in the rate of exchange of water between the eastern margin and the remainder of the Sound.

- Reductions in vertical mixing and bottom stress (due to wave motion) will also occur in regions between or adjacent to harbours.

Toxicants

- TBT would be released from the hulls of ships using channels traversing these inter-harbour areas. In addition, TBT-contaminated water and fine particulates exported from the harbours would enter these areas. Reduced flushing of these inter-harbour areas would intensify the impacts of TBT beyond the immediate confines of the harbours.

- TBT (as well as trace metal and organic contaminants) will be most strongly associated with fine organic-rich sediments. Thus, any increase in accumulation and settlement of fine particulates in the areas between developments will lead to an increase in contaminants. Although in this form these contaminants have a low bioavailability, once they settle to bottom sediments they may be released in soluble form to the pore waters associated with these sediments, where burrowing organisms may be exposed to these contaminants.

Nutrient cycling and algal blooms

- Lengthened flushing times, reduced mixing and reduced bottom stress, in conjunction with nutrient loads, will lead to qualitatively similar impacts to those predicted within harbours. There is also potential for exchange of water containing high nutrients, phytoplankton biomass, turbidity and depleted oxygen between harbours and adjacent regions.

- To the extent that multiple harbours lead to low flushing over an extended region along the eastern shore, there is potential for trapping of nutrients originating outside this region, e.g. the groundwater loads south of James Point.

- If zones between harbours contain sufficient shallow habitat, there is potential for development of a high biomass of drift and attached macroalgae.

Ecological

- In addition to the ecological effects mentioned above, the dredging of shipping channels across these inter-harbour areas will cause the loss of existing benthic habitats (including seagrass and low relief reef habitats). These deepened areas will have changed light regimes and sediment characteristics and this is likely to result in changes to benthic communities.

Broader Cockburn Sound

Hydrodynamic

- Studies under well-mixed conditions (late summer, seabreezes and southerly winds) show discernable (though not strong) effects of the major developments scenario on the overall circulation in the Sound. The flushing time of the Sound under these conditions appears to be quite long (a month or more) and the short model runs and limited analyses conducted do not permit comment at this stage on the effects of the major developments scenario, either on the flushing time of the Sound, or on residence times in regions of the Sound away from the developments. The Sound is vertically stratified for much of the year, and it is not clear whether developments along the eastern margin will affect density-driven flows in the Sound. More detailed modelling would be required to answer these very important questions.

- Stratification in the Sound may allow lower quality water from the developments and adjacent marine areas to be transported as layers of limited thickness, slowing vertical mixing and hence slowing dilution of associated contaminants.

- Different meteorological conditions (at other times of the year) may result in transport of water from the eastern margin along different paths. The eastern margin developments may represent sources of lower quality water to parts of the Sound which have longer residence time.

- The construction of a second shipping access channel to the Sound would alter the circulation in the vicinity of the channel and may alter circulation and flushing elsewhere in the Sound, depending on its location and configuration. This aspect has not been addressed in detail and further work is required.

Toxicants

- At the scale of broader Cockburn Sound a major impact is from TBT leaching from antifouling paints on the hulls of ships. The dispersion of higher level TBT concentrations from within the breakwaters will add to this load. The inputs of TBT to the Sound are likely to increase in proportion to the frequency of ship visits and the requirements for ship hull cleaning and maintenance.

- Intertidal gastropods (marine snails) in Cockburn Sound have the reproductive disorder *imposex* due to their existing exposure to TBT. This is just one indicator of the biological effects of TBT in the Sound. Increased TBT concentrations would be expected to exacerbate these effects.

- The increase in ship movements within Cockburn Sound will tend to increase the risk of spills in the Sound.

Nutrient cycling and algal blooms

- It is possible that the developments could increase the proportion of inshore nitrogen loads transferred to the central basin of the Sound. This could occur through a change in the mode of nitrogen efflux from the marine sediments, involving reduced denitrification

(that is, resulting in less export of inert nitrogen gas to the atmosphere) and increased ammonification (that is, resulting in a greater release to the harbour waters of soluble ammonia) and the build up of dissolved inorganic nitrogen, which is readily available for biological uptake and algal growth.

- It is likely that major harbour development scenarios on the eastern margin will change the spatial and temporal pattern of exchanges with the rest of the Sound. The nutrient cycling and algal bloom responses within and between the developments, documented above, will affect the utilisation and sedimentation of nitrogen loads on the eastern margin. Together, these factors will affect the distribution of phytoplankton blooms and the flux of organic matter to the sediments.

- Parts of Cockburn Sound away from the potential harbour developments experience nutrient and chlorophyll levels with potential for development of harmful or nuisance blooms. If harbours or adjacent areas act as seed areas for dinoflagellates, there is potential for these to spread to other nutrient-enriched areas of the Sound. Dinoflagellate blooms in other locations in Australia (e.g. Huon Estuary and d'Entrecasteaux Channel) follow this pattern. Experience elsewhere suggests that there may be an increased risk of dinoflagellate blooms in canal estate developments.

