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THE PEEL-HARVEY ESTUARINE SYSTEM

PROPOSALS FOR MANAGEMENT

Department of Conservation and Environment
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PROPOSALS FOR MANAGEMENT

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INTRODUCTION

The first phase of the Peel-Harvey Estuarine System study aimed 'to determine the causes of the excessive growth and accumulation of green algae in Peel Inlet and if possible to propose methods for its control'. The Report which was published in 1980 (DCE Report No 9) records the scientific findings of that phase of the study and DCE Bulletin No 88 (1981) summarises the conclusions and makes recommendations for management.

The reports concluded that the 'algae problem' was caused by the nutrient enriched (eutrophic) condition of the estuary and especially by the great increase in phosphorus input to the estuary over the previous 30 years. It was shown that this phosphorus came principally from superphosphate fertilizer applied to phosphorus deficient soils of the coastal plain catchment.

The recommendations stressed the need both to reduce the input of phosphorus to the estuary and if possible to increase the flushing of nutrient rich water to the sea. The need to continue and to improve the weed harvesting measures was recognised. Recommendations were also made for further research and for ongoing monitoring both of the estuary itself and of the nutrient sources. Report No 9 concluded with the caution:

> It must be stressed that any modification of the estuarine environment, whether it be by reducing the input of nutrients, by modifying river drainage, by dredging, or by any other means, will produce complex changes in the ecosystem, not all of which are easily foreseen. Before decisions are made about practical measures for eliminating the algal problem careful consideration must be given to other possible consequences of the action, as well as to the social and economic implications.

That then is the background to the second phase of the study which began late in 1981 with the aim of determining how best to implement these recommendations. It expanded rapidly and has merged gradually into the third phase, that of implementing management measures, mainly those designed to reduce the loss of phosphorus from pastoral land on the coastal plain catchment of the estuary.

The present report summarises the results of the second and third phases of the study at the point at which recommendations for management of the estuary have been made to Government (Chapter 7). In particular Chapters 3 and 4 examine the requirements for implementation of the principal proposed management measures and their anticipated effects on the estuarine ecosystem. These are discussed in greater deail in the appendices and the many publications listed in the Bibliography. Chapter 1 updates our understanding of the history and causes of the eutrophic condition of the estuary and stresses that there has been further deterioration since 1980. Chapter 2 considers the objectives and reasons for management and the basis for predictions made in Chapters 3 and 4.

In Chapter 5 measures still under investigation are examined for their potential to supplement the principal management measures. Lastly, it is recognised that decisions as to what is to be done about the algal problems of the estuary will not be based on environmental considerations alone; they will be influenced by economic, social and even emotional factors associated with the problems and their solution and Chapter 6 attempts an assessment of these, particularly as viewed by the local community.

The study has had considerable publicity through articles in the Coastal Districts Times (at Mandurah) and other papers and the distribution of a series of leaflets (DCE Bulletin 146) and posters, also a film (Crisis for an Estuary) and at public meetings addressed by members of the study team. These appear to have led to a high level of understanding of the nature of the eutrophic condition and the problems involved in managing it, though they have not dispelled a measure of impatience in the local community with the delay in curing the 'algal nuisance'. It is hoped that in consequence of the public information programme judgments will ultimately be made on an informed basis.

In case it should be thought that the sole purpose of the study has been to solve the problem of the eutrophic condition of the estuary it is relevant to quote the following paragraph from Bulletin No 88:

> While reduction of the eutrophic condition of the estuary is the principal problem with which this report is concerned, increasing human use of the estuarine system must also be recognised as posing problems. In particular the suitability of the estuary for recreation and as a site for development, must be weighed against its value as a fishing ground, prized by amateurs and professionals alike.

The investigations have been funded throughout by the Western Australian Government principally through the Department of Conservation and Environment. However, while this Department has been responsible for co-ordinating the study much of the work has been undertaken by specialists in other institutions. The principal bodies have been the Department of Agriculture, Fisheries & Wildlife, Public Works Department, Government Chemical Laboratories, the Waterways Commission and the Peel Inlet Management Authority; at the University of Western Australia, the Botany and Soil Science Departments and the Centre for Water Research; at Murdoch University the School of Environmental and Life Sciences; the CSIRO Division of Groundwater Research; also Alcoa of Australia and CSBP and Farmers Ltd.

Finally, it is a pleasure to acknowledge the active co-operation from all members of the research team and many others too who have willingly given help and advice throughout the study. The names of our fellow workers appear in the bibliography at the end of this report and in the reports on symposia (DCE Bulletins 160 & 195), but there are many others, farmers, fishermen and our own professional staff who have all contributed to making this a most rewarding and successful study. We are most grateful to all who have assisted in any capacity.

CHAPTER 1

THE ALGAL PROBLEM, ITS NATURE AND ITS CAUSES

INTRODUCTION

Investigation of the algal problem of Peel Inlet began in 1976 in response to a request from the Environmental Protection Authority (EPA) to its Estuarine and Marine Advisory Committee (EMAC) to identify its cause and, if possible, to propose long-term solutions. The investigation showed the estuary to be nutrient enriched and the cause of the problem was identified as the abundance of plant nutrients, especially phosphorus, entering the estuary from agricultural drainage (Department of Conservation and Environment Report No. 9, 1980). In response to this report EMAC made recommendations for management of the problem (DCE Bulletin No. 88, 1981).

The nature of the algal problem changed radically in late 1980 with the first large scale bloom of the blue-green alga, *Nodularia,* which affected the whole Peel-Harvey estuary. This suggested that the estuary had become even more eutrophic. During 1982 and 1983 practical measures were developed for reducing the input of phosphorus from agricultural sources and these measures were implemented, and monitored, on a large scale in 1984.

During 1983 an assessment was made of the potential of a large number of suggested management measures, of which only a few were considered to justify further evaluation (DCE Bulletin 165, 1984). That report showed that modification of agricultural practices alone was unlikely to reduce the input of phosphorus to the estuary sufficiently to prevent *Nodularia* blooms and greatly reduce the weed problem, at least within ten to fifteen years. It recommended investigation of the practicability of increasing the loss of nutrients from the estuary by creating a new channel from Harvey Estuary to the sea. An extended study of the potential of this 'Dawesville Channel' was made during 1984. Such a radical measure clearly requires the most careful evaluation, not only of its potential for reducing the eutrophic condition of the estuary and its practicality as an engineering measure, but also for its effects on both the existing estuarine ecosystem and the local community.

This chapter is a summary of the investigations which have led to an understanding of the nature and causes of the algal problem as a necessary background to assessing the proposals for management discussed in later chapters. A more detailed account of these investigations is presented in Report No. 9 and Appendices 1 and 2.

THE NATURE OF THE PROBLEM

The algal problem is one of excessive growth of algae in the water of the estuary and of their accumulation and decomposition on the shores, with the resulting unpleasant odours.

Two very different kinds of algae now contribute to the problem: large green algae, 'weed', which grow on the bottom and float to the surface in masses; and the blue-green alga *Nodularia,* which grows as microscopic filaments throughout the water but floats to the surface in calm weather to form a scum. The weed problem is mainly in Peel Inlet; *Nodularia* affects mainly Harvey Estuary, but increasingly also Peel Inlet in recent years (Fig. 1.1).

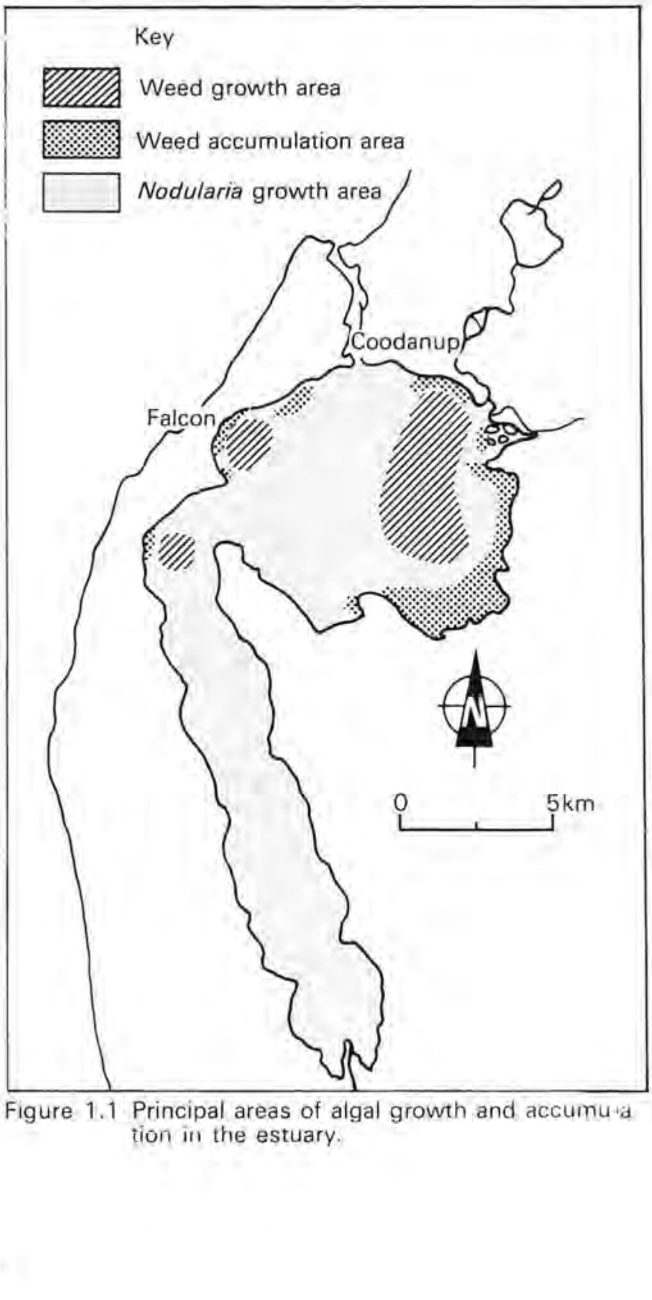


Figure 1.1 Principal areas of algal growth and accumulation in the estuary.

As perceived by local residents the algal problem has several aspects:

- The accumulations of decomposing weed foul the shallows and beaches of Peel Inlet and decay to a black sludge.
- The hydrogen sulphide gas given off during decomposition of algae causes great discomfort to people living near the beaches.
- The green surface scum formed by *Nodularia* in spring and early summer in both Peel Inlet and Harvey Estuary is unaesthetic and discourages tourists.
- *Nodularia* gives off its own peculiar nauseating odour, in the water and even more in its accumulations.
- Occasional mass mortality of fish and crabs is associated with the *Nodularia* blooms.
- Long strings of 'rope weed' *(Chaetomorpha)* entangle the propellers of power boats.
- Fishermen find that certain kinds of algae foul their nets, making hauling difficult. Catches are poor where there are severe *Nodularia* blooms.
- The odours from decomposing weed and *Nodularia* have been blamed for serious illness in local residents. Hydrogen sulphide gas is harmful to health in the high concentrations sometimes experienced along the shores (more than 1 ppm).
- The algal problem is seen by some to have had an adverse effect on tourism (especially boat usage) and on the business community generally, to have reduced property values adjacent to the estuary and made it difficult to sell homes.

At first the weed caused a year-round problem, but it is now mainly one of later summer and autumn when the water is clearest. The quantity of weed has also varied greatly. It is reported to have been abundant in 1973-74, but since 1976 the worst periods have been 1978-79 and the early months of 1984. There was relatively little weed in 1981-82.

Despite its unpleasant features for the human population, the abundance of weed did not indicate a particularly unhealthy biological condition; plants and animals flourished. However, it was clear that the estuary was rich in plant nutrients — that it was 'eutrophic'.
Measures to ameliorate the worst features of the algal problem by removal of accumulating algae by tractors, and more recently by the offshore harvesters, are only partially successful in keeping beaches near inhabited areas free from decomposing weed. The current (1984-85) cost of this undertaking is $208,000 a year.

The destruction of rushes and other marginal vegetation by the tractors has resulted in considerable erosion of the shoreline. In places this has retreated 10 m or more over the last eight years, with the loss of a number of shady trees. In some other places, where the tractors have not operated, the massive accumulation of weed has itself smothered the rushes.

On the other hand there is little doubt that the abundance of green algae has benefited the fishing industry through increased catches of sea mullet and yellow-eye mullet. These are mainly marketed as rock lobster bait.

There is no clear connection between weed abundance and the fluctuating crab and prawn populations. In the last two years catches of king prawns are variously estimated to have been worth between $500,000 and $2m to professional fishermen. However, river prawn catches have declined. While these changes are associated with the algal problems in the minds of fishermen there is no good evidence to show what the connection may be.

The *Nodularia* blooms are normally confined to spring and early summer, October to December, and have been worse and more prolonged in Harvey Estuary. There were occasional blooms before 1980 but since then they have been annual events.

Until the *Nodularia* bloom of 1980 there was little to suggest that the condition of the estuary was deteriorating progressively. However, subsequent annual blooms have increased in size irrespective of the phosphorus load and are evidence that the estuarine system is now seriously out of balance. The massive blooms, and especially their collapse in December-January, result in deoxygenation of the water and mass mortality of small fish which cannot escape the bloom and of the bottom-living invertebrate fauna on which many fish feed.

THE PROBLEM ALGAE

These nuisance algae have no doubt been present in the estuary for very many years and many of the large green algae also occur in coastal waters. However, until the 1960s the dominant aquatic plants in the estuary were not algae, but the seagrasses *Ruppia megacarpa* (locally called gardie weed) and *Halophila ovalis* (paddle weed). Both still grow in the shallower water of Peel Inlet, but are no longer common in Harvey Estuary where *Ruppia* was formerly abundant.

Seagrasses are flowering plants, with roots in the sediments from which they draw nutrients in the same way as land plants. Algae, on the other hand, do not have roots and draw their nutrients direct from the ambient water. This is true both of the macroscopic algae, which may attach to a substrate, and of the various microscopic algae.

The bulk of the weed now growing in the estuary consists of a few species of large green algae. During the 1970s the principal alga was *Cladophora* (goat weed) which grew as small cottonwool-like balls forming a carpet over the bottom. Subsequently several other algal species, rope weed, sea lettuce, *Enteromorpha,* and a filamentous form of *Cladophora,* have all been abundant at times. A red alga has also sometimes been common.

Unlike the weed algae, the blue-green alga *Nodularia* is planktonic, and its chains of microscopic cells are distributed throughout the water body, turning it green. However, they are buoyant and in calm weather float to the surface where they form a thick green scum and drift ashore.

Nodularia is known to be toxic to animals drinking the water. But it is unlikely this will be a problem here because by the time blooms have developed estuary water is too salty for stock to drink.

Other planktonic plants (diatoms and dinoflagellates) are also so abundant at times as to colour the water brown. They are not a direct cause of any problem, but are important because of the role they play in recycling nutrients to other algae and because they reduce light penetration to bottom-living plants.

Another blue-green alga, *Oscillatoria,* has also been common since 1982. This forms a slimy felted mat on the surface of the sediment and when growing rapidly breaks off in lumps that float to the surface. These are unsightly, but so far have only been a relatively minor problem in the estuary.

THE HISTORY OF THE PROBLEM

Weed accumulation

The earliest report of an algal nuisance was in 1960 when fishermen complained of a slimy red alga *(Monosporus australis)* clogging their nets. However, the first recorded complaints about weed fouling the shores date from 1969, although aerial photographs suggest the presence of large piles of weed off the Coodanup shore in 1965 and 1967. Since 1969 the weed problem has been continuous, although the size and nature of accumulations have changed from time to time.

Weed accumulation is confined to the shores of Peel Inlet, Harvey Estuary north of Dawesville, and near the mouths of the Serpentine and Murray Rivers.

Since 1974, following complaints from residents near the Coodanup shore, efforts have been made to keep the beaches near habitations free from weed by means of tractors equipped with rakes. This has met with varying success. In 1983 a floating weed harvester was first used to collect weed in water deeper than half a metre to prevent it drifting ashore.

Major accumulations often form in the shallows some distance offshore where they are inaccessible to both harvesters and tractors. There are also massive accumulations along the sparsely inhabited eastern and southern shores and the northern shore between Coodanup and Falcon where tractors have not been used. They have resulted in increased shallowing of the already shallow areas of Austin Bay.

Nodularia blooms

A *Nodularia* bloom was reported in the Serpentine River in 1970 and blooms occurred in Harvey Estuary in 1973 and 1974 but aroused little comment. Both 1973 and 1974 were years of high rainfall and river flow, considerably greater than experienced at any time during this study, and also probably of high nutrient input to the estuary (Fig. 1.2).

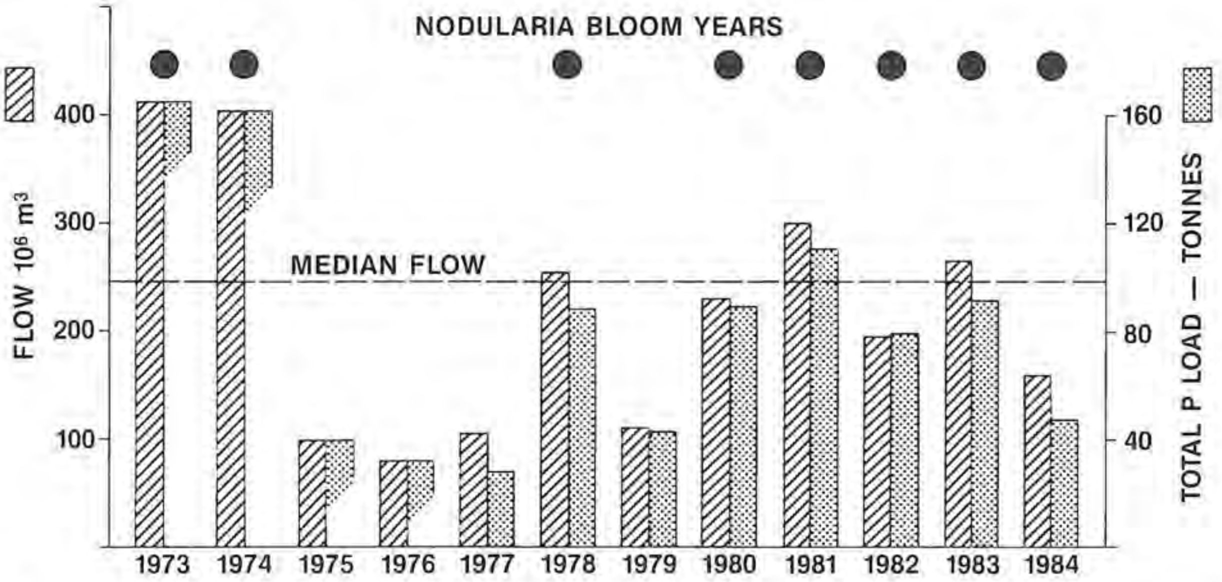


Figure 1.2 Harvey River flows and phosphorus loads, May to September. Phosphorus loads: 1977-84 observed, 1973-76 estimated only.

The next three years (1975-1977) were very dry and riverflow was little more than half the average. No more blooms were reported until the bloom of 1978 which affected Harvey Estuary. There was no bloom in 1979. The bloom of 1980 developed in Harvey Estuary and drifted out into Peel Inlet and since then annual blooms have affected both.

Nodularia blooms start in late September or early October and die out in December or early January, although in 1982 the heavy rains of January prolonged the bloom into February.

THE CAUSE OF THE PROBLEM

The problem is caused by the high level of plant nutrients present in this shallow, poorly flushed estuary, where the water is often well mixed and the bottom well lit. The input of nutrients to the estuary now greatly exceeds loss to the sea, and the plants are well fertilized.

Both the nutrients nitrogen and phosphorus are essential to plant growth and a shortage of either can limit the size of the algal crop. However, it is generally phosphorus rather than nitrogen that is in shortest supply in Peel Inlet and it is therefore generally phosphorus that is the 'limiting nutrient' which determines the size of the weed crop. Phosphorus is also the nutrient which limits growth of *Nodularia* in Harvey Estuary, even though Harvey River water contains relatively little nitrogen. This is because *Nodularia*, like legumes, fixes atmospheric nitrogen and is therefore independent of the river water for its nitrogen supply.

For this reason and because the Murray River discharges a large load of nitrogen, there is no practical way by which to reduce the nitrogen supply to algae in the estuary, and phosphorus is therefore the target for management.

While the high nutrient levels are clearly seen as the principal cause of the symptoms of eutrophication in the estuary, other environmental factors predispose the estuary to the eutrophic condition as described in Chapter 2 and discussed more fully in Appendix 1.

SOURCES OF PHOSPHORUS

Potential sources of phosphorus input to the estuary are: river and drain flow, groundwater flow, urban sewage, surface runoff, seawater, and the atmosphere. However the rivers and drains are by far the greatest source, contributing over 90% of net input.

The principal source of phosphorus to the rivers and drains is the sandy soils of agricultural land on the coastal plain. This phosphorus is from that applied as superphosphate fertilizer to soils that are naturally deficient in phosphorus; in many places for the last thirty years or more. Phosphorus is readily leached from these sandy soils whilst by contrast the clayey soils of the wheatbelt have the property of binding phosphorus.

Input from river flow has increased greatly since the 1950s when it was measured by the CSIRO Division of Fisheries and Oceanography. This is owing to clearing of extensive areas of the deep grey sandy soils for cultivation in the 1960s and 1970s and to the store of phosphorus (the super-bank) that has built up in the surface soil, mainly in the organic matter and inorganic residues. A large proportion (60-70%) of phosphorus coming to the estuary is now from this source, rather than from fertilizer applied in the current year.

The amount of phosphorus coming into the estuary each year is now in direct proportion to the volume of river flow (Fig. 1.2). It is greatly in excess of export to the sea. Much of the phosphorus carried in river water is trapped by diatoms and is retained in the decaying organic matter (detritus) of the surface sediment of the estuary when they settle to the bottom. This phosphorus is then available, at least in part, as the immediate source of phosphorus for both *Nodularia* and weed growth (Fig. 1.3). The store of nutrients has accumulated progressively in the sediment and has now become an important carryover source of phosphorus, complementing the external (river) source and so maintaining algal growth from one season to the next.

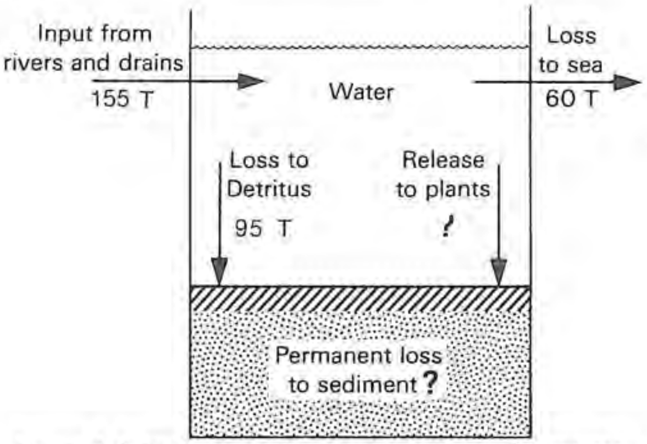


Figure 1.3 The annual phosphorus budget. Figures are approximate only and vary greatly from year to year.

THE FUTURE OF THE PROBLEM

The estuary is a highly complex ecosystem which has undergone rapid change during the last thirty to forty years. It has changed from being a relatively low nutrient (oligotrophic) system dominated by seagrasses to a nutrient-enriched (eutrophic) system with an excessive growth of large green algae and planktonic blue-green algae.

Some of the changes seen during the eight years of the study were not, and probably could not, have been predicted. It is equally not possible to predict with any certainty what changes there will be in the future. Needless to say, however, the scene will be very different if the present eutrophic condition is allowed to continue, from what it will be if the nutrient supply is reduced.

If no action is taken to reduce the nutrient supply it is most unlikely that the algal problem will resolve itself, within the foreseeable future. The estuary will continue to be eutrophic, and there will be an excess of plant production. It is especially difficult to foresee the nature of the weed problem, the kinds of weed with their different characteristics, and even the magnitude of the problem. But the problem is likely to continue indefinitely, in one form or another, and the water quality will deteriorate further.

It is now clear from the 1984 experience that *Nodularia* blooms are likely to be annual events until such time as there is a substantial reduction in the amount of phosphorus available for growth. In Harvey Estuary the blooms may now have reached their maximum intensity, but in Peel Inlet, where the blooms have generally been less dense, they still have the potential to be larger under favourable environmental conditions.

The duration of blooms appears to be largely determined by physical factors — temperature, salinity, and perhaps turbulence — so that they are unlikely to be more prolonged than at present, except as the result of unusual weather conditions, such as those of January 1982 when the heavy rains lowered salinity and introduced a fresh supply of phosphorus.

Since the principal cause of the algal problems is the excess of plant nutrients, the preferred solution is to reduce the supply of nutrients, especially phosphorus, available to algae in the estuary. If this is done the present trend will be reversed, the estuary will become less eutrophic and the quantity of algae will decrease. How rapidly it will decrease and by how much will depend primarily on the amount of nutrient available for plant growth.

The algae and other plants, the primary producers, are ultimately the source of food on which all animal life, including fish, crabs and birds, is dependent. The aim of nutrient reduction should be to re-establish a balance between primary production and the animal consumers (secondary production). It is probable that the estuary can support a somewhat higher level of primary production than it did before the 1960s, and sustain a larger fishery, without there being an algal problem. Nutrient levels do not have to be reduced to those of the 1950s in order to achieve a healthy, productive ecosystem.

In conclusion, it is relevant to note that the last ten years (1975-1984) have, with the exception of 1981 and 1983, all been years of below average river flow from the coastal plain catchment and consequently of below average input of phosphorus to the estuary (Fig. 1.3). It must therefore be anticipated that, with the inevitable return to a more normal rainfall pattern, the present eutrophic condition of the estuary and its algal problems will be exacerbated until action is taken to reduce the amount of phosphorus available to algae in the estuary.

CHAPTER 2

MANAGEMENT — PRINCIPLES AND OBJECTIVES

INTRODUCTION

The management objective stated in the report 'Management of Peel Inlet and Harvey Estuary' (DCE Bulletin 170) and endorsed by the Government is still valid:

> Based on the findings of the research work, it was concluded that the principal objective of the management programme should be to reduce the algal nuisance to acceptable levels without further damage to the estuarine environment. This objective was to be accomplished without causing loss of production of the estuarine fishery or agriculture in the catchment.
>
> Not everyone will agree on what constitutes an 'acceptable' level of algal abundance, but it was felt that an achievable and desirable aim would be that:
>
> - *Nodularia* blooms should not occur more frequently than once in five years on average;
> - weed should not foul beaches near populated areas.

Dissecting this statement it says:

- Reduce the algal nuisance,

  — to acceptable levels, as defined,

  — without further damage to the estuarine environment,

  — without loss of production of the estuarine fishery,

  — without loss of production of agriculture in the catchment.

It says nothing about:

- Why the estuary should be managed.
- Who wants it managed.
- How urgent management is.
- What the community should be prepared to pay for management.

This chapter examines these points in detail to make clear the principles on which the management recommendations have been made. The basis for the prediction of the results of the proposed management measures is also discussed.

REDUCE THE ALGAL NUISANCE — TO ACCEPTABLE LEVELS

The practical objective of management is to **reduce** the eutrophic condition to the point at which algae are no longer a nuisance; that is, to a level **acceptable** to the community.

These terms involve a social subjective judgement and the management objective only says what was considered to be an **achievable** and **desirable** aim. The extent to which the proposed management measures can achieve the objective is considered in subsequent chapters.

However, the weed problem is not just an immediate social issue. The weeds, green algae of various kinds, are a normal part of an estuarine ecosystem and are a direct or indirect source of food for fish and other fauna. Indeed the algae appear to have benefited the professional fishery. It is the excessive abundance of green algae and the blooms of blue-green algae such as *Nodularia* that create a nuisance; they are symptoms of an unhealthy condition of the estuary water, a condition in which there is no longer a reasonable balance between primary production, plant life, and secondary production, the animal consumers.

The algal problem is thus also one of great environmental significance and it is equally important to consider what may be acceptable in terms of the 'health' of this important aquatic ecosystem. What this can and should be is discussed in a later section — What sort of ecosystem?

WHO WANTS THE ESTUARY MANAGED?

Pressure for action to prevent the algal nuisance has come principally from people who live near Peel Inlet beaches where weed accumulates and rots, and from the business community of Mandurah who see it as harmful to tourism and development of the area. During *Nodularia* blooms there are also frequent protests on health and aesthetic grounds.

The Peel Inlet Management Authority has the unenviable task of trying to keep the beaches free of rotting algae. The current management measures involve considerable ongoing cost, with no prospect that they will cure the problem or give any permanent return for the money expended.

It is relevant to note that while professional fishermen were the first to observe and protest about the abundance of algae, they have latterly appreciated that this has probably benefited the mullet fishery, although the seasonal blooms of *Nodularia* make fishing difficult.

Chapter 6 considers social aspects of the algal problem in more detail.

WHY SHOULD THE ESTUARY BE MANAGED?

Community pressure and important environmental considerations make new management programs essential. Present measures are only partially successful in controlling the weed nuisance and do nothing to prevent it.

The estuary is seriously eutrophic and there is every reason to think that with a return to a more normal rainfall regime, and with increasing pressure for development of the area the condition of the estuarine ecosystem will continue to deteriorate.

Peel-Harvey, like the Swan, should be a healthy estuary at the centre of a thriving community.

HOW URGENT IS MANAGEMENT?

It is evident from public statements that solution of the algal problem is regarded as urgent (Chapter 6); the issue has become a political one. In this report it is assumed that priority must be given to measures which can achieve the stated aims within three to five years rather than to measures which may take ten or more years to be effective, or measures which will require further prolonged study, even though they might be less costly and cause less interference with the present estuarine ecosystem.

It is more difficult to say how urgent the problem is from the environmental point of view. Until action is taken to reduce the amount of phosphorus available to algae, the overt problems of weed accumulation and annual blooms of *Nodularia* must be expected to continue on at least the same scale as at present. With a return to higher rainfall and river flow, more phosphorus will come into the estuary, probably increasing weed growth, prolonging *Nodularia* blooms, and favouring other blue-green algae which are already present in the estuary *(Microcystis* and *Oscillatoria).* The oxygen deficiency that is now more frequently experienced in response to the increasing accumulation of decaying organic matter is particularly disturbing. Given appropriate weather conditions such as an absence of wind, with a stratified water body, this could result in massive mortality of fish and crabs.

There is no suggestion that deterioration has yet reached the stage of being irreversible; nevertheless the sooner action is taken to implement the recommended management measures the less likelihood there is of further damage to the environment.

For the above reasons the investigations have emphasised the need to identify measures which can achieve an early and certain reduction in the eutrophic condition of the estuary. DCE Bulletin 165 (Management of the Eutrophication of the Peel-Harvey Estuarine System) identified the measures having such a potential, they are stated as the 'Preferred Strategy' in DCE Bulletin 170 and are described and evaluated in Chapter 3. Chapter 4 sets out the anticipated response of the plant and animal life of the estuary to the recommended strategy.

Other measures with the potential to contribute to a solution of the estuary's problems, in the longer term are discussed in Chapter 5.

It is possible that the problems of the nuisance algae could be alleviated by biological measures that would use the abundant nutrients to produce harvestable crops, for example algae for extraction of alginates or of weed-eating fish. Such solutions have not been investigated because they present problems that would take many years to solve, and with no certainty of success in this estuary with its present hydrological extremes.

THE COST OF MANAGEMENT

DCE Bulletin 165 estimated the cost of the management measures recommended there and a study of the economics of management reported in Appendix 3 is summarised in Chapter 6. It is evident that there can be economic gain from treating the problem of eutrophication at source, by modifying agricultural practices on the coastal plain. However, because this alone will not cure the estuary's problems, at least within ten to fifteen years, other more costly measures have to be considered. The benefits of these to the community have to be considered in more subjective terms: the benefits from an early return to a clear, more attractive estuary, free from the stench of rotting algae — considerations on which it is not possible to put a dollar value. The value of restoring the estuarine ecosystem to an assured healthy condition is even more difficult to assess.

WHAT SORT OF ECOSYSTEM?

The management objective states that the algal nuisance should be reduced 'without further damage to the estuarine environment'. It is obvious that not only will the proposed management measures make the estuary less eutrophic, but they will also change the nature of the environment in other ways, some of which it is difficult to predict. The recommended measures have therefore been critically examined in this respect.

Taken literally, 'without further damage' is a negative approach to management. Much damage has already been done to the environment and the aim of management must be to create a 'healthy' estuarine ecosystem, in which, primary and secondary production are in balance, and which can also be enjoyed by the growing human population of the area.

However the necessary reduction in nutrients available to algae can only be achieved in the short term by flushing excess nutrients to the sea; by construction of the proposed Dawesville Channel. This measure will make the estuary more marine that at present, with associated changes to the plant and animal communities.

These changes will involve some degree of reversal to an earlier, though geologically very recent, phase of the estuary when there was much greater exchange between the estuary and the ocean. It is evident from the fossil record that Peel Inlet was then a healthy, highly productive environment. How far this reversal will go it is difficult to predict, though from the analogy of Leschenault Inlet it may not be very far.

The history of eutrophication is a short one, and there is a much longer history of changes which have predisposed the estuary to this condition. Putting Peel-Harvey in the context of other estuaries of the south west it can be seen to be on the road to extinction through natural, geomorphological processes, though construction of the training walls at the mouth (in 1967) have given it a slight reprieve. A number of turning points in the geologically short history of the estuary can be recognised.

Even before the estuary was flooded by the rising sea level 6000 to 7000 years ago the site of the proposed Dawesville Channel appears to have been blocked by a sand dune, which has subsequently been partially lithified.

For a time Peel Inlet was a marine embayment, rather like Oyster Harbour today, with a rich invertebrate fauna.

Then rather abruptly about 3000 to 4000 years ago exchange with the ocean became obstructed, just as has happened to other estuaries of the south-west, and the diverse, more marine fauna was replaced by a restricted fauna, dominated by a few strictly estuarine species.

From this time until 1967 there were occasions when exchange with the ocean was interrupted completely for several months at a time.

Drainage of the coastal plain, starting in 1900, followed by damming of the hills catchment and, from 1945, the addition of large doses of phosphorus, are man's contribution to the deterioration of the ecosystem.

Even though the estuary was a 'healthy' one 40 years ago, it was already vulnerable to the impact of an excess of plant nutrients. It is now even more vulnerable because of the demands of the rapidly increasing human population.

It is relevant to ask, what is or was the 'natural environment' of the Peel-Harvey estuary which we wish to conserve? Is it that of 1985, 1950, 1829, or perhaps 3000 years B.C.?

Construction of the Port of Fremantle in the 1890s involved blowing up a rock bar at the mouth of the Swan and dredging the large tidal delta. But for this it is most unlikely that the estuary of the Swan River would be in such a remarkably healthy condition today, despite the large urban areas surrounding it. The tidal range in the estuary is almost the same as in the open sea and tidal flushing is much greater than in the Peel-Harvey estuary. Moreover the area of the Swan estuary is only one-fifth that of Peel-Harvey.

The Peel-Harvey estuary is now two large coastal lagoons with but one small channel to the sea, which has to be artificially maintained, and this is as far as can be from the principal source of nutrients, the Harvey River. This condition predisposes the estuarine waters to eutrophication. It is onto such an inherently unsatisfactory situation that human pressure has increasingly been imposed.

Marine mollusc shells of 4000 to 6000 years ago on an estuary beach.

The proposed Dawesville Channel will change the nature of the estuarine environment by giving each lagoon its channel to the sea, converting one senescent estuarine ecosystem into two healthy estuaries. The management measures cannot, and should not, merely reverse the deterioration of the last 30 to 40 years, leaving the estuary still vulnerable to the impact of future developmental pressures of all types. They will make it a different, healthy and much more resilient system.

THE FISHERY

The effect the management measures will have on fish and fishery production is extremely difficult to predict, not only because fish are at the end of a complex food chain, but also because of the human element. An attempt at such a prediction is made in Chapters 4 and 6 and it is evident that there are likely to be changes to the fishery over the years with a probable reduction in the present mullet fishery in the long term. This fishery is largely dependent, indirectly, on the present over production of green algae and it may well be that reduction of the weed problem, to an acceptable level will prove to be incompatible with maintenance of the present fishery. There is little doubt that there will continue to be abundant fish in the estuary, but to what extent the professional fishery will be able to adapt to the more marine conditions is beyond the scope of this study.

AGRICULTURE IN THE CATCHMENT

The objective that management should be achieved without loss of production of agriculture in the catchment is accepted for a number of reasons, political, economic and practical. It is obvious that there would be strong opposition from the rural community to any administrative action to stop the use of fertilizers in the catchment, something that would in any case be difficult and costly to police. Production from agriculture on the coastal plain catchment is currently worth about $40 million a year and the cost of buying up all the farms on sandy soils of the coastal plain was estimated at $50 million at 1983 values. From the practical point of view, even if all application of phosphorus fertilizers were stopped forthwith enough phosphorus would continue to flow into the estuary to support algal growth for many years to come because of the large store now held in the soils and being discharged annually to drainage.

For these reasons the aim has been to produce phosphorus fertilizers, and devise fertilizer application methods, which will minimize phosphorus loss to drainage, consistent with maintaining profitable agricultural production in the catchment. The policy has been to persuade farmers to adopt the new methods and fertilizers by showing them that they can be to their advantage. So far, as shown in Chapter 3, this has been remarkably successful and the methods developed here are applicable to sandy soils elsewhere.

Inevitably there are problems associated with such a policy, especially that it accepts that there will continue to be a considerable input of phosphorus to the estuary from the catchment. Without compulsion farmers are free to reject the advice given on fertilizers and some may continue to do so. With improvement in the economics of farming some farmers may apply more than the currently recommended quantities of fertilizer, as has been done in the past, or with a reduction in the present level of advice and assistance from agricultural advisers farmers may revert to the use of superphosphate, at the old rate of a bag to the acre (18 kgP/ha). These are hazards which need to be taken into consideration in deciding on management policy for the estuary.

THE BASIS FOR PREDICTION

Lastly, it should be noted that the recommendations have been made on the basis of existing land use in the catchment. More intensive farming, for example for stockfeed lots could result in much higher phosphorus losses from the catchment. The overall lower phosphorus application rates and the use of Coastal Superphosphate will result in a reduction in the direct loss of phosphorus from the soil surface, and this can be estimated with reasonable accuracy. It is much more difficult to determine the rate of depletion of the soil stores from which about 70% of the present input of phosphorus is derived, both because of the complex chemical processes involved and because of the unpredictability of the weather and the influence of this on the rate of loss from the soils.

Careful analysis of the data does give confidence in the range of figures on which predictions as to the response of the estuary are based. Nevertheless, without the experience of a period of high rainfall and river flow, such as 1973-1974, it is difficult to know what will happen under such circumstances.

Predictions about physical changes to the estuarine environment, on which in turn predictions as to changes in the flora and fauna largely depend, are based mainly on the mathematical modelling. This necessarily has its limitations. Changes to the tidal range and pattern and the volume of exchange between estuary and ocean following construction of the Dawesville Channel are made with some confidence, but the degree of mixing between estuary and ocean waters and the consequent loss of phosphorus from the estuary is more difficult to predict. This is partly because of the stratification that occurs, separating a surface layer of water of relatively low salinity from a bottom layer of higher salinity.

To assess the effects of stratification requires construction of a far more complex model than the one-dimensional model used to determine changes to the tidal regime and volumetric exchange. At the time of writing there has been limited success with this 2-D model.

It is still more difficult to predict how fast the phosphorus store in the estuary's sediments will be depleted. The store is large, but to what extent and for how long it will continue to be available to algae depends on the persistence of conditions favourable for the release of phosphorus, especially lack of oxygen.

This in turn depends partly on persistence of the weed algae; thus involving a circular argument which there is not the experience to resolve. Hence the difficulty in predicting the rate of decline of the weed problem.

Predicting changes to the plant and animal life of the estuary involves not only assessing the effects of a reduction in the available plant nutrients and of changes to the physical environment, but also of the probable interaction between the various elements of the biological complex, from bacteria to birds.

There is probably now so much phosphorus available to algae from the sediment store that it is no longer the principal factor limiting weed growth. Rather it is now the amount of light at the bottom, which has been reduced by the abundant phytoplankton, hence the prediction that the anticipated clearer water will favour a temporary increase in weed growth.

Predicting changes to the life of the estuary would be an impossible task but for the evidence available from other estuarine environments in WA and from experience here and elsewhere. Most of this is evidence from other fairly stable, estuarine situations and, as will be clear from Chapter 4, it has been valuable in assessing the probable ultimate state of the estuary. However, it furnishes little evidence as to the nature and rate of the transformation process.

The detailed studies of the single species *Nodularia spumigena* make it possible to predict with considerable confidence how quickly it will respond to the management measures. On the other hand there is no firm basis for predicting how fast the complex web of interaction between weed algae, microbial life, and the invertebrate fauna dependent on it, will change to the detriment of the professional fishery, now largely based on mullet and prawns, or indeed whether it will be disadvantaged at all in the long run.

It is probably platitudinous to say that we will only know with certainty what sort of estuary there will be on the basis of experience. But, having in the foregoing stressed all the problems associated with the timing and accuracy of the predictions, it must be emphasized that to gain a greater degree of confidence would require considerably greater expenditure on investigation and an unacceptable further delay. However desirable this might be from the scientific point of view it is not compatible with the urgent need to make management decisions.

For a more detailed assessment of the levels of probability of predictions reference should be made to the various appendices.

CHAPTER 3

MANAGEMENT — THE PREFERRED STRATEGY

INTRODUCTION

Bulletin 170 presented a preferred strategy for management of the estuary. This had three parts: continued harvesting of weed from the beaches and from offshore; agronomic measures to reduce the input of phosphorus to the estuary; creation of a new channel from Harvey Estuary to the ocean to increase the amount of phosphorus lost from the estuary. This strategy was presented with the confidence that it had 'the potential to restore the estuary to a condition where the beaches will be largely free of weed and the water clear most of the time'.

The data on which the strategy was based was considered to be inadequate in several respects, because of the need to justify the high cost involved and because of uncertainty as to what other effects the measures might have on the environment, besides achieving the objective of ending the algal problems of the estuary. The experimental and observational data on which to judge the potential of the fertilizer reduction measures were scanty, particularly because Coastal Superphosphate had only been used in experimental form in small field trials; it had not been manufactured commercially. Similarly, while it was clear that construction of a new channel (the Dawesville Channel), in conjunction with the fertilizer modification measures, would lower the phosphorus level sufficiently to achieve the management objectives, it was not known how else the estuarine environment would be changed, either physically or in respect to its plant and animal life.

It will be evident from what follows that, in some respects, it is still not possible to predict in detail the nature and extent of all the changes which will result from implementation of the management measures recommended in Chapter 7. However, predictions are now made on firmer ground than a year ago because, in respect to the fertilizer measures, there is now the experience of one year's implementation throughout the coastal plain catchment, together with detailed monitoring of the results. There are now also the results of further mathematical modelling enabling more informed predictions of the physical effects of the Dawesville Channel to be made and its implications for life in the estuary, including fish and the fishery.

This chapter states the nature of the management proposals, and summarizes the results of investigations relative to their implementation and addresses the anticipated results of their implementation on the physical environment and on the algal problems. The effects on other plant and animal life and the fishery are discussed in Chapter 4.

WEED HARVESTING — WHAT IT CAN DO

The aim of weed harvesting is to keep beaches free of weed near populated areas to ameliorate a situation that is offensive to local residents. It does not and cannot attempt to keep the estuary free of weed or even to keep all beaches free of decomposing weed. In the 1983-84 season about 8000 tonnes of material (weed, sand and water) were removed from the beaches while the estimated dry weight of weed in February 1984 was 46,000 tonnes (about 300,000 tonnes wet weed).

Stranded weed is harvested from about 2 km of beach along the northern shore of Peel Inlet (40 ha), from a similar length along its western shore and from a short stretch along the north-western shore of Harvey Estuary. There are extensive strandings along the eastern, southern and north-western shores of Peel Inlet that are not immediately adjacent to presently populated areas; about 25 km of shoreline.

The various species of algae which cause the weed problem grow mainly in water deeper than half a metre in the eastern half of Peel Inlet and in Cox Bay (Fig. 1.1). From there they are driven by wind and wave action to the shallows where they may be stranded for some time, later to be driven ashore. The extensive accumulations of living and decomposing weed in the shallows are unattractive, but it is principally the decomposing weed close to the shore which is offensive because of the evolution of hydrogen sulphide and other gases. Decomposition occurs anywhere, under the growing masses in deeper water, in the shallows, or on the beaches themselves.

The weed nuisance is now only acute for about three months each year, following the *Nodularia* blooms, at a time when the water is clearest. Before the advent of *Nodularia* blooms it was more uniformly distributed over the warmer months of the year. The odour of decomposing weed is especially nauseating at times when a scum of *Nodularia* is added to the stranded weed, causing it to rot more rapidly.

Two methods are employed to keep beaches free of weed: raking accumulated weed from beaches and adjacent shallows; harvesting the weed where it grows in deeper water. The first involves the use of front-end loaders equipped with rakes and scoops to remove the weed and semi-liquid black ooze and load it into trucks for dumping on land. At present, two such loaders are used to collect weed within about 100 m of the shore.

Harvesting growing weed is by means of two floating weed harvesters that can only work in water more than 40 centimetres deep. These collect clean, growing weed, largely free of decomposing material or sand, and most of this is also disposed of by dumping. These measures combine to keep beaches near populated areas reasonably free from decaying algae most of the time, thereby greatly reducing the offensive odours of rotting algae. The offshore harvesters aim to collect a high percentage of the weed before it drifts ashore, but in practice much of it is not intercepted. There are many occasions when strong winds and changing water levels combine to drive weed onto the extensive shallows where it is inaccessible either to the harvesters or to the front-end loaders. Such conditions are, of course, not predictable, making management difficult to plan.

Although necessary and likely to continue to be so for some time to come, these measures are an inefficient method of managing the weed problem. Expensive machinery is only fully operative for a relatively small part of the year, at which time the present equipment may require several days to remove the larger strandings of up to 500 tonnes, and it cannot be used where the weed is first stranded in shallow water offshore. It has to work in salt water (which is corrosive, so that maintenance costs are high), and at a considerable distance from the work base.

Both measures are costly: during the 1984-85 financial year beach harvesting cost $120,000 and offshore harvesting $88,000, but as will be seen from Figure 3.1, beach harvesting is much the more cost effective.

Over the years, harvesting methods have been greatly improved and investigations are continuing into alternative methods of weed collection, but at present there appears to be no cost effective alternative solution to the methods of beach clearing currently being employed (Brindley, Appendix 3).

While beach clearing will have to continue to be relied on for some years to come, it has to be recognized that it does considerable damage to the beaches. Destruction of the marginal vegetation, especially rushes, has resulted in erosion of the shoreline, which in places has retreated as much as 10 m with the loss of many shady trees, mainly *Casuarina* and *Melaleuca*. Therefore every effort must be made to minimize such damage and to harvest the weed in as environmentally sensitive a manner as possible.

SUMMARY

Weed harvesting has the capacity to keep the beaches reasonably free of decomposing weed most of the time and the most effective way to do this is by the beach clearing method. Weed harvesting will have to be continued for some years and it may be necessary to increase the capacity of the present equipment if beaches are to continue to be kept free of weed until the available sediment phosphorus source is sufficiently depleted by the other measures of the preferred strategy. Measures will have to be taken to prevent damage to the beaches.

Harvesting is ineffective against *Nodularia* and it does nothing to remove the cause of the algal problem — the excess of plant nutrients available to algae.

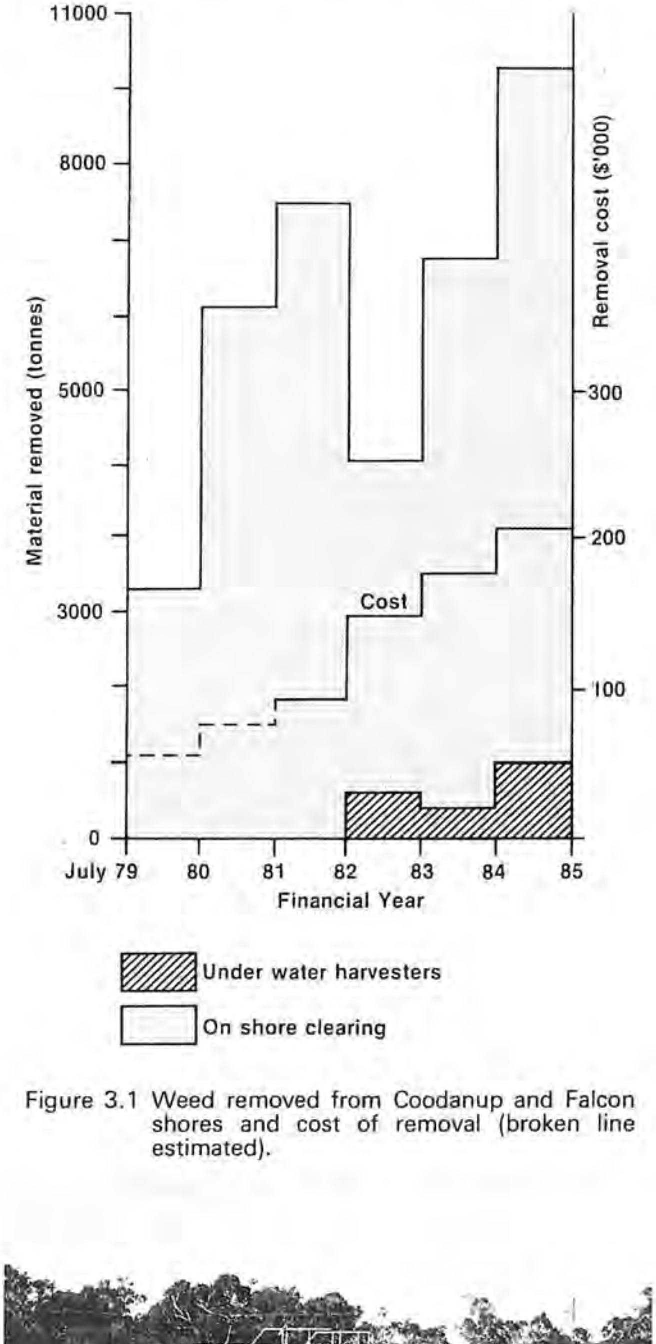


Figure 3.1 Weed removed from Coodanup and Falcon shores and cost of removal (broken line estimated).

Weed harvester.

REDUCING PHOSPHORUS INPUT TO THE ESTUARY — WHAT THE FERTILIZER MODIFICATION PROGRAMME CAN ACHIEVE

Fertilizer applied to pasture on the coastal plain catchment is the main source of phosphorus entering the estuary, and it is for this reason that the catchment management studies have aimed at finding how best to reduce phosphorus losses while maintaining the current type and profitability of agriculture. In the past superphosphate has been widely applied each year at a rate of one bag to the acre (180 kg/ha), or 18 kg phosphorus per hectare, to paddocks which no longer require fertilizing at this rate. The main aim has been to devise new fertilizers and fertilizer application methods more appropriate to the sandy soils of the coastal plain and to persuade farmers to adopt these methods. Other measures which have the potential to further reduce the loss of phosphorus are discussed in Chapter 5. The material summarized in this section is discussed in greater detail in Appendix 1 and papers by Yeates and Birch in Appendix 3.

Recently the studies have also been extended to investigate the potential of alternative types of land use which can further reduce phosphorus losses to drainage (Chapter 5).

THE HISTORY OF CULTIVATION ON THE COASTAL PLAIN

Until early this century the coastal plain catchment of the estuary was largely uncultivated and was covered with an open woodland and extensive swamps along the Serpentine and Harvey Rivers. Subsequent clearing and drainage for cultivation, with the consequent increase in river and drain flow, have probably more than compensated for reduced flow from the hills catchments as the result of damming the rivers there. Some 155,000 ha of the coastal plain catchment is now cleared for cultivation (125,000 ha on sandy soils and 30,000 ha on the heavier soils) and agricultural production from this land is valued at $50 million a year.

Application of inorganic fertilizers to cultivated land over the last forty years has resulted in an enormous increase in plant nutrients, especially phosphorus, entering the estuary. During the last decade an average of about 1500 tonnes of phosphorus has been applied annually to the coastal plain catchment.

The soils

A large proportion of the soils of the coastal plain are infertile sands that are naturally deficient in phosphorus and have low capacity to bind and retain it, in contrast to the clayey soils of the plateau catchment. They are also very porous. They vary greatly in character, fourteen different soil associations being identified, but three main kinds are recognised with respect to their ability to retain or release phosphorus (Fig. 3.2).

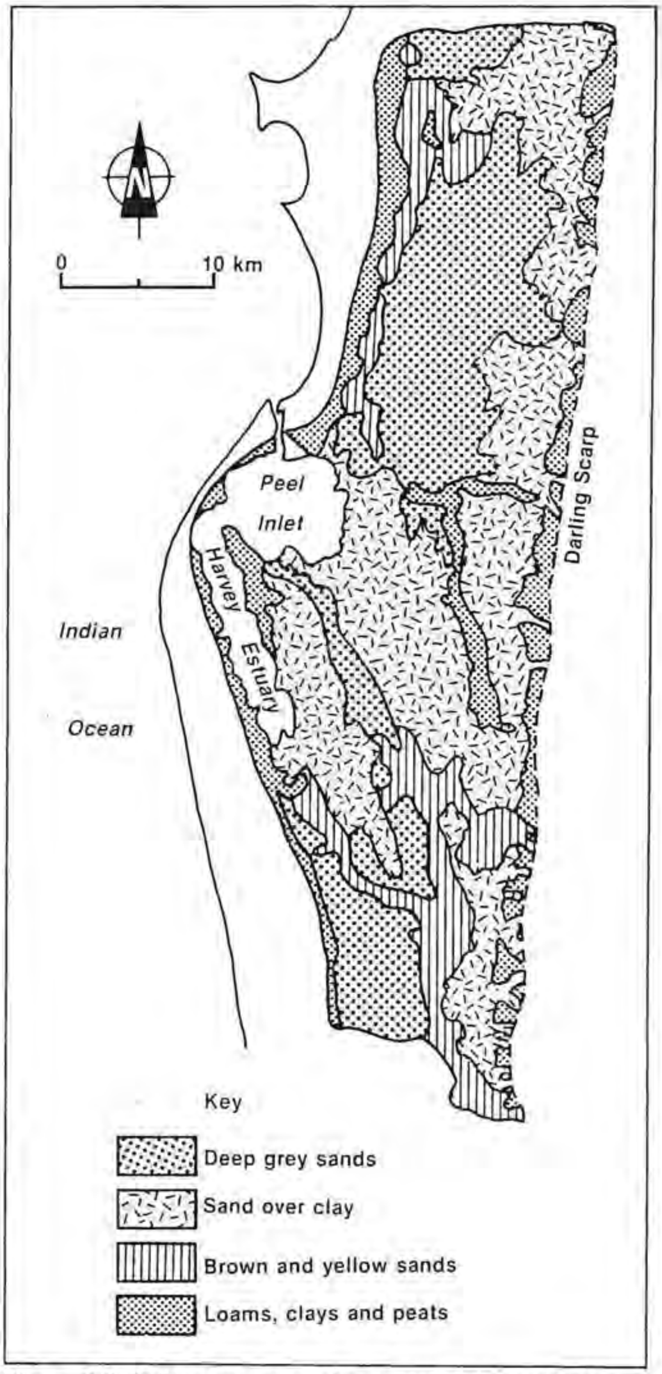


Figure 3.2 Soil categories on the coastal plain catchment of the Peel-Harvey estuary.

Clay-loam soils and brown and yellow sandy soils with a high iron content bind phosphorus and only release it slowly. Soils of this type constitute about 25% of the coastal plain catchment; they are the most naturally fertile and were the first to be developed for agriculture. Soils with 30 to 50 cm of sand over clay cover 37% of the area. Deep grey sands (with dunes and swales) cover the remaining 38%. These last are the poorest, most porous soils with the least capacity to retain phosphorus and were those most recently cleared and drained.

The density of drainage (the length of drains per hectare) is also an important factor; it determines both the volume of flow to the estuary and in consequence also the quantity of phosphorus discharged to it. The coastal plain catchments of the Serpentine and Harvey rivers are of approximately equal size, but the density of drainage in the Harvey catchment is almost twice that of the Serpentine. Phosphorus discharged to the estuary by the Harvey River is about twice that from the Serpentine.

The fate of phosphorus — the soil store

Figure 3.3 illustrates the fate of phosphorus applied to the three soil types. The figures are necessarily approximate being based on small scale experiments and on only two years of data, but they emphasize the striking differences between these soils with respect to the proportion of applied phosphorus which is either released to drainage or retained as a soil store.

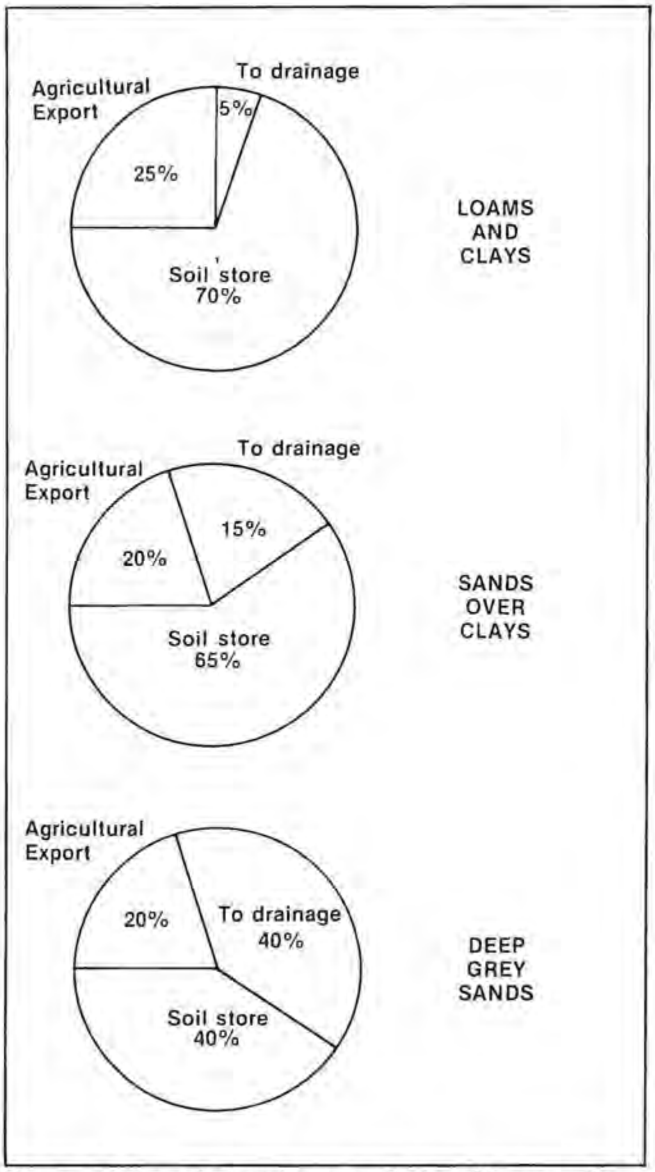


Figure 3.3 Fate of phosphorus applied to different soils, figures approximate only.

The actual rate of release to drainage, leaching, varies considerably from place to place and time to time; it depends not only on the capacity of the particular soil type to bind phosphorus but also on the type of crop and the timing and intensity of rainfall.

The **soil store** is phosphorus which has accumulated as the result of continued application of superphosphate in excess of the requirements of the pastures. While the different soil types have different capacities to store and release phosphorus, the amount held in the store also varies with past rates and duration of application and the type of crop, so that there is variation from one paddock to another even on the same soil type.

Fertilizer requirements

In practice, therefore, application rates need to be assessed on the requirements of individual paddocks, based on soil tests to determine the amount of phosphorus available for plant growth (measured as bicarbonate-extractable phosphorus in the top 10 cm of soil). The amount required is that needed to maintain a sufficient phosphorus store to achieve optimum (not necessarily maximum) economic production from the land.

Soil surveys made in 1983 and 1984 have shown that this store is now adequate on about 70% of paddocks with sandy soils and could support crop production for at least one year, and in most cases probably for five or more years, without further application of phosphorus (Fig. 3.4). Clearly, to continue to fertilize these paddocks is both wasteful and adds to the excess store from which phosphorus will continue to be leached to drainage for many years.

Direct loss of phosphorus to drainage

While about 70% of phosphorus lost to drainage from the sandy soils comes from this soil store, the remaining 30% is direct loss from fertilizer applied in the current year. Until 1984 phosphorus was applied as superphosphate, of which 84% is water-soluble and so is readily leached to drainage. In the new 'slow release' Coastal Superphosphate only 20% is in water-soluble form and a much smaller proportion is lost direct to drainage. More of the phosphorus remains to supply plant requirements in subsequent years and therefore less needs to be applied. This is illustrated in Figures 3.5 and 3.6 and it will be noted that only on previously unfertilized land is there benefit from using superphosphate rather than Coastal Superphosphate. The higher cost of the latter is more than offset by the smaller quantity required.

The use of Coastal Superphosphate in place of superphosphate thus about halves the proportion of phosphorus lost to drainage from the current year's application. It also reduces the total amount of phosphorus which needs to be applied to maintain production.

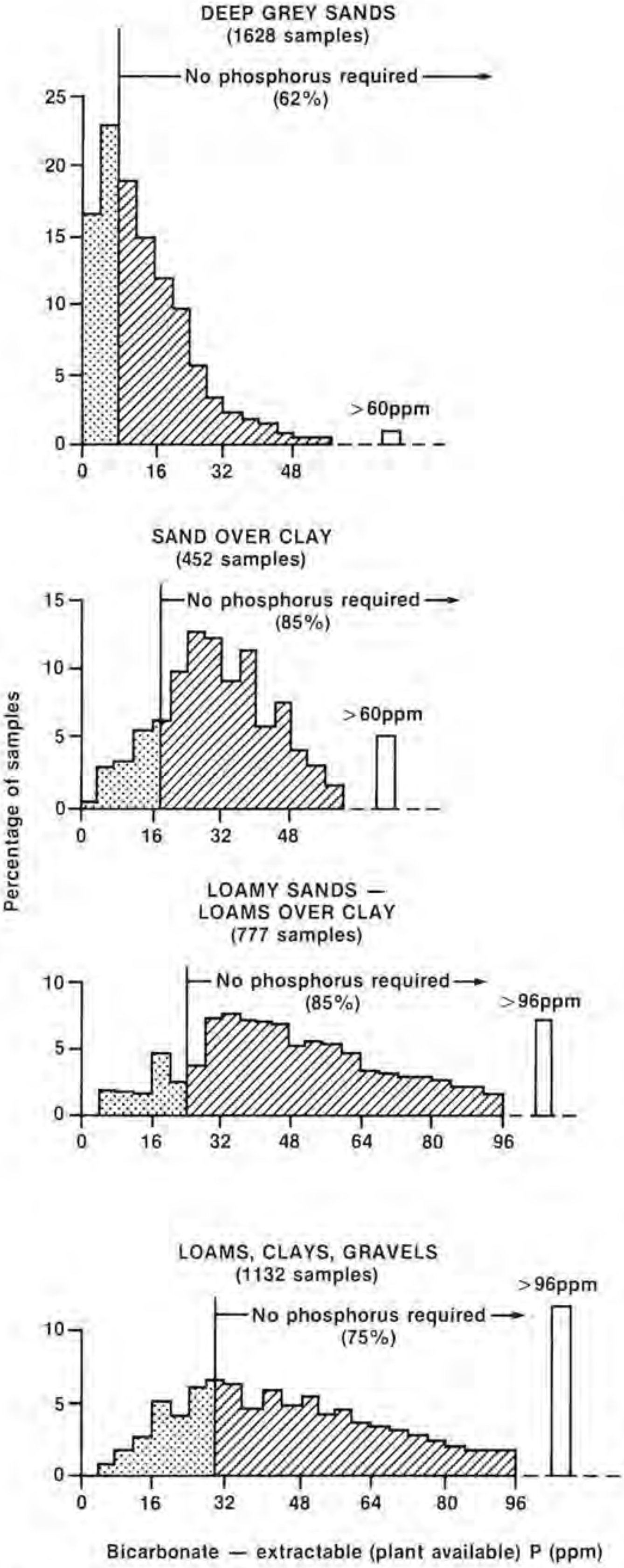


Figure 3.4 Phosphorus soil test levels for coastal plain catchments of the Peel-Harvey estuary, 1983-1984.

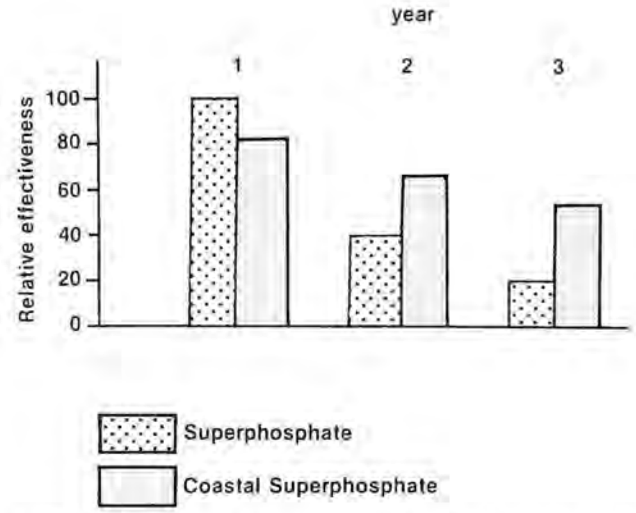


Figure 3.5 Relative effectiveness of superphosphate and Coastal Superphosphate with respect to plant nutrition over 3 years on previously unfertilized deep grey sand.

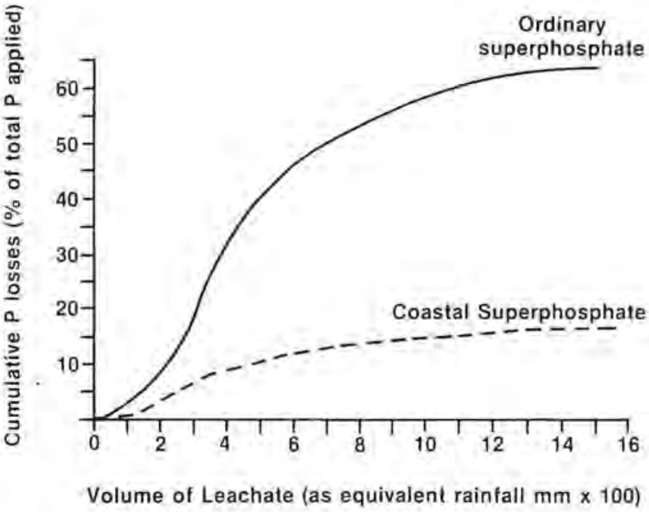


Figure 3.6 Cumulative leaching losses from phosphorus applied to the surface of a deep grey (Gavin) sand in 30 cm columns and subjected to continuous leaching.

Sulphur requirements

Because some 70% of paddocks now have an excess of stored phosphorus it might be expected that a corresponding reduction in application rates should be achieved. Unfortunately, although phosphorus is the principal element in which sandy soils are naturally deficient, they are also deficient in sulphur and potassium. Both elements are incorporated in superphosphate fertilizers, thus if phosphorus is no longer to be applied then alternative sources of sulphur and potassium must be found.

Potassium can readily be applied independently (as muriate of potash) but as yet sulphur cannot and it must continue to be supplied in superphosphate, of which 10% is sulphur, or in Coastal Superphosphate which contains three times as much and so can be applied at a lower rate than superphosphate to achieve the same sulphur application (Fig. 3.7).

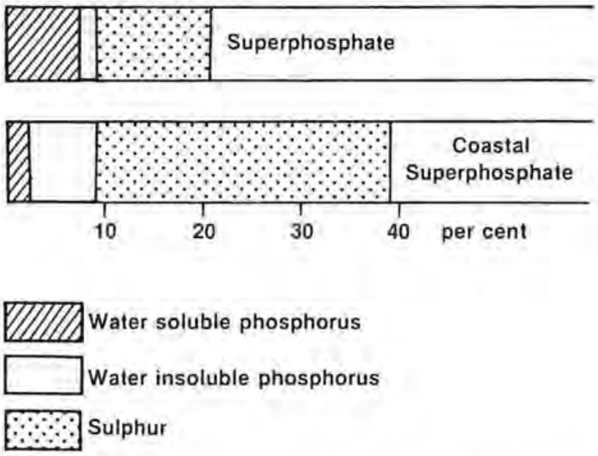


Figure 3.7 Composition of superphosphate and Coastal Superphosphate fertilizers.

Gypsum, a waste product in the manufacture of superphosphate, or lake-bed gypsum are cheap sources of sulphur but they need to be applied in late winter/spring when many coastal plain paddocks are waterlogged, and there are some difficulties with spreading. Experiments are in progress to prepare a more acceptable sulphur fertilizer, but until they are successful phosphorus will continue to be applied where soil stores are already excessive. When such a fertilizer is available a further reduction in the quantity of phosphorus applied to the catchment can be expected.

Clay-loam soils

In the foregoing, attention has been concentrated on the sandy soils of the coastal plain because it is from these that approximately 80% of phosphorus of agricultural origin is derived. The remaining soil types, mainly loams and clays, which comprise 25% of the coastal plain catchment, account for about 20% of drainage input despite higher fertilizer application rates. This is because of the high proportion retained in the soil store (Fig. 3.3). This phosphorus is tightly bound and only very slowly leached to drainage, but leaching will continue for longer than from sandy soils.

Soil tests show that 75% of paddocks do not require phosphorus to be applied at present (Fig. 3.4). Although superphosphate has to be used rather than Coastal Superphosphate on these soils, they do not require sulphur so that fertilizer need not be applied to supply this element. The net result is that an immediate reduction of possibly up to 30% of phosphorus loss from these soils can be gained by adopting the recommended measures, with a further reduction to perhaps 50% in the long term with depletion of the soil stores.

Although the contribution of these heavy soils to the phosphorus load to the estuary is relatively small, measures to ensure that this is minimized must remain an important part of the fertilizer management strategy.

Summary

The type of fertilizer used (superphosphate) and rates of applications have been shown to be inappropriate for continued use on the mainly sandy soils of the coastal plain. This has resulted in the wasteful use of phosphorus, in excess of crop requirements.

In consequence there is a big loss of phosphorus to drainage to the estuary. This loss is derived from two sources: direct loss from the current year's application of fertilizer (30%), and leaching from the excess phosphorus accumulated in the soil stores (70%).

The direct loss can immediately be reduced by substituting the slow-release Coastal Superphosphate for standard superphosphate on sandy soils, or more effectively by using a sulphur fertilizer.

Loss from the excess soil store can progresively be reduced by limiting the application of phosphorus until required, as indicated by soil tests.

These facts largely dictate the measures required to minimize the loss of phosphorus to drainage and the following measures were implemented in 1984:

> soil testing of all paddocks on the coastal plain catchment to measure the phosphorus content (as bicarbonate-extractable phosphorus);
>
> introduction of Coastal Superphosphate to replace superphosphate for use on sandy soils of the catchment;
>
> on the basis of this data, evaluation of fertilizer requirements for maintenance of an economic level of production;
>
> advice to individual farmers as to the appropriate type and rate of fertilizer to be applied to their paddocks.

The Extension Service of the Department of Agriculture was responsible for implementing these measures.

Their implementation in 1984 has resulted in a reduction of phosphorus fertilizer applied to the coastal plain catchments compared with the average for the previous decade; about 40% in the Harvey River catchment and 20% in that of the Serpentine River.

In 1984, 60% of this phosphorus fertilizer was superphosphate, the remainder being Coastal Superphosphate. A further reduction in this percentage can be expected with farmer acceptance.

Introduction of a sulphur fertilizer, in addition to gypsum, will allow a further reduction in the amount of phosphorus applied and will remove the present necessity for applying phosphate fertilizers as a source of sulphur. Such a sulphur fertilizer is expected to be available in 1986.

A further, temporary, reduction in application rates may be possible over the next three to five years while the soil stores are being depleted to maintenance levels.

In the long term, it will be necessary to continue to apply phosphorus at about half the pre-1984 rate if pasture growth is to be maintained to support the present level of economic production (Fig. 3.8).

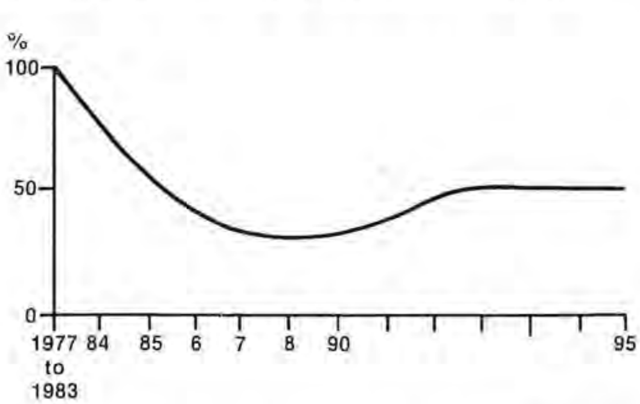


Figure 3.8 Projected phosphorus application rates to the coastal plain catchment of the Peel-Harvey estuary, per cent of 1977-83 rates.

Implementation of the measures in 1984 resulted in an estimated decrease in input of phosphorus to Harvey Estuary of about 25%. This was probably attributable mainly to the limited use of superphosphate and hence the amount lost from the current year's application of fertilizer.

Further, long-term reduction in input must depend on depletion of the excess soil phosphorus store. It is anticipated that, with continued adoption of the recommended measures, there will be a progressive reduction in input of 30 to 40% over the next three to five years.

Thereafter, there should continue to be a further decrease in input as the soil stores are reduced to maintenance level throughout the coastal catchment. A 60% reduction on the present input level may be achieved over a ten to fifteen year period. This is a reduction from the present average of 140 tonnes to 55 tonnes a year from the coastal plain catchment. This will about halve the present total input of phosphorus to the estuary (Fig. 3.9).

Other catchment management measures which have the potential to further reduce the input of phosphorus to the estuary in the long term are discussed in Chapter 5.

Success of the fertilizer reduction campaign has depended on: a high level of research into fertilizers and methods of their application; research into the soils, and phosphorus and water movement through them; experimental application of the new fertilizers and monitoring the results, both in crop production and phosphorus release to drainage; soil sampling throughout the coastal plain catchment, and an active extension programme with advice to individual farmers; and the willingness of most farmers to co-operate.

Continuation of this work, and especially that of the Extension Service of the Department of Agriculture, is essential to success of the management programme.

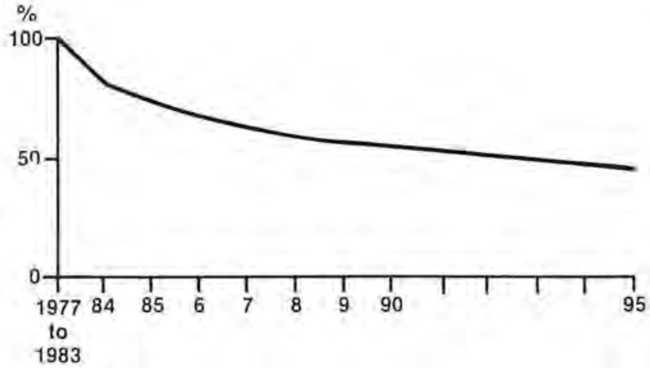


Figure 3.9 Projected input of phosphorus to the Peel-Harvey estuary from the coastal plain catchment, per cent of 1977-83 average (155 tonnes).

INCREASING THE EXPORT OF PHOSPHORUS — WHAT THE DAWESVILLE CHANNEL CAN ACHIEVE

The main aim of this measure is, in conjunction with the fertilizer modification campaign, to reduce the nutrients retained in the estuary by flushing them to the sea, and to do this sufficiently to prevent the algal nuisance. A bonus will be that the resultant higher salinities will be unfavourable for the development of *Nodularia* blooms. Creating a new channel to the sea may greatly alter the estuarine environment and it is necessary not only to determine the extent to which the measure will achieve the specific objectives but also what other changes it will make to the estuary. Some of these could be to its detriment, others advantageous. For this reason it has been necessary to undertake both detailed engineering studies and mathematical modelling of the hydrodynamics of the estuary, as it is now and as it will be if the channel is constructed. The results of these studies are summarized here from papers by Paul and Tong in Appendix 3.

The Mandurah Channel cannot be enlarged sufficiently to achieve the desired objective, even with respect of Peel Inlet; moreover, it is too far from the largest source of phosphorus, Harvey River, for any such action to be effective in significantly reducing the retention of phosphorus from that source. It is necessary therefore to construct a new channel to the sea in a more appropriate position. The location of the proposed channel near the north end of Harvey Estuary (Fig. 3.10) is dictated mainly by the practical considerations of length, topography and existing development. However, the site selected is also the preferred location on purely geomorphological grounds and is probably the site of a former connection between Harvey Estuary and the sea (in Holocene or late Pleistocene times).

The alternative of a channel at Falcon is ruled out by the level of development there and, more importantly, because it would have limited effect on flushing Harvey Estuary. The possibility of discharging Harvey River water direct to the sea was also examined and rejected on the grounds of cost and the need for an unacceptably large impoundment that would itself become grossly eutrophic.

The selected site has a number of practical benefits minimizing the problems of construction and maintenance of the channel (Fig. 3.11). It is a low point in the coastal dune system with relatively little rock, most of which can be excavated. Only limited blasting should be required. At the seaward end the shoreline has limestone rock for some distance so that beach erosion will not be a problem: the coastline as far north as Mandurah could not recede to any appreciable extent. There is sufficiently deep water close offshore to allow for the design of training walls which will enhance the bypassing of the littoral sand drift, which is expected to prevent formation of a predominant sand bar at the ocean entrance (similar to that at the entrance to the Mandurah Channel) and will keep the channel scoured. This will reduce both the need to dredge to maintain the channel and the potential for a tidal delta to develop at the estuary end of the channel.

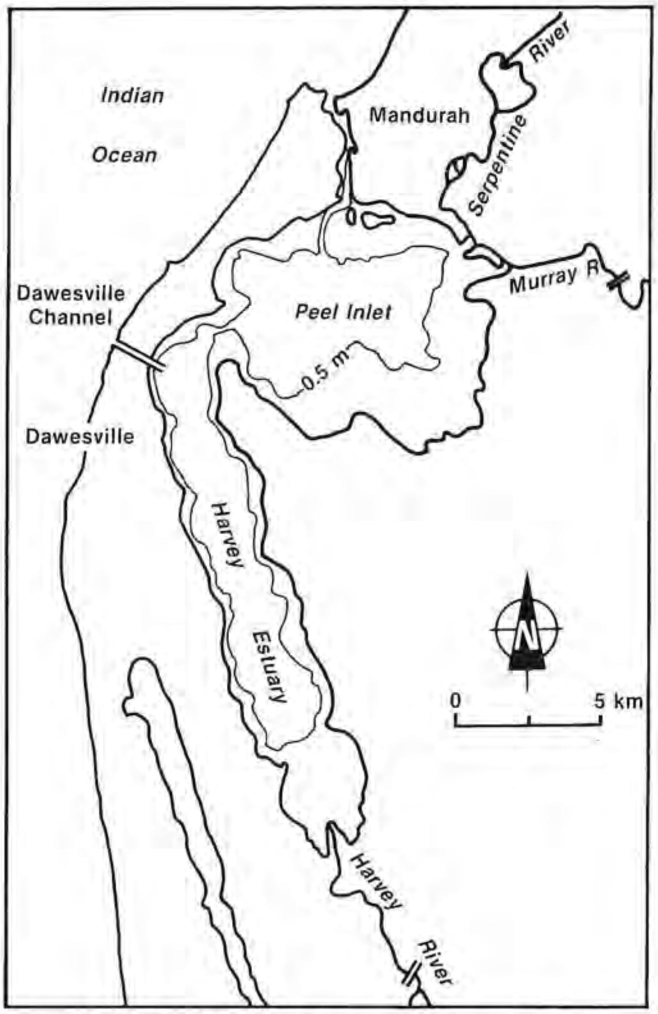


Figure 3.10 The Peel-Harvey estuary to show the location of the proposed Dawesville Channel.

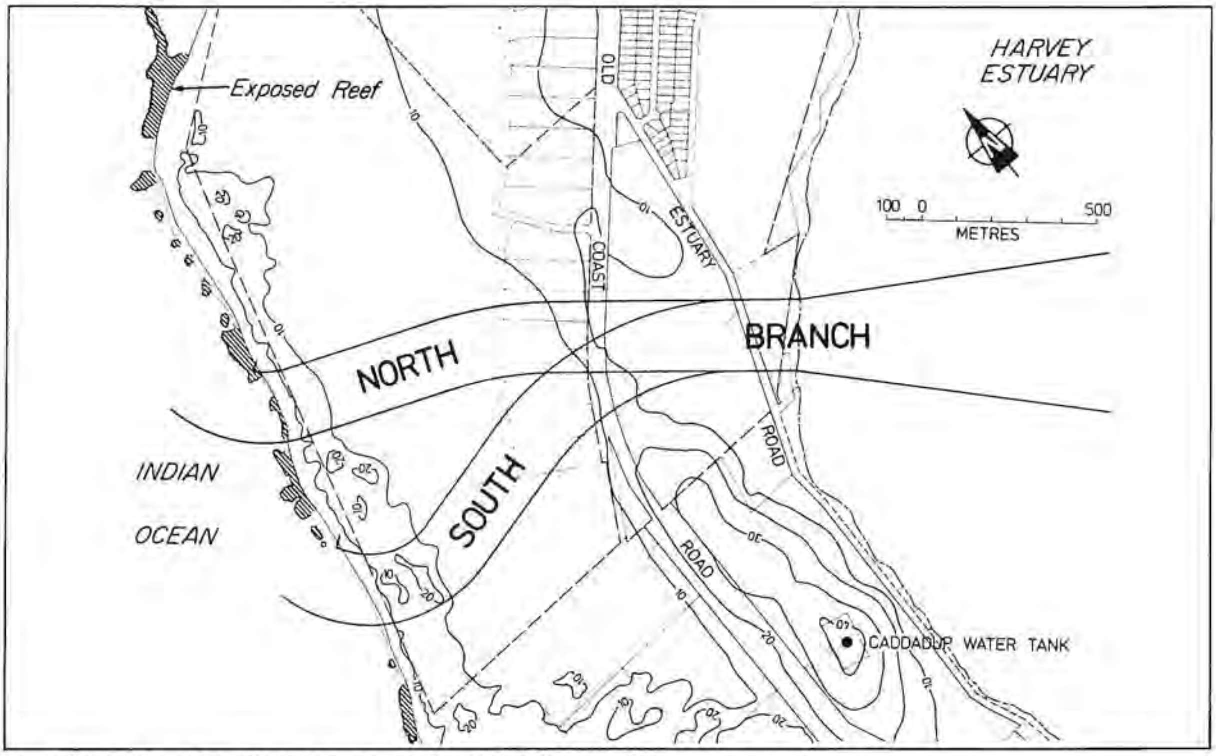


Figure 3.11 Site options for the proposed Dawesville Channel. Contours – metres.

The design and dimensions of the channel have been determined, with the assistance of results from the mathematical modelling, to maximize stability of the channel, and reduce siltation problems at the ocean entrance. Two alternative alignments of the channel have been considered (Fig. 3.11), but the northern one is preferred because it involves a smaller total volume of material to be excavated, it provides for an entrance location which will enhance the natural by-passing of littoral sand, and it provides a better balance of land available for redevelopment between the north and south sides of the channel.

The channel is designed with a depth of 4.5 m below Australian Height Datum (AHD, approximately mean sea level), a bottom width of 200 m and side slopes of 1:5. The length of the bridge required on the Old Coast Road is 330 m.

Cost

The estimated total cost of implementing the Dawesville Channel on the north channel alignment is $31 million. Further investigations will be required before the proposal can reach the tender stage and will require a year to complete. These should not appreciably affect the cost (within the 10% margin) and they will not change the anticipated effects of the channel on the estuarine ecosystem.

What the channel will achieve

The mathematical modelling indicates that the volume of exchange through the Dawesville Channel will be more than double the present flow through the Mandurah Channel (Table 3.1). It will also have the effect of moderately increasing flow through the Mandurah Channel by some 15-20% and will nearly double the exchange between Peel Inlet and Harvey Estuary (more in winter). The effect will be to greatly increase the flushing of estuary water to the sea. The modelling estimates 'flushing time' — the time it takes to flush water out of the estuary. This will be reduced to one third of what it is now; in Peel Inlet from the present average of 30 days to 10 days and in Harvey Estuary from 50 days to 17 days. (Or, instead of only 1/30th of Peel Inlet water being flushed out each day, 1/10th will be flushed out daily, and from Harvey Estuary 1/17th instead of the present 1/50th).

The effect this increase in water exchange between estuary and ocean will have on the retention of phosphorus cannot be determined accurately. This is because the model assumes that all the water flushed out of the estuary is replaced by sea water and that the sea water then mixes completely with water in the estuary. This does not happen because mixing depends greatly on wind stress, on differences in density between ocean and estuary water, and on other hydrological factors of which the model takes no account. Nor has it yet been possible to model the effect that stratification of the water body has on the part played by the plants and sediments in retaining and recycling phosphorus.

Table 3.1 Water exchange per tidal cycle through estuarine channels without and with the Dawesville Channel, under typical summer conditions.

	Without Dawesville Channel $m^3 \times 10^6$	With Dawesville Channel $m^3 \times 10^6$
Mandurah Channel	5.5	6.3
Peel-Harvey Channel	3.5	6.4
Dawesville Channel	—	15.6

There can be little doubt that there will be a great increase in loss of phosphorus to the ocean, both in soluble form (PO_4-P) and in particulate form (phytoplankton, suspended sediment and some weed). In combination with the catchment measures this will be adequate to reduce the amount of phosphorus available for plant growth by the 70% considered to be necessary to prevent the present eutrophic conditions.

What still cannot be predicted is how long it will take to reach this condition. There is little doubt that once the Dawesville Channel is operational *Nodularia* blooms will cease, except perhaps in years of exceptionally heavy rainfall and at the southern end of Harvey Estuary. Not only will there be much less phosphorus, but salinity will be too high for *Nodularia* to propagate successfully.

However, because the large weed algae derive much of their phosphorus from the store in the surface sediment they may continue to reach unacceptable quantities until the store of available phosphorus is exhausted, by one means or another. Water in the estuary will be clearer than at present and the algae will benefit from this because their growth is now limited more by the amount of light than by the availability of phosphorus. In consequence there may well be a temporary increase in weed growth, lasting some three to five years; the figure cannot be predicted accurately.

The effect of the Dawesville Channel on the nuisance algae is discussed more fully in Chapter 4.

CHANGES TO THE PHYSICAL ENVIRONMENT

Predictions as to changes to the physical environment that will result from construction of the Dawesville Channel are based mainly on mathematical modelling of the hydrodynamics of the system.

The physical features of the estuary are described in more detail in Appendix 1, and the modelling and the changes this predicts to the estuarine environment are discussed more fully by Tong in Appendix 3.

Tidal regime

Tides in the estuary largely reflect those in the ocean, attenuated by the restricted Mandurah Channel. Astronomic daily tides in the ocean are of small range (0.2 to 0.9 m) and in the estuary seldom exceed 0.1 m because of the restriction of flow imposed by the Mandurah Channel (Fig. 3.12). Longer period changes of ocean water level are not damped by the channel and so cause corresponding changes of water level in the estuary. Although these are also of small range they are significant in an estuary with an average depth of only one metre, with extensive areas which are exposed at extremely low water. Meteorological 'tides' have periods varying from five to fifteen days, related to barometric pressure, wind strength and direction, and other meteorological factors. They have a range of up to 0.5 m and although they are little attenuated in the estuary there may be some delay in response to them. There is also a seasonal change of ocean and estuary level, the summer level being 0.2 to 0.3 m lower than in winter.

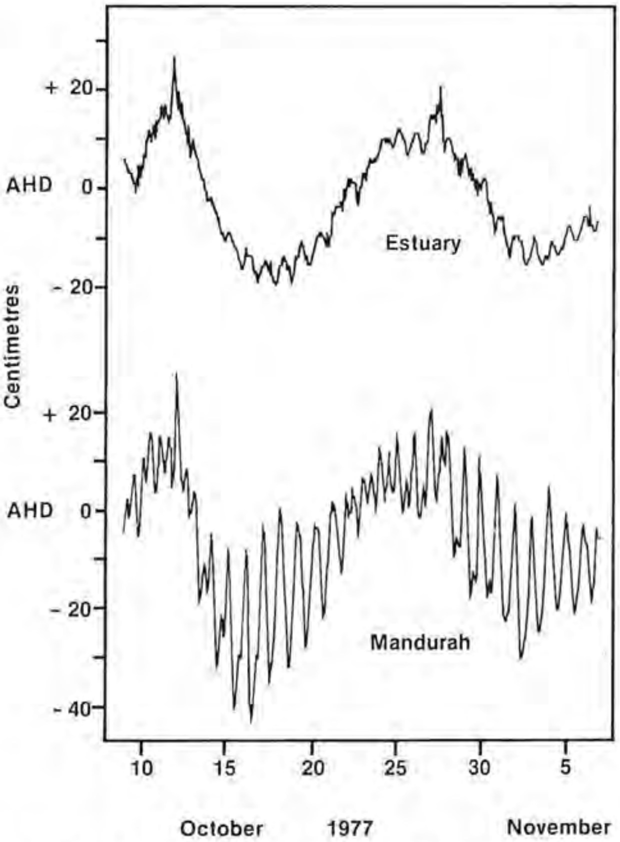


Figure 3.12 Tide records from Peel Inlet and Mandurah. (AHD – Australian Height Datum.)

Water level in the estuary responds to river flow, and floods cause a considerable rise in water level. A relatively small flood such as that which preceded the record in Fig 3.13 caused a rise of 0.5 m.

Construction of the Dawesville Channel will have no significant effect on changes in water level attributable to the long period meteorological and seasonal 'tides', though the response to meteorological tides may be accelerated, particularly to storm surge peaks. Flood water levels will recede more rapidly than at present, as shown in Fig. 3.1 where the predicted drop is 0.4 m in three days as compared with the recorded ten days (as modelled).

The greatest change will be to the astronomic tides which will increase in range to a maximum of about 0.35 m, as shown in Table 3.2 and Figures 3.13 and 3.14. The actual change in water level experienced in any one day will on occasions be greater than 0.35 m because of the combined effects of daily tides and long period changes, as can be seen from the Figures.

Table 3.2 Examples of present and predicted daily tidal ranges, in metres.

Ocean Range	Range at Dawesville	
	Without Dawesville Channel	With Dawesville Channel
0.85	0.11	0.35
0.70	0.08	0.30
0.30	0.06	0.15

Casuarina obesa on an eroded beach.

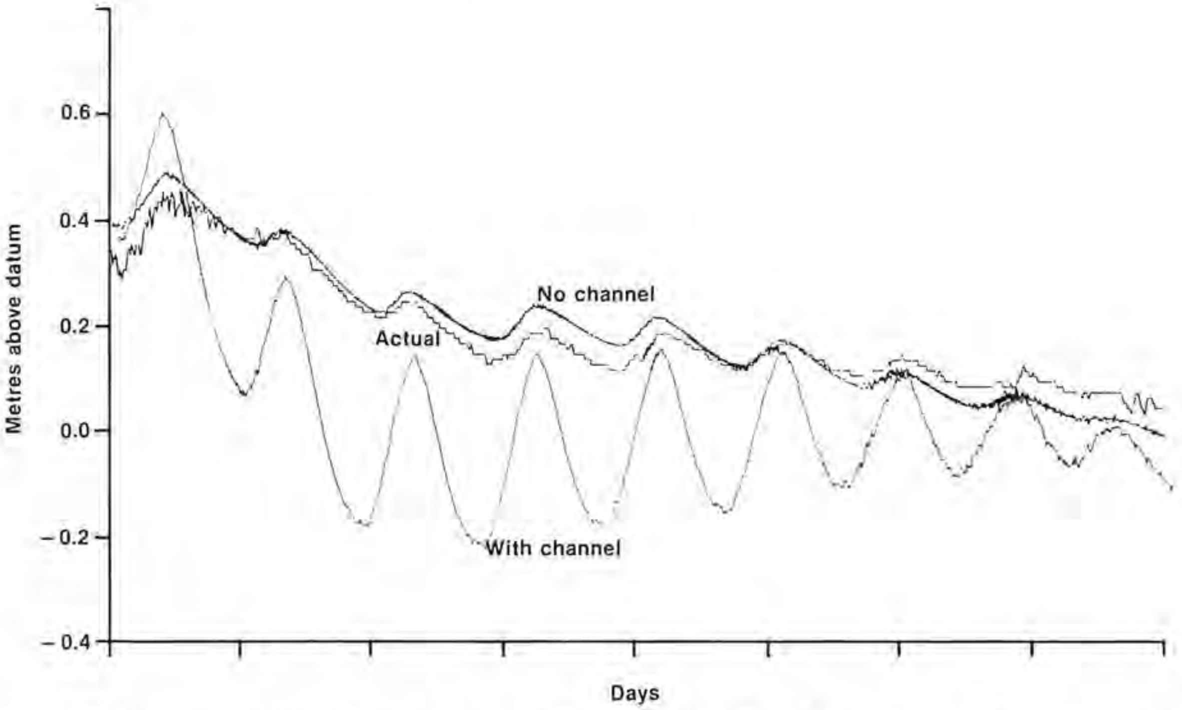


Figure 3.13 A winter tide record from the estuary (at Dawesville) with modelled tide record and anticipated tide with the Dawesville Channel.

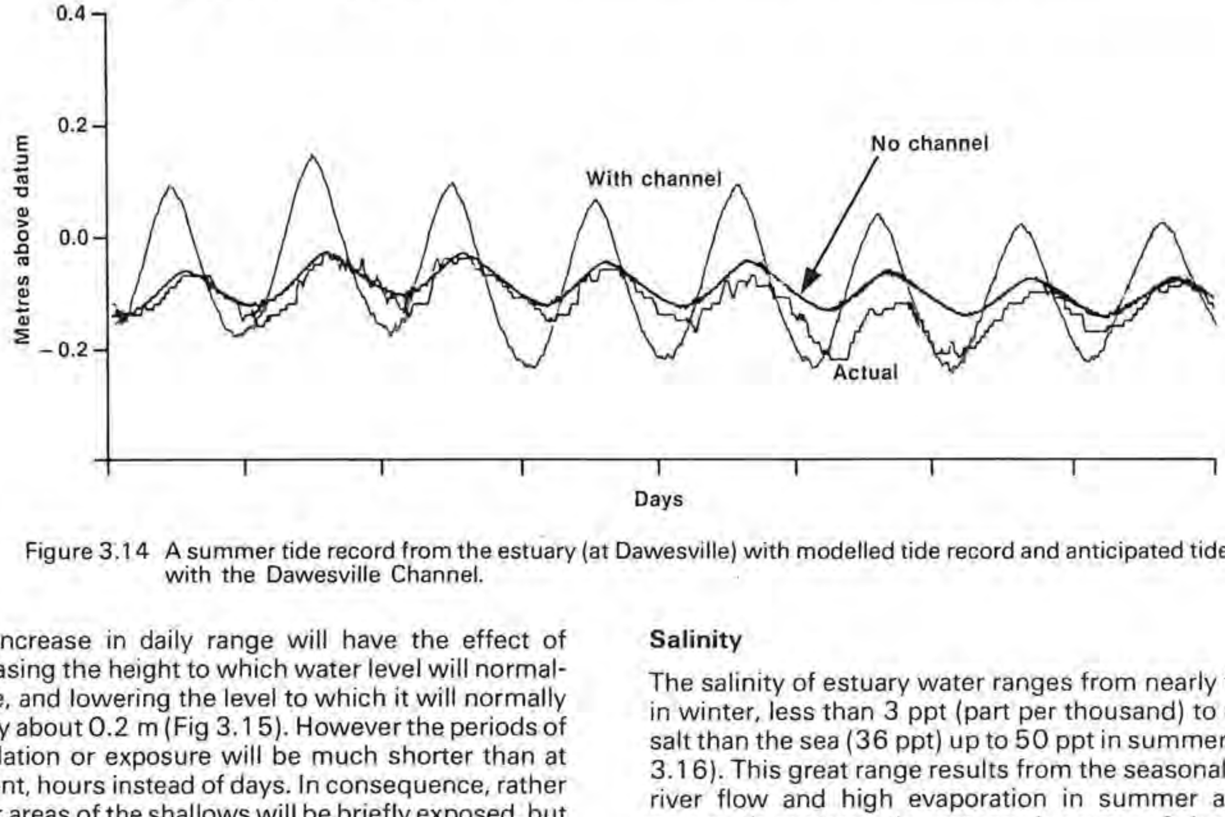


Figure 3.14 A summer tide record from the estuary (at Dawesville) with modelled tide record and anticipated tide with the Dawesville Channel.

The increase in daily range will have the effect of increasing the height to which water level will normally rise, and lowering the level to which it will normally fall, by about 0.2 m (Fig 3.15). However the periods of inundation or exposure will be much shorter than at present, hours instead of days. In consequence, rather larger areas of the shallows will be briefly exposed, but only in the flattest areas will the water retreat more than 100 m further than at present.

At the upper extreme there will be a small increase in the extent to which low-lying areas will be flooded by daily tides, especially on the eastern shore of Peel Inlet and the southern end of Harvey Estuary. Elsewhere the shores are generally too steep for there to be much more extensive flooding.

Salinity

The salinity of estuary water ranges from nearly fresh in winter, less than 3 ppt (part per thousand) to more salt than the sea (36 ppt) up to 50 ppt in summer (Fig. 3.16). This great range results from the seasonality of river flow and high evaporation in summer and it occurs throughout the estuary because of the poor water exchange between estuary and ocean. It is greatest at the southern end of Harvey Estuary. There are considerable differences between one year and another, depending on variation in rainfall and evaporation, and in some years salinity does not fall below 15 ppt or exceed 40 ppt.

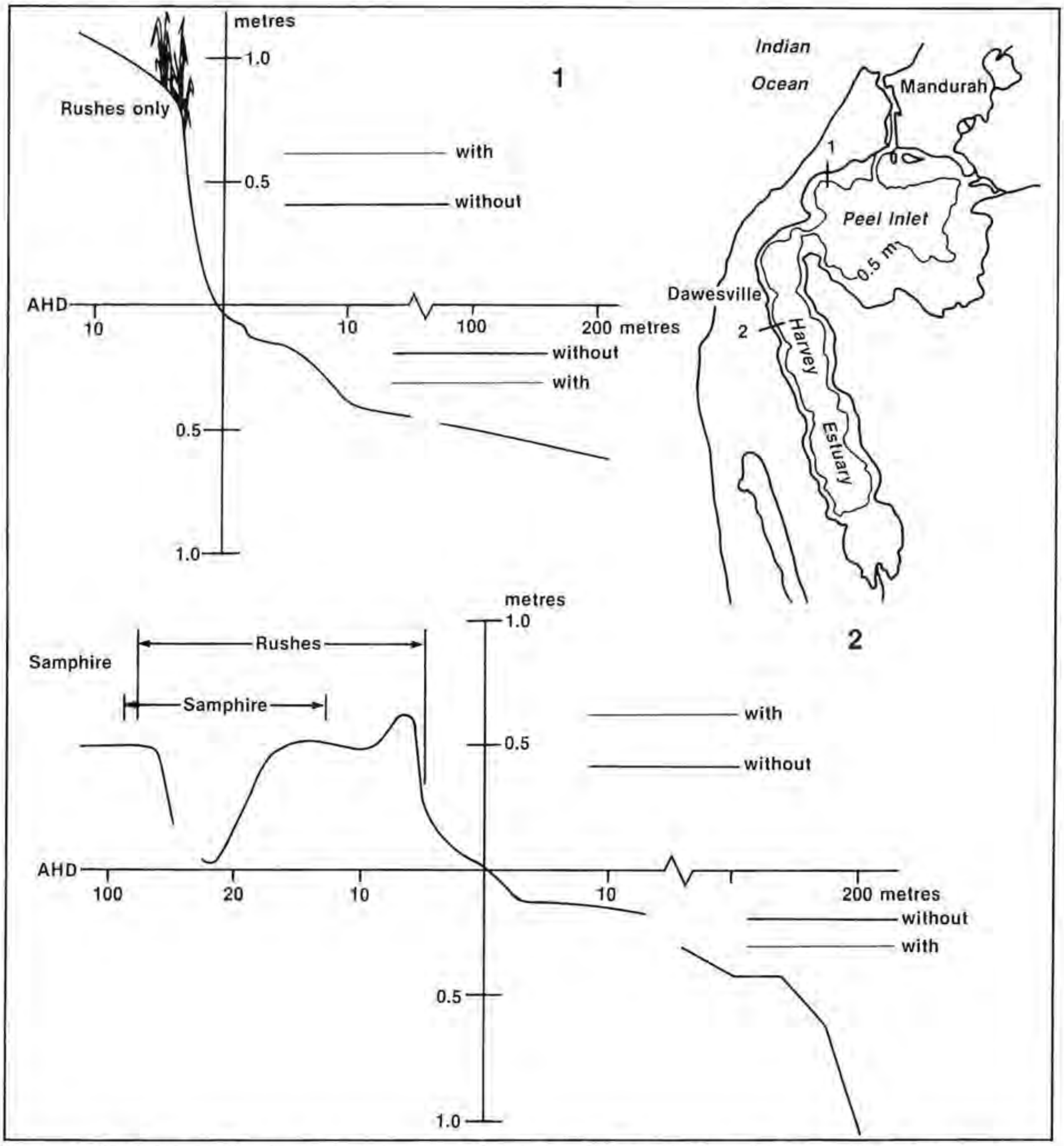


Figure 3.15 Shore profiles in the estuary and 10-day inundation extents, with and without the Dawesville Channel.

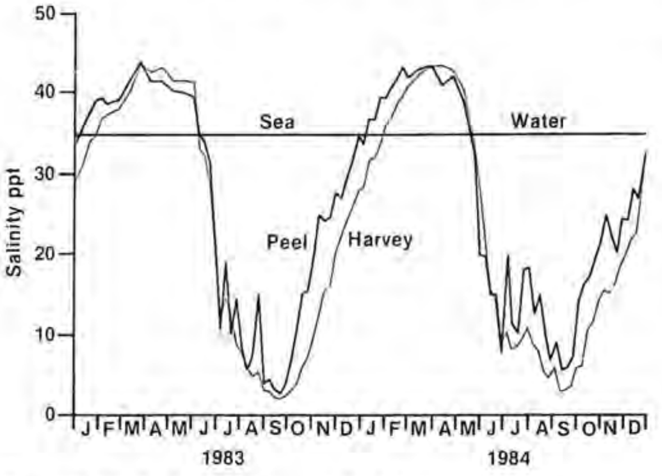


Figure 3.16 Surface salinity in Peel Inlet and Harvey Estuary in 1983 and 1984.

Estuary water is often stratified, despite the shallow depth, sometimes with a difference of 10 ppt or more between upper and lower water bodies (Fig. 3.17). Persistent strong winds mix the water to a uniform salinity, but with the return to calm weather the stratified condition is quickly re-established.

The models used are one-dimensional and are effective in modelling a well mixed body of water. However the problems associated with modelling the stratified condition, and the effect this has on phosphorus exchange between water and sediment, has not yet been modelled.

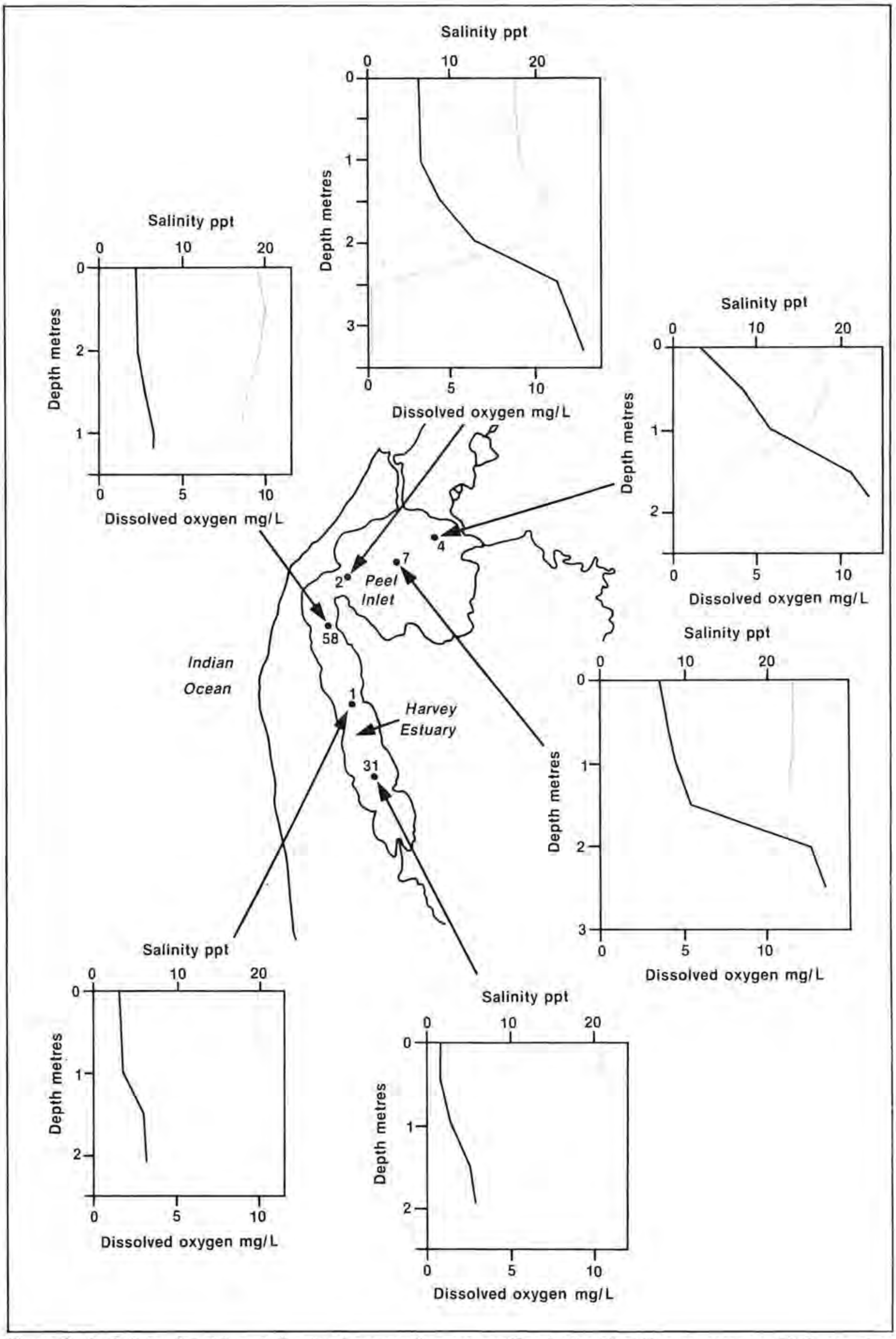


Figure 3.17 Salinity (black) and dissolved oxygen (green) profiles in the Peel-Harvey estuary, 12 September 1984.

Construction of the Dawesville Channel will have the effect of greatly narrowing the salinity range, thus making the estuary much more marine than it is now. Figures 3.18 and 3.19 represent the predicted salinities in the middle of Peel Inlet and Harvey Estuary, but it should be emphasised that the curves represent average conditions and that salinities will be lower in wet years and near the river mouths. The duration of low salinity periods will be much shorter than at present, with salinity rising to near marine salinity much earlier following the easing of river flow.

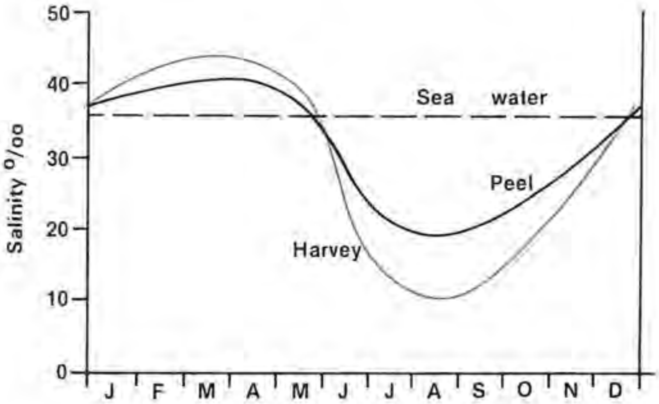


Figure 3.18 Average seasonal salinities in Peel Inlet and Harvey Estuary 1978-1984.

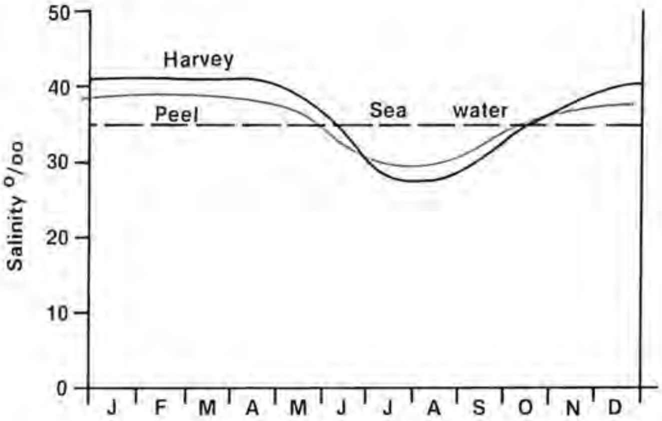


Figure 3.19 Predicted average salinity in Peel Inlet and Harvey Estuary with the Dawesville Channel.

Flushing

The effect the Dawesville Channel will have on flushing estuary water to the sea is discussed in the previous section (page 21), along with some of the difficulties which result from uncertainties about the extent of mixing between estuarine and marine waters, and need not be repeated here. The flushing effect on water in the tidal rivers has not been examined, but the greater flushing there is expected to be beneficial to their condition. It may be noted that flushing will be particularly effective in the Yunderup Canals, which are poorly flushed at present.

At this stage the lack of an appropriate model affects particularly the accuracy of predictions with respect to the rate at which phosphorus will be lost to the sea, not only the direct loss of phosphorus in river water, but also phosphorus released from the sediment store. Although the mechanism by which phosphorus is released from the sediment is understood, the rate of release depends on complex factors which are difficult to model accurately; these include the frequency and persistence of a stratified condition, the amount of decomposable organic matter available to microorganisms in the surface sediment, and the consequent depletion of oxygen in the bottom water which can become seriously deoxygenated (Fig. 3.17). Despite this deficiency it is not anticipated that it will be necessary to revise the predictions in this report in such a way as to invalidate the recommendation in Chapter 7 to construct the Dawesville Channel; rather detailed modelling will fine-tune the predictions covering time-scales, and rates of phosphorus depletion.

The present tendency for the water to be stratified during and immediately after river flows will be enhanced by the Dawesville Channel because the salinity of northern Harvey Estuary water will be close to that of the ocean rather than that of Peel Inlet and southern Harvey Estuary. The density-driven marine water along the length of Harvey Estuary will greatly enhance flushing.

Water clarity

At present water in the estuary is made turbid much of the time by phytoplankton, and in Harvey Estuary also by suspended fine sediment. With the Dawesville Channel, the lower nutrient levels will result in there being less phytoplankton, and increased exchange with the ocean will dilute the phytoplankton even further. The water will be clearer throughout the estuary. Harvey Estuary will still be more turbid than Peel Inlet because of the continued resuspension of fine sediment by wind-caused waves, but in the longer term it should become progressively less turbid as the fine suspended sediments are lost through ocean exchange.

Other effects

Construction of the Dawesville Channel is not expected to cause other significant changes to the physical environment of the estuary. The rate of water movement will increase, but this will only be appreciable in the vicinity of the channel and perhaps in the narrow Peel-Harvey channel.

The potential for development of a delta at the estuary end of the Dawesville Channel is recognized and the design of the channel aims to minimize this. There is likely to be some increase in transport of the fine flocculent material suspended by wave action out of the estuary. Movement of coarser, sand-size sediment in the shallows could increase, particularly on the eastern shore of Harvey Estuary, accelerating the present slow rate of longshore transport.

IS ENLARGING THE MANDURAH CHANNEL AN ALTERNATIVE?

The 5 km long Mandurah Channel is the only route by which estuary water is flushed to the sea and restriction to flow through it is principally from constrictions at the two ends of the channel: the ocean entrance and Fairbridge Bank at the seaward end and the tidal delta, with the Sticks Channel, at the southern end. The proposals outlined in Appendix 7 for enlarging the channel would remove these obstructions, allowing water to flow freely the 8 km from the deep water of Peel Inlet to the sea (Fig. 3.20).

Construction of such a channel is estimated to increase the flushing of Peel Inlet water to the sea by 15 to 25%, though by how much it will reduce the retention of phosphorus cannot be determined precisely for reasons discussed previously. It is likely to reduce both the size and duration of *Nodularia* blooms generated in Peel Inlet to some extent, but is not expected to significantly reduce weed growth and the improved clarity of the water may lead to a temporary increase in weed.

By itself, enlarging the channel will have little effect on flushing water from Harvey Estuary or on the retention of phosphorus there, and hence on the *Nodularia* blooms. Tidal flow carries *Nodularia* blooms from Harvey Estuary along the western side of Peel Inlet and out through the Mandurah Channel. The increased tidal flow would increase this movement to some extent.

As suggested in Appendix 3 (Paul & Hutton), enlargement of the channel would provide an opportunity to monitor the effects of relatively small dredging improvements on estuarine water quality during the detailed investigation and design phase for the Dawesville Channel.

It will be evident that enlargement of the Mandurah Channel is not an alternative to construction of the Dawesville Channel. It will contribute to reducing the eutrophic condition of Peel Inlet, but it will not achieve the management objectives, even in conjunction with the fertilizer reduction measures.

CONCLUSIONS

The management strategy proposed in Bulletin 165, and largely adopted in Bulletin 170, was based on the conclusion that to reduce the frequency of *Nodularia* blooms in Harvey Estuary to one year in five it would be necessary to reduce the phosphorus load to the estuary by 70%. That conclusion was itself based on the observation that in 1979, when there was no *Nodularia* bloom, the phosphorus load was about 30% of the estimated average load to the estuary. Subsequently, in 1984, there was one of the largest blooms even though the phosphorus load was only slightly greater than in 1979 (Fig. 1.2).

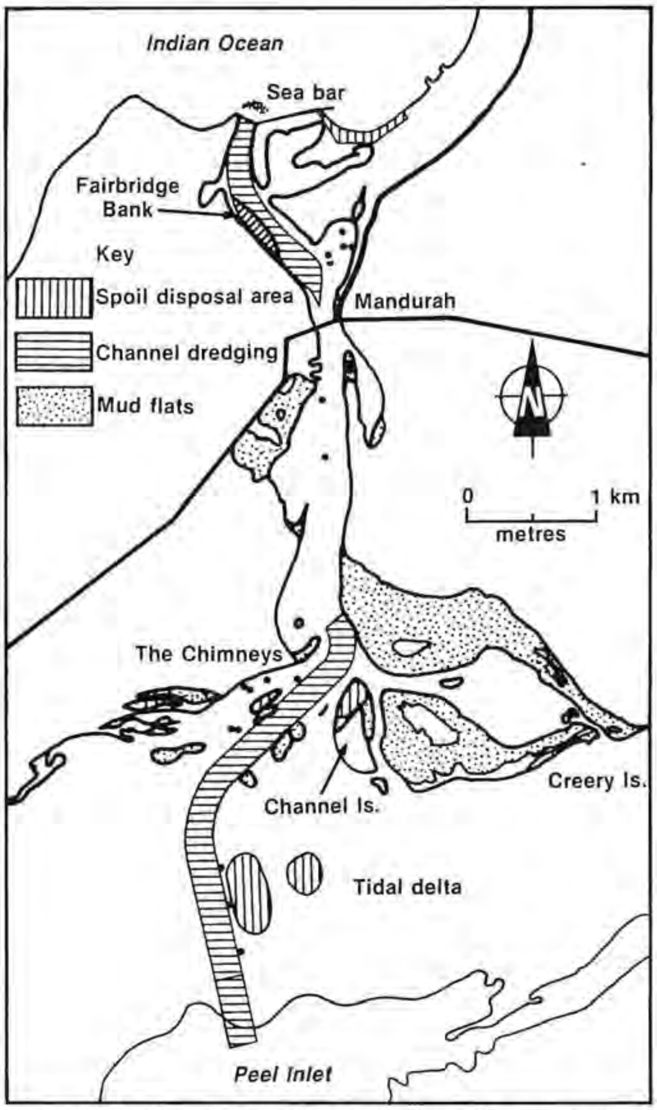


Figure 3.20 The Mandurah Channel, with proposed dredging.

The external load of phosphorus is supplemented from the internal store in the surface sediment, a store which now has the potential to support a bloom such as that experienced in 1984. It must be concluded that the 70% reduction is now the minimum required and that in the short-term at least even this will not be sufficient.

Neither Bulletin attempted to estimate the reduction in phosphorus required to prevent the excessive growth of weed algae; there is no historical or other basis on which to make a reliable estimate. The size of the weed crop is not now limited by the available phosphorus, of which there is an abundance from the sediment store, but by the amount of light reaching the algae. Light penetration to the algae is now restricted by *Nodularia* and other planktonic algae in the water. Again it must be concluded that the 70% reduction in phosphorus load to the estuary is the minimum requirement.

A method by which it may be possible to deplete the supply of available phosphorus from the sediment store rapidly is discussed in Chapter 5. This is a short term measure only and could not be repeated annually.

Implementation of the fertilizer reduction measure has already reduced the amount of phosphorus lost to drainage from the coastal plain catchment and its continuation is expected to reduce it to 30 to 40% of the pre-1984 level over the next three to five years. In the longer term (ten to fifteen years) a reduction of 60% may be achieved. However, it must be concluded that implementation of this measure alone has not the potential to reduce either *Nodularia* blooms or weed growth to an acceptable level.

Other catchment management measures which may contribute to a further reduction in input of phosphorus in the long-term are discussed in Chapter 6.

Construction of the Dawesville Channel will greatly increase flushing of water and phosphorus from the estuary, but it is not possible to put a figure on the reduction there will be in phosphorus available to algal growth. It is estimated that **by itself** this measure has not the potential to reduce the retention of phosphorus sufficiently to achieve the management objective of preventing weed from fouling beaches. Nevertheless the higher salinities that will be experienced are expected to make *Nodularia* blooms infrequent events.

There can be no doubt that the fertilizer reduction measures and the Dawesville Channel will together reduce the retained phosphorus sufficiently to achieve the management objectives. The *Nodularia* blooms will 'not occur more frequently than one in five years on average' (they will probably be rare events) and weed growth will decline to the point at which it does not 'foul beaches near populated areas'. However, the weed nuisance will continue until the sediment store of available phosphorus is sufficiently depleted, though it cannot yet be predicted how long this will be.

Weed clearing measures will be required for some years to come, and may indeed have to be increased for a time, because the greater clarity of the water both in Peel Inlet and in the northern part of Harvey Estuary may enhance growth.

The proposed management measures, especially construction of the Dawesville Channel, will profoundly alter the estuarine environment in ways which it is difficult or impossible to predict precisely on the basis of experience elsewhere. It is therefore of paramount importance that the present monitoring programme should be maintained and if necessary expanded, before, during and after implementation of the management measures. The experience gained will be of immense value, not only in ensuring a successful outcome for the Peel-Harvey estuary, but also to those responsible for estuarine management elsewhere. The Peel-Harvey story is of world significance and it must be fully studied and documented.

Ocean beach at the site of the proposed Dawesville Channel.

CHAPTER 4

ANTICIPATED RESPONSE OF THE PLANT AND ANIMAL LIFE OF THE ESTUARY

INTRODUCTION

This chapter summarizes conclusions reached with respect to the effect implementation of the preferred strategy will have on the flora and fauna of the estuary, and more especially the effect of construction of the Dawesville Channel.

Construction of the Dawesville Channel will result in a considerably different environment for estuarine organisms, particularly in Harvey Estuary. The more marine salinities that will be experienced, with no prolonged exposure to low salinities; the greater tidal range and daily pattern of exposure and inundation along the shores; the great reduction in nutrients; greater clarity of the water; and the improved access to the estuary for marine organisms — all have the potential to affect the plant and animal life of the estuary.

It is impossible to predict precisely how these changes will affect the estuarine flora and fauna, but it is possible to predict changes on a general descriptive level with a reasonable degree of confidence. Predictions made in this chapter are based on information gained from research in the Peel-Harvey estuarine system and in a number of other estuaries of south-western Australia. They are presented in greater detail in Appendix 2.

THE NUISANCE ALGAE

The two very different kinds of algae that grow at nuisance levels in the Peel-Harvey estuarine system, large green algae (macroalgae or weed) and the microscopic blue-green alga *Nodularia,* are influenced to different degrees by different environmental factors, and their responses to the Dawesville Channel are best discussed separately.

Nodularia

Growth of this blue-green alga is favoured at salinities from about 3 to 30 ppt. It does not grow well at salinities outside this range. It requires the element phosphorus in the form of an available nutrient compound, but is not dependent on a combined form of nitrogen since it can use nitrogen gas dissolved in the water. *Nodularia* grows well at relatively low light levels, and at water temperatures between 16° and 30°C, conditions which prevail in Harvey Estuary during spring and early summer (Fig. 4.1). In Peel Inlet conditions are less favourable since salinities return to marine levels more rapidly, light levels are higher, and concentrations of nitrogen compounds in the water are high enough to lessen any competitive advantage *Nodularia* may have over other phytoplankton which cannot use nitrogen derived from the atmosphere.

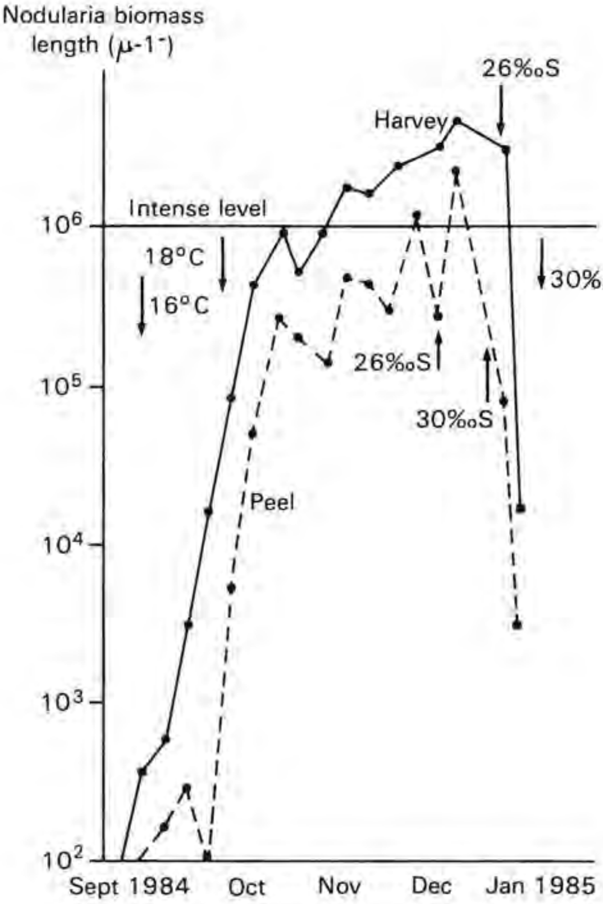


Figure 4.1 Mean *Nodularia* biomass (length. um .ml^{-1}) in Peel Inlet and Harvey Estuary between September 1984 and January 1985. Surface to bottom integrated samples.

Construction of the Dawesville Channel will make the salinity regime unfavourable for *Nodularia* growth; the available phosphorus will be greatly reduced, the water will be clearer, and light levels will be less favourable. Thus, if *Nodularia* blooms do occur, they will be of lesser magnitude and considerably shorter duration.

Macroalgae

The so-called "nuisance" macroalgae are a nuisance in human terms only: as far as estuarine ecology is concerned, they provide cover from predators for many estuarine animals and, indirectly, a rich food resource for crabs, prawns and commercially important fish.

The nuisance macroalgae tolerate the broad range of salinities experienced in the estuary, and the change in salinity regime with the Dawesville Channel is unlikely to do anything beyond allowing a few marine species (which cannot tolerate periods of low salinity) to establish. Critical factors affecting the growth of macroalgae will be the changes in nutrient levels and turbidity of the water.

Before the 1960s, nutrient levels in Peel-Harvey waters were too low to support nuisance levels of macroalgae, but they are now more than sufficient, and growth appears to be controlled more by light than by nutrient supply. *Nodularia* and other phytoplankton blooms have made the water so turbid during spring and summer (the main growing period for macroalgae) that macroalgae receive insufficient light for maximum growth. The generally more turbid water of Harvey Estuary is the main reason why macroalgae are not a nuisance there, except north of Dawesville.

Following construction of the Dawesville Channel the water will be clearer and macroalgae can be expected to be more abundant, perhaps reaching levels experienced in the late 1970s. Predictions are complicated by the possible role of the considerable store of nutrients that has built up in estuarine sediments. Benthic macroalgae are sustained by nutrients released from underlying sediments, and it is difficult to predict precisely how long sediment nutrient reserves will take to deplete. In the short term at least, sediment nutrient supplies could mean that despite low water column nutrient levels, large macroalgal blooms will occur in the improved light climate. In the longer term macroalgal levels should drop as sediment nutrient reserves are depleted.

Although the channel will reduce nutrient levels, this will probably mainly affect macroalgae in Harvey Estuary and western Peel Inlet. In the northern and eastern areas of Peel Inlet, the nutrient supply for macroalgae may be less affected (though the full extent of nutrient loss from Peel Inlet following construction of the channel remains to be modelled more closely). Any substantial reduction in macroalgae in this area will depend upon a reduction in nutrients coming from the Serpentine and Murray catchments, and improved oceanic flushing.

OTHER PLANT LIFE

Other types of totally aquatic plants that will be affected by the Dawesville Channel are phytoplankton (microscopic plants that are suspended in the water), benthic diatoms (microscopic plants that live on and amongst sediments), and seagrasses (plants with roots, rhizomes, leaves and flowers).

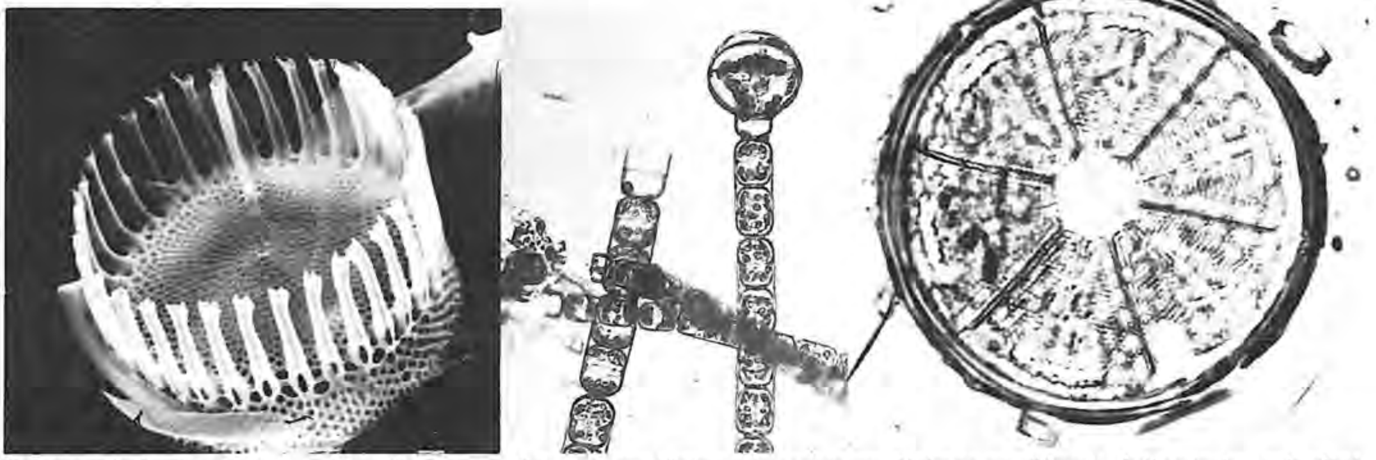
Phytoplankton

The size of phytoplankton blooms is largely determined by supplies of the essential nutrients nitrogen and phosphorus, which will be reduced following construction of the Dawesville Channel through increased oceanic exchange. The principal phytoplankton, other than *Nodularia*, are diatoms and dinoflagellates, and the more marine salinities will probably be accompanied by some change in species composition of these.

The combination of the Dawesville Channel and the fertilizer modification campaign will lead to a considerable decrease in water column nutrient levels, particularly phosphorus, and this in turn will lead to a considerable reduction in the abundance of phytoplankton. Increased exchange with the ocean will also dilute any blooms that do occur. The reduction in phytoplankton blooms should also indirectly aid in reducing the nuisance algae problem. Nutrients entering the estuarine system in river runoff are presently trapped by winter blooms, and when they are grazed or die they become part of the sediment, adding to the sediment nutrient bank which fuels both *Nodularia* and macroalgae growth.

Benthic diatoms

Critical factors affecting benthic diatom communities in estuaries are light, temperature and, for intertidal species, frequency of inundation. Because benthic diatoms have direct access to nutrients released from the sediments in or on which they live they are little affected by nutrient levels in the water, and salinity changes only affect the species composition of the communities.



Common planktonic, epiphytic and benthic diatoms of the estuary: *Skeletonema costatum, Melosira moniliformis, Actinoptychus splendens.* Photo: J. John.

The improved light conditions with the Dawesville Channel will enable benthic diatoms to become more productive in deeper waters, and they will also benefit from the larger intertidal area that will be regularly inundated.

Seagrasses

Important factors affecting seagrass growth are light supply, salinity and nutrient levels in the water. The three seagrasses which grow in the Peel-Harvey estuarine system, *Zostera mucronata, Halophila ovalis* and *Ruppia megacarpa,* are all essentially subtidal plants and are therefore restricted to waters that are sufficiently shallow for an adequate light supply to reach them. *Halophila* tolerates lower light levels than *Ruppia,* and is therefore found in slightly deeper water in Peel Inlet. The turbidity of Harvey Estuary water has prevented the persistence of extensive meadows of seagrasses. The salinity tolerances of these seagrasses also vary: *Zostera* only grows near the Mandurah channel where the water is most saline, *Halophila* tolerates lower salinities, and *Ruppia* grows over a broad range of salinities from freshwater to hypersaline.

Finally, although seagrasses take in nutrients through their roots and are independent of water column nutrients, high nutrient levels in the water promote the growth of phytoplankton and epiphytes (diatoms and algae attached to the leaves) which shade the seagrass leaves and inhibit growth.

The Dawesville Channel will result in several changes favourable to seagrasses. Improved light conditions will allow seagrasses to extend to deeper waters in Peel Inlet. In Harvey Estuary, the improved light conditions will allow *Ruppia* to re-establish, the more marine salinity regime will be favourable to the establishment of *Halophila,* and *Zostera* will probably establish near the channel. The clearer water and lower epiphyte loads will be beneficial. There may be some loss of *Ruppia* beds from the shallows of Peel Inlet due to increased exposure of the shallows. The temporary increase in macroalgae may also result in accumulations smothering seagrass beds in shallow water.

Ruppia megacarpa.

WETLAND VEGETATION

Wetland or fringing vegetation occupies the upper tidal zone from about mean water level (MWL) to just above extreme high water mark (EHWM). It plays an important role in estuarine ecology since it stabilizes the shoreline and provides a sheltered habitat for estuarine birdlife. The Peel-Harvey system has only three extensive areas of fringing vegetation: near the southern end of the Mandurah channel, the eastern shore of Peel Inlet, and southern Harvey Estuary. Elsewhere there is only a narrow fringe of wetland vegetation and the lack of large fringing wetlands makes what little is left even more important.

Within the fringing vegetation there is a zonation of species with increasing distance from the water's edge and increasing elevation. This zonation is largely determined by the salinity of the soil and the degree of waterlogging. The species which dominate the fringing vegetation of the Peel-Harvey system have to cope with inundation by hypersaline water in summer and by almost fresh water in winter. The tidal characteristics are also such that the plant may be waterlogged for days on end, then subsequently exposed for the same length of time. Because these plants can tolerate such extreme conditions, they are very resilient and very stable.

In most respects, the Dawesville Channel will lead to an improved environment for the fringing vegetation, the status of which can be expected to improve. The more regular pattern of inundation and exposure will be more favourable than the present pattern of long periods of inundation and waterlogging stress, followed by long periods of exposure and desiccation stress. Soil salinities should also decrease due to the more frequent inundation and exposure, which is likely to allow less salt-tolerant species to extend into areas where they previously could not survive. The only unfavourable aspect is the possibility of macroalgal accumulations being washed up on the shore and smothering the fringing vegetation, as happened in eastern Peel Inlet during the 1970s. If necessary, susceptible areas could be protected from this by fencing, and thought should be given to re-establishing fringing vegetation in previously denuded areas.

Halophila ovalis.

THE INVERTEBRATE FAUNA

Invertebrate fauna can be broadly separated into zooplankton and benthic invertebrates. Zooplankton are microscopic animals that live suspended in the water column, where they feed principally on phytoplankton and/or other zooplankton, and are in turn fed upon by small fish. Benthic invertebrates are small animals which live on or in the estuarine sediments and weed beds (macroalgae or seagrass), and feed primarily on detritus and/or each other.

Benthic invertebrates include worms, shrimps, tiny crustaceans and molluscs, and are themselves the principal food of many fish and birds. In most estuaries, including the Peel-Harvey system, benthic invertebrates constitute by far the greatest proportion of invertebrate fauna. They also constitute a major link between estuarine plant productivity and larger consumers such as fish and birds because they process the large amount of organic detritus generated by estuarine plants.

Zooplankton

Zooplankton levels usually depend on phytoplankton levels and on the residence time of water in an estuary. In the Peel-Harvey estuary phytoplankton levels are greatly in excess of the requirements of zooplankton populations, and the expected decrease with the Dawesville Channel should in itself not affect zooplankton levels greatly. Residence time of the water is now long, but the increased flushing should have little effect on zooplankton abundance. *Nodularia* is not grazed by zooplankton, it appears to be unpalatable and its expected disappearance with the Dawesville Channel and probable replacement by diatoms (which are grazed) will favour zooplankton.

Benthic invertebrates

Major factors which affect the composition, distribution and abundance of benthic invertebrates in Peel-Harvey and similar estuaries are salinity regime, substrate type, tidal regime, deoxygenation, plant productivity, and type of estuarine plants. The Dawesville Channel will affect all of these except substrate type.

The benthic invertebrate fauna of the estuary is dominated by a few estuarine species, species which are confined to estuaries. The more marine conditions which will follow construction of the Dawesville Channel will allow a greater number of marine species to invade the estuary, adding to the diversity of species living there. The regime will also result in less fluctuation in abundance, since most benthic invertebrates grow best at oceanic salinities.

The greatest abundance and diversity of benthic invertebrates are reached on shallow subtidal sandflats. Abundance is also quite high in the lower intertidal zone (mean water level to extreme low water mark), although there are fewer species. The deep, muddy basins of the Peel-Harvey estuarine system are low in both numbers and diversity of some species.

Deoxygenation of the deeper water of Harvey Estuary during *Nodularia* blooms has caused massive mortality of benthic invertebrates. With construction of the Dawesville Channel such events should be rare, and the influx of well-oxygenated marine waters should be beneficial to the fauna of the deep muddy basins.

Plant productivity in the Peel-Harvey system greatly exceeds the requirements of the benthic invertebrate community. Thus even if plant productivity drops dramatically with the Dawesville Channel — which is unlikely — abundance of benthic invertebrates should remain high.

The type and abundance of plants can affect the composition and density of benthic invertebrates. With the Dawesville Channel, the relative importance of phytoplankton will probably decrease, and primary production will become more dominated by seagrass and macroalgae. This is unlikely to affect actual numbers of benthic invertebrates, but will cause a shift in species composition towards those organisms which prefer macroalgae and seagrass beds as habitats.

FISH LIFE

There is little doubt that there has been an increase in the abundance of fish in the estuary as a consequence of the weed-growth, but there is no evidence that the few species of weed-eating fish are much more plentiful. The increase is attributable mainly to the protection from predation afforded by the massive weed growth and also to the great quantity of associated detrital material and benthic invertebrate fauna. On the other hand there has been considerable fish mortality associated with the *Nodularia* blooms, mainly of small fish, probably due to lack of oxygen associated with the blooms. Larger fish appear better able to avoid areas of blooms.

It must be assumed that management of the eutrophic condition of the estuary and reduction in weed growth, a principal objective, has the long-term potential to reduce populations of fish such as mullet, which have benefited from the increased cover and abundant food supply afforded by the weed. But the expected increase in *Ruppia* and perhaps *Zostera* should provide some degree of shelter for juvenile fish. There can be no doubt that the reduction in *Nodularia* blooms will be beneficial to fish by making the present bloom-affected areas more accessible to them at what is probably the most productive time of the year.

Opening the Dawesville Channel, thus giving a second point of access to juveniles of species which spawn in the sea (the majority of estuarine fish species), making salinities more marine, and increasing the daily tidal range, will have an effect on fish populations, especially in Harvey Estuary.

To what extent the second channel will directly affect recruitment to estuarine populations is impossible to predict, but it will probably be beneficial and cannot be harmful. It must be advantageous to those species such as mulloway and tailor which prefer the more marine part of the estuary during the summer months.

The more marine conditions may increase the number of species using the estuary. About 60 species have been caught in the system, only half the number (120) recorded from the nearby estuary of the Swan River. However it is to be expected that greater numbers of many common species such as yellow-eye mullet, cobbler and tailor will use the estuary during most if not all the year. This also applies to the blue manna crab.

The few species of fish, such as black bream, yellow tail trumpeter and several species of hardyheads and gobies, which only live in true estuarine systems, are unlikely to be greatly affected because of their tolerance to a wide range of salinities. There will certainly be a readjustment in the relative abundance of the many different species using the estuary, with an expected increase in the more marine species and perhaps a decrease in some of the estuarine species.

It is unlikely that the change in tidal range and pattern will make any significant change in fish usage of the estuary, though it must affect the feeding pattern of the many species which feed in the intertidal areas.

The management measures may well benefit amateur line fishermen because of the greater availability of the more marine species such as whiting, mulloway and possibly Australian herring and trevally. The popular blue manna crab fishery will probably also benefit, but it is not clear what effect the measures will have on populations of king and school prawns. The effect they will have on the professional fishery, one of the largest commercial estuarine fisheries in Australia, is discussed in Chapter 6.

WATERBIRDS

Predictions on the effect of the Dawesville Channel upon the many species of waterbirds are highly speculative, in part because waterbirds will be affected by the changes to most of the categories of estuarine flora and fauna discussed so far, and in part because there are so many gaps in existing knowledge about waterbirds of the Peel-Harvey system, their diets and the way in which they utilize the system (feeding and roosting patterns, what water levels are preferred, etc.). The system is the single most important waterbird site in the south-west, especially for the many migratory species of waders, and any potential deleterious effects should be viewed seriously.

Migratory waders feed mainly on intertidal areas at low tide, but may also be found in shallow waters on inland, non-tidal wetlands. The change to larger daily tides may to some extent disrupt present feeding patterns, especially during pre-migratory fat deposition in late summer/early autumn. It may also detrimentally affect resident wader species by limiting or interrupting feeding opportunities, or affecting accessibility to preferred prey species (benthic invertebrates).

The greater tidal range will also decrease the available area of favoured roosting sites (sandy cays and spits) for wading and fish-eating birds such as pelicans, cormorants and terns. Waterfowl (ducks and swans) rest on the water and will be little affected in this way. If the higher tides permit easier boat access to previously undisturbed areas some thought should be given to providing additional roosting sites (possibly using dredge spoil) preferably in areas of difficult access.

SUMMARY — THE WELL-BEING OF THE ESTUARY

There is little doubt that the proposed management measures, catchment management and the Dawesville Channel, will achieve effective control of *Nodularia* blooms. These blooms should cease almost immediately following opening of the Dawesville Channel. However there can be no guarantee that macroalgae accumulations will lessen in the short term, since the water will be clearer and it will probably take some years to exhaust the large supply of phosphorus in the surface sediment.

Wave sorted shells of estuarine molluscs, from above: *Spisula trigonella, Xenostrobus securis, Arthritica helmsii.*

The remaining estuarine plants, including benthic diatoms, seagrasses and fringing vegetation, are all likely to benefit from the Dawesville Channel. Benthic diatoms and in particular seagrasses are expected to extend their distribution within the system, and the status of fringing vegetation is expected to improve. Zooplankton levels are expected to change little, nor should benthic invertebrates be detrimentally affected to any degree.

The effects on fish and birds are less easy to predict. Beneficial aspects of the Dawesville Channel for fish and crustaceans include an additional entry point to the system for juveniles and adults of many commercially and recreationally important species, the reduction of *Nodularia* blooms, the extended period of favourable salinities, and the expected short-term increase in macroalgae levels. On the other hand, the more marine salinities may be disadvantageous to sea mullet and king prawns.

The major group of waterbirds which could be detrimentally affected by the Dawesville Channel are the resident waders because the larger daily tidal variations may reduce their feeding opportunities. Other groups of birds should be less affected since the extensive areas of tidal flats will if anything increase, although feeding patterns will have to adjust to daily tidal fluctuations. Major dietary items should also remain abundant. Detrimental changes could be a decrease in area of suitable roosting sites (sandy cays and spits) during high tides and increased access by boats to presently undisturbed areas. Management consideration should be given to these potential problems.

CONCLUSION

In an overall sense, the Dawesville Channel will have more beneficial than detrimental effects on estuarine ecology. The major 'detrimental' effects, including the expected short-term increase in macroalgal levels, and possible decline in numbers of some commercially important fish and crustaceans, are more detrimental in human terms than in terms of the well-being of the estuary. Two other local estuarine systems have undergone modifications similar to the Dawesville Channel. Leschenault Inlet had a channel cut through to the sea in 1951, and the Swan River estuary had rock and sand bars at the mouth removed in the 1890s. There is little doubt that both systems have changed, but they are still viable, productive ecosystems.

Two final points should be made. Firstly, statements made here are in the light of physical and chemical changes predicted so far by computer modelling. As more information becomes available, the effects on estuarine flora and fauna can be better evaluated. Secondly, discussion has been confined to conditions produced by the Dawesville Channel itself, and does not include immediate effects such as those associated with construction and dredging of the channel.

CHAPTER 5

SUPPLEMENTARY MANAGEMENT MEASURES

INTRODUCTION

The recommended strategy set out in Chapter 3 offers the optimum solution for the long-term control of the algal growth problems within a reasonable time (3-5 years). However, there are several other management measures which have been evaluated which could augment this strategy. These include:

- application of algicides
- use of nitrate to control release of phosphorus from sediments
- soil amendment with bauxite residue
- control of rural point sources of phosphorus
- changes in land use in the catchment
- controls on clearing and drainage

APPLICATION OF ALGICIDES

A possible way of attacking the algae is by using chemicals called algicides which, like herbicides, poison the plants and interfere with their growth. The use of some common algicides such as copper sulphate and other copper compounds cannot be recommended because of their probable toxic effects on fish. However, new organic compounds offer a better prospect for control, particularly of *Nodularia* and other blue-green algae.

Nevertheless, before such a measure can be recommended, answers are needed to the following questions:

- How effective will algicides be in a well-mixed estuary like the Peel-Harvey system?
- Will there be any undesirable side effects?
- How often will it be necessary to apply the algicide?
- What will it cost?

The one chemical known to be available which appeared promising was Terbutryn and it has been further evaluated. Laboratory experiments demonstrated that 0.1-0.2 ppm of active ingredient in sediment applied up to three times per bloom period was sufficient to prevent *Nodularia* germination. The cost for this treatment was estimated at $250,000 per year. Toxicity tests on shrimp indicated an LD_{50} (dose for 50% mortality) of 5.7 ppm or 25-50 times that required to prevent *Nodularia* germination.

If a multiplier of 100 is selected as the desired safety factor between the LD_{50} for a non-target organism and the dose required to control the target organisms, as is suggested as appropriate by some authorities, then some doubt exists about the safety of using Terbutryn. These doubts are mainly concerned with the long-term sub-lethal effects on crustaceans and other non-target organisms, especially juveniles.

The further investigations required to adequately assess side effects of Terbutryn would probably take one or two years. If these tests were undertaken and gave satisfactory results Terbutryn could only be used to prevent one or two *Nodularia* blooms before the Dawesville Channel could be built. Therefore since long-term use of algicides is not favoured for the control of *Nodularia* there is little incentive for further work to be conducted, except for completing the ongoing work on toxicity testing of shrimps. Only if this further work is more encouraging than that already completed would there be any case for undertaking full-scale field trials.

A report on the investigations is given by Dolin & Spickett in Appendix 3.

USE OF NITRATE TO CONTROL RELEASE OF PHOSPHORUS FROM THE SEDIMENTS

As pointed out in Chapter 3, construction of the Dawesville Channel will cause an increase in clarity of water in the estuary. This in turn could lead to an increase in growth of benthic macroalgae because of greater light penetration, with nutrition provided by the enriched bottom sediments. Eventually the nutrient store in the sediments will be depleted because of improved marine flushing, but at what rate is not certain.

To prevent the continued abundance of macroalgae and this presumably temporary increase in algal growth, it has been proposed to investigate the use of nitrate to inhibit release of phosphorus from the sediments. Nitrate can inhibit phosphorus release because it promotes oxidation of the surface sediments. Phosphorus can be released from sediments when organic material settles to the bottom (e.g. from diatom blooms) and decomposes via bacterial mediation. During the process of decomposition bacteria use oxygen from the water and if there is a large amount of decomposable material, coupled with stagnant overlying water, there is a depletion of oxygen leading to anoxic conditions in the surface sediments. Under these chemical conditions sediment-bound phosphorus becomes more soluble and is released into overlying water. Since nitrate contains a large proportion by weight of chemically bound oxygen, the bacteria in the sediments are able to use this as an alternative source to dissolved oxygen in water. This in turn offsets establishment of anoxic conditions and subsequent phosphorus release.

If this measure is found to be practicable it has the potential to exhaust the supply of available phosphorus. However, before the use of nitrate can be finally recommended further work is required to determine rates of application required and the economics and logistics of effective application in the estuary. Preliminary work has been done and further work is planned in 1985-86. It is not suggested that nitrate could be used on a continuing basis for the prevention of algal growth.

AMENDMENT OF LEACHING SOILS WITH BAUXITE RESIDUE

This measure aims to reduce the quantity of phosphorus leached to drainage from sandy soils by incorporating the residue from bauxite mining into these soils in order to improve their capacity to retain phosphorus and water. In conjunction with the Department of Agriculture and the Department of Conservation and Environment, ALCOA of Australia has studied the use of suitably treated bauxite residue for this purpose. This would also provide a means of disposing of a major waste product of the alumina industry.

ALCOA currently disposes of about 8 million tonnes of residue each year, consisting largely of Darling Range soil which has been crushed and treated with caustic soda. It has been found that the finer part of this material, the part known as 'red mud', can be filtered and treated with gypsum to produce a loam suitable for spreading on and mixing into sandy soils. This loamy residue has a high capacity to adsorb phosphorus, so less fertilizer would be lost to the estuary from sandy soils treated with the residue.

Research to date indicates that about 200 tonnes per hectare spread on sandy soils would eliminate most of the present phosphorus runoff into drains. The residue also improves the water-holding capacity and pasture production on the dry sandy ridges (10% of the catchment). However there have been pasture establishment problems on the sandy flats where the soil becomes saturated in winter.

In terms of management, the major problems are:

- timing
- logistics of spreading
- potential cost to Government

Sufficient quantities will not be available till 1987 and it would take approximately ten to fifteen years to cover the sandy soils in the catchment. As far as costs are concerned, ALCOA are prepared to pay the equivalent of their present disposal costs ($0.91 per tonne) leaving a residual cost of $3.54 per tonne to be the responsibility of Government or the farmers.

With approximately 6.2 million tonnes being required to treat the 31,000 ha of sandy soils in the Harvey Estuary catchment the total potential cost could be $22 million spread over 10-15 years. This presupposes that the majority of farmers would agree to having bauxite residue spread on their properties.

The most likely application of this option is therefore as a possible adjunct to the fertilizer program in the long term. This is mainly because of the length of time required and the logistics of spreading on farms rather than its cost since treatment of the Harvey Estuary catchment at $22 million is comparable to the cost of the Dawesville Channel.

Glenister (Appendix 3) reports on field trials with bauxite residue and discusses the potential of this measure.

CONTROL OF RURAL POINT SOURCES

Rural point sources of phosphorus include sewage effluent from townships, eutrophic swamps and intensive agricultural activities such as piggeries, holding yards and feed lots. Evidence to date suggests that these sources at present contribute only a minor component of the phosphorus input to the estuary.

Freshwater sedge ***Lepidosperma longitudinale.***
Photo J. Chambers.

However there is potential for considerable increase in phosphorus inputs especially via the Serpentine River if an increased proportion of waste phosphorus enters drainage from intensive piggeries or feedlots. To prevent this occurring the present methods of waste disposal in relation to drainage need to be investigated and, where applicable, alternative methods evaluated. A suggestion to use reed beds lined with bauxite residue for retaining waste phosphorus appears promising and will be investigated further (Chambers & Wrigley, Appendix 3). It was previously shown that this method would not be effective in removing the relatively low concentrations of nutrients from the large volumes and high rates of water flow which drain into the estuary from agricultural run-off via the major rivers and drains.

CHANGES IN LAND USE

The input of phosphorus to the estuary could also be reduced by replacing the present cultivation of shallow-rooted pasture plants with deep-rooted plants or trees which require less applied phosphorus and would reduce the volume of drainage water. Several alternatives have been evaluated which include:

- replacing pasture with pines *(Pinus pinaster* and *Pinus radiata)*
- replacing pasture with *Eucalyptus globulus* (Tasmanian blue gum)

Drainage channel through duplex soils.

If the 32,000 ha of sandy land in the Harvey Estuary catchment were taken out of pasture production, the reduction in phosphorus input to the estuary could be sufficient to solve the *Nodularia* problem within about ten to fifteen years. However, the resumption cost of approximately $40 million is very high and replacing the existing agriculture with pines would provide a lower economic return. On the other hand, planting *Eucalyptus globulus* could be about as profitable as existing agriculture (Mattinson & Morrison, Appendix 3).

Therefore there could be a net positive contribution in the long term from this option either as a Government buy-back proposition or by encouraging farmers to plant key parts of their properties to *E. globulus.* Unfortunately there is still some concern about the background economic and technical information on *E. globulus* and also on its effectiveness in reducing phosphorus discharge, so further investigation is recommended.

CONTROLS ON CLEARING AND DRAINAGE

If all the uncleared sandy land in the catchments of the Harvey and Serpentine Rivers was cleared and drained, phosphorus input to the estuary could increase by up to 38%. However, this is considered most unlikely because part of the country is poor sandy ridges, and part would be required for stock shelter. If allowances are made for these factors and for introduction of modified fertilizer practices, the predicted increase is less than 10%. These assumptions need to be further evaluated and it is recommended that an interdepartmental working group (PWD, DCE and Agriculture) be formed for this purpose and to develop long-term policies. It is suggested that controls on clearing and drainage should only be implemented if a significant (more than 5-10%) increase in phosphorus input could occur. Birch (Appendix 3) addresses this question more fully.

THE PLACE OF SUPPLEMENTARY MEASURES IN MANAGEMENT

None of the supplementary measures evaluated so far are likely to have significant impact on the algal problems in the short term (3-5 years). Possible exceptions are the use of nitrate and algicides. However both of these measures are subject to further testing and in the case of algicides further toxicity testing on crustaceans will have to be more promising than early work to justify full-scale field testing.

In the long term it will be important to ensure that there are no significant increases in phosphorus input from further clearing and drainage and from rural point sources in the catchment. Further investigation of the potential of planting *Eucalyptus globulus* is warranted. Such a measure could provide a valuable adjunct to the Fertilizer Modification Campaign. Use of bauxite residue to reduce drainage losses now appears destined for a minor role unless work on the proposed Dawesville Channel does not proceed.

CHAPTER 6

ECONOMIC AND SOCIAL CONSIDERATIONS

COSTS AND BENEFITS OF THE PROPOSED MANAGEMENT MEASURES

It should be realized at the outset that the Preferred Strategy, or package of management measures discussed in Chapter 3, is constrained for at least two reasons:

- it has been decided what the required level of reduction of algal nuisance will be
- it is necessary to achieve the reduction to this 'acceptable' level in a realistic time period.

These subjective assessments of what is acceptable and realistic impose constraints in that the preferred strategy will not necessarily minimize costs and maximize benefits to society. For example, if (as is the case here) it is considered that to be socially acceptable any management measure adopted must be effective within three or five years, then such long-term strategies as changes in land use from agriculture to forestry must be excluded from the preferred strategy. On simple cost-benefit grounds, however, such a measure may be shown to be effective.

Costs and Cost-effectiveness

Studies were carried out to evaluate the costs of reducing the algal nuisance by:

- fertilizer modification
- bauxite residue incorporation
- changes in land use from agriculture to forestry, i.e. plantings of *Pinus pinaster* and *Eucalyptus globulus*
- construction of the Dawesville Channel.

Each of the above strategies achieves a different level of reduction of input of phosphorus to the estuary over different time scales and thus a method of directly comparing the cost-effectiveness of each strategy is required. It is also necessary to investigate the profitability of the catchment options from the farmer's perspective. There are, for example, costs to farmers of both agricultural income foregone and the planting and care of trees.

Ultimately these costs are offset by returns from selling the forest products, probably for woodchipping *(E. globulus)* or sawlog production *(P. pinaster)*.

The methodology used and assumptions made in the calculation of costs, cost-effectiveness and present value to farmers of the alternative land uses is described by Mattinson and Morrison in Appendix 3.

Figure 6.1 shows the net present value to farmers of the alternative land uses evaluated, for varying discount rates. Table 6.1 gives estimates of costs, phosphate reduction and cost-effectiveness for the different strategies for reducing the algal nuisance. A discount rate of 4% is applied.

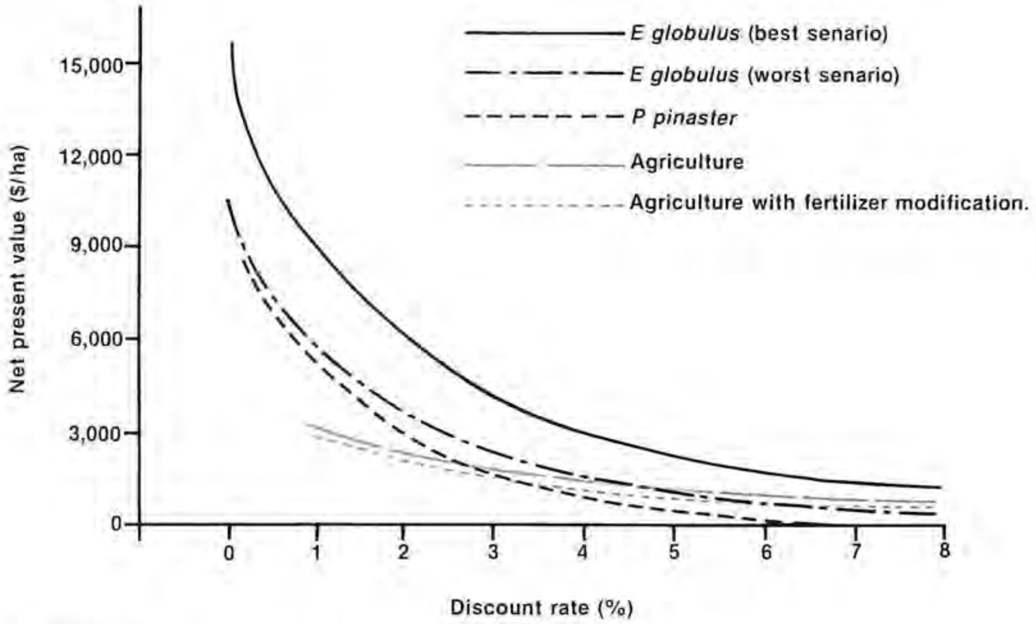


Figure 6.1 Net present value to farmers of all alternative land uses (after Mattinson & Morrison 1985).

Table 6.1 reveals that a high level of uncertainty exists with respect to the actual costs and cost-effectiveness of each strategy, and this is accommodated by the generous upper and lower ('best' and 'worst') bounds quoted in the Table. The 'best' *E. globulus* and fertilizer strategies have the unusual outcome of having net benefits rather than costs. That is to say, these strategies generate sufficient income to farmers to more than offset all the costs of research and extension.

Table 6.1 also shows that the above two strategies are the most cost-effective, and that the Dawesville Channel and *P. pinaster* are the two least cost-effective strategies. However, again it must be emphasized that although a strategy may not be as cost effective (as is the case with the Dawesville Channel), it could still be favoured because:

- it gives a higher level of reduction in the algal nuisance;
- it achieves the necessary phosphorus reduction in a much shorter time;
- it provides a long-term assurance of a healthy estuarine environment.

Eucalyptus globulus is potentially a more profitable land use than agriculture and further research should be carried out to ascertain its effectiveness in phosphate export reduction. Further work also needs to be done to develop strategies such as Government/farmer co-operative ventures whereby farmers could be granted a guaranteed income until costs could be recouped at clearfelling.

Benefits from a reduction in the algal nuisance

Any assessment of the benefits to be derived by residents and/or visitors to the area, by a reduction in the algal nuisance, must necessarily be highly subjective. Quantification of these benefits has been attempted by analysing:

- market valuations of real estate and the impact thereon of the algal nuisance (principally the odour problem)
- attitudes of visitors to the algal nuisance.

The former revealed that land values in the area did not seem to be affected in any significant way by the algal problem. This could be interpreted in one of two ways:

- the algal nuisance has a low value
- buyers did not know of the algae, or expected the problem to be solved in the near future.

Table 6.1 Costs, phosphate reduction and cost-effectiveness for different strategies of reducing the angal nuisance.

		Agriculture		Alternative land use		Estuary based
		Fertilizer modification	Bauxite residue	*Eucalyptus globulus*	Private pines	Channel
Net present value $'000 at 4%						
	Best	2,100	-12,000 to	27,300 to	-7,000	-12,100 to
	Worst	to 500	-16,200	-2,100		-30,500
Phosphate percentage reduction in estuary						
	Best	50 to	75 to	67 to	23	40
	Worst	30	67	66		
Cost-effectiveness, $'000/% P reduction						
	Best	16.7 to	-160.0 to	407.5 to	-321.8	-302.5 to
	Worst	42.0	-241.8	-38.2		-762.5

Implications for Management

The fertilizer modification strategy has a net benefit within the estuary's catchments and, as was discussed in Chapter 3, this measure is required to complement the Dawesville Channel in order to achieve the required level of reduction in available phosphorus.

The Dawesville Channel does not compare favourably with the other strategies on grounds of cost-effectiveness, but (in combination with the fertilizer measures) is the only option which can achieve the desired result in a socially acceptable time.

A very small visitor survey (sample size 45) showed that more than half did not identify algae as a nuisance in the Mandurah region. A subsequent more detailed survey did not entirely support these findings.

No implications for management of the algal nuisance can be drawn from the benefits alone, though it must be noted that the adverse effects of the algae are low for both residents and visitors *in general.* However, for some residents, the nuisance is considerable, as the later survey (see Section 6.3) reveals. These are the residents of Coodanup and Falcon in particular.

Conclusions

Costs and benefits for the fertilizer strategy alone and the fertilizer strategy **plus** the Dawesville Channel have been considered.

Table 6.2 summarizes the results of this analysis. Given the high level of subjectivity involved in the quantification of net benefits, it is difficult to be definitive about the results. On the basis of these studies, it would be concluded that the construction of the Dawesville Channel would result in a net social cost. However, as previously stated, it must be remembered that this conclusion does not involve consideration of:

- the necessity for a rapid solution to the problem and the likelihood of a further deterioration in the condition of the estuary if the Dawesville Channel is not proceeded with;
- the social effects of being seen to defer a decision on the only means of achieving a major improvement in the estuary's condition in the short term;
- other benefits which might arise from the creation of new attractive land adjacent to the Dawesville Channel. These include both the sale of that land in the first instance and the possible development opportunities (canals, waterfront developments, etc.).

THE ESTUARY FISHERY — GAINS AND LOSSES

Introduction

The overall effect of a reduction in the amount of phosphorus available to algae will be a concomitant reduction in the frequency of *Nodularia* blooms (if not their elimination), and also the eventual reduction in the macroalgae (weed) in the estuary. The response of the fishery to these outcomes can be postulated from a review of work done in 1983 and 1984 into the relationships of both macroalgae and *Nodularia* with the fish fauna and the scale fishery. This is reported in detail by Lenanton in Appendix 3.

Overall effects

Reduction in macroalgae (weed)

Comparisons have been made between the trends in catch per unit effort (CPUE) for sea mullet, cobbler, yelloweye mullet, and for the total scale fisheries in the Peel-Harvey and Swan-Avon estuaries. These comparisons were made during the period of excessive weed growth in the Peel-Harvey.

These studies reveal that, during the 1970-79 period of weed increase, the total scale fishery in Peel-Harvey increased by 1.8 times, while in Swan-Avon, the increase was only 1.2 times. There was no comparable increase in weed growth in the Swan-Avon estuary.

Increases in Peel-Harvey for yelloweye mullet, sea mullet and cobbler were 1.9, 2.1 and 3.3 times respectively, whilst no increases occurred with sea mullet or cobbler from the Swan-Avon estuary.

It could thus be concluded that any reduction in the macroalgae mass in the Peel-Harvey estuary below the 1970 level has the potential to reduce the CPUE for the dominant fish species, and the total scale fishery.

Elimination of *Nodularia*

Studies carried out between the months of November and March in the years 1979-80 (no bloom) and 1980-81, 1982-82 *(Nodularia* blooms) showed that juvenile fish were being affected by *Nodularia*.

Despite this, the trend in CPUE for the total scale fishery has continued to increase. It is also noteworthy that during the course of the investigations referred to, claims were made that fishermen and the large commercial-sized fish were also being affected by *Nodularia* blooms.

Traditionally, fishermen use gill netting when the water clarity is poor and the more productive haul netting when water clarity is high. This means that in *Nodularia*-affected areas, especially Harvey Estuary, the less productive gill netting technique must be employed.

Table 6.2 Costs, benefits and net social cost of the fertilizer strategy and the fertilizer plus channel strategy.

Scenario		Fertilizer strategy ($m)	Fertilizer plus channel strategy ($m)
Best	Cost	+ 2.1	-10
	Benefit	6.0 to 7.2	8.9 to 11.4
		(32.6 to 39.3)	(48.3 to 62.1)
	Net social benefit	+8.1 to 9.3	-1.1 to +1.4
Worst	Cost	+0.5	-30
	Benefit	Nil	5.3 to 8.9
			(29.0 to 48.3)*
	Net social benefit	+0.5	-24.7 to -21.9

* Numbers in brackets refer to upper 95% confidence limit

Detailed investigations involving the use of logbooks by fishermen were carried out in 1982, 1983 and 1984. Data collected indicates that the elimination of *Nodularia* would reduce the incidence of fish and blue manna crab deaths.

Specific effects

Modelling studies have confirmed that the proposed Dawesville Channel will alter the present hydrological regime of the Harvey Estuary; Chapter 3 addressed the physical effects of the channel which in general will result in:

- more marine conditions being established in the estuary earlier in the spring and persisting longer into autumn and winter (it is apparent that the mean salinity of the estuary will not fall much below 30 ppt when the new channel is in place);
- an improvement in water clarity;
- an increased daily tidal amplitude.

All of the above have the potential to affect the fish and crustacean fauna, as discussed in Chapter 4.

Over the period April 1979 to July 1981 monthly samples were taken of the fish fauna and the blue manna crab from beach seine, gill net and otter trawls. Environmental data was also recorded at each sampling, and from this information the following conclusions can be drawn:

Gains

- The additional ocean entrance will provide a further avenue for the recruitment of the blue manna crab, the western king prawn and all the marine fish that use the system. However the extent of the use of this new entrance is difficult to predict.
- It is clear that the changed hydrological regime, with longer periods of marine conditions, will result in an increase in the diversity of species in Harvey Estuary.
- Data on the blue manna crab, particularly the preferred salinity range of this species, clearly indicate that extended (summer) periods of marine salinities are liekly to lead to a more prolonged period of its colonization of the estuary.
- Clearer water conditions will permit use of the more productive haul netting fishing techniques.
- Increases in macroalgae or seagrasses in Harvey Estuary may improve the available cover for fish, and thus increase the survival of juveniles.

Losses

- The anticipated changes are likely to be unfavourable to species such as mullet.
- Increases in daily and seasonal tidal amplitude will produce more extensive intertidal areas and reduced areas of subtidal shallows, both of which may adversely affect the manner in which fish and crustaceans utilize the banks.
- Professional and amateur fishermen's access to shallow banks may be affected.
- Continuation or expansions of the extensive harvesting of weed may place species such as cobbler at risk.

Recommendations for monitoring

- In the event that the Dawesville Channel is proceeded with, it is essential that the direct effects of the channel on the fish fauna and the fishery be monitored and compared with data collected