Ecological

- The major developments scenario, including the inter-harbour areas, together represent a substantial proportion (approximately 20 %) of the area of sea floor in the Sound where light levels were once sufficient to support the growth and survival of perennial seagrass meadows. As a result of harbour construction, much of these areas would be either permanently deepened, or the water column would become more turbid, thus significantly reducing the bottom light regime and the level of benthic photosynthesis over this large area. Such a loss of photosynthetic productivity may have significant implications for the ecological health of the wider Sound. This is an area where further understanding of the ecological connectivity and functioning of the Sound is required.

- There is a possibility that microalgal blooms from the harbours may spread to other parts of the Cockburn Sound basin. This may impact commercial exploitation of filter feeders (e.g. mussels) as well as aesthetic values and recreational activities.

- Similarly, pest species such as macroalgae or worms, initially introduced by shipping and established in the harbours, may spread, with the potential to alter the functioning of ecosystems in the Sound. The risk of introductions of foreign species is likely to increase in proportion to increased shipping traffic. These species are known to be introduced through dislodgement of the hull fouling on ships and through exchange of their ballast waters.

- The increased frequency of shipping will also be a factor which increases the risk of spills of oil, or other cargoes.

7.3 Information requirements

It was the EPA's intention that this Statement of Advice should be provided within tight time constraints, based on available information and the marine scientific experience of the workshop participants. Within these constraints it has been possible to identify the qualitative nature and direction of ecological changes that could occur in response to a major harbour developments scenario. However, further information and understanding would be required in order to estimate the magnitude of these changes (particularly for the between harbours and broader Cockburn Sound scale). The workshops were expected to identify a number of areas where improved understanding would be needed if the Government and the EPA were to seek

more detailed advice on the ecological response of Cockburn Sound to harbour development scenarios. The following information requirements were identified:-

Hydrodynamic

- The effects of density stratification on the circulation and mixing of contaminant and other materials should be included in hydrodynamic models used to investigate harbour developments.

- Simulations should be carried out for a far wider range of meteorological and seasonal conditions, and assessed against appropriate field measurements.

- Hydrodynamic simulations need to extend over ecologically meaningful time frames (up to several years).

- Data describing seasonal variations in density fields, winds, tides and other parameters are available from a number of previous studies, although further data are required to characterise the 'autumn' (pre-winter runoff) period, when lengthened water residence times in the deep Cockburn Sound basin are likely to be of ecological significance.

- Estimation of turbidity in the Sound would require the development of a sediment mobilisation and transport model, appropriately coupled to the hydrodynamic model.

Toxicants

- Ship movements and hull areas need more accurate projections.

- Data are required on the predicted movements of suspended sediments.

Nutrient cycling and algal blooms

- More accurate estimates of the groundwater nitrogen flux into Cockburn Sound (within harbours, between harbours and at broader scales) and its seasonal variation are needed.

- estimates of sediment oxygen and nutrient fluxes (particularly denitrification) on the eastern margin (both inside and outside the existing Jervoise Bay harbour development) and throughout Cockburn Sound are required. These should be coupled to an improved understanding and prediction of vertical mixing and the role that it plays in the dissolved oxygen budget.

- Water quality models are needed to predict algal biomass, oxygen depletion and light attenuation .

- Improved knowledge and incorporation into models of feedbacks between ecological processes and nutrient cycling (e.g. the role of zooplankton and benthic filter-feeders in controlling algal densities and distribution).

- Improved knowledge of dinoflagellate cyst distributions and conditions leading to germination.

Ecological

- Data describing existing biological assemblages on the eastern margin, both within and beyond existing harbour areas.

- Improved understanding of implications of changes in water and sediment quality for distribution and function of biological communities.

- Relationships between assemblages and local populations of fish and crabs, and consequently the connections between those local populations and the fisheries.

8. Conclusions

It is clear that, for combinations of harbour developments in Cockburn Sound similar to those considered here, the resultant marine ecological change will not be confined solely to within the breakwaters, but will also extend to inter-harbour marine areas and the broader Cockburn Sound. Hence, there are significant environmental issues which need to be addressed 'up-front', as part of the strategic planning and decision making process.

The advice provided here was prepared within a short time-frame, at the request of the EPA. If decision makers require more quantitative information on the ecological changes that are predicted to occur in Cockburn Sound, then it will be necessary to conduct more detailed technical studies, and to satisfy key information needs, as identified in section 7.3. This will require adequate resourcing.

Finally, planners and decision makers will require not only an improved, science-based understanding of environmental changes that could occur as a consequence of long-term developments in Cockburn Sound, but also an understanding of what the community wants for the long-term future of the Sound.

9. References

Kinhill (1998a). *Modelling of the Circulation and Flushing within Cockburn Sound - Part 1.* Report prepared by Dr K Zic and Mr C Gomes on behalf of Kinhill Pty. Ltd. for the Department of Environmental Protection. September 1998. Perth: Kinhill Pty. Ltd.

Kinhill (1998b). *Modelling of the Circulation and Flushing within Cockburn Sound - Part 2.* Report prepared by Dr K Zic and Mr C Gomes on behalf of Kinhill Pty. Ltd. for the Department of Environmental Protection. October 1998. Perth: Kinhill Pty. Ltd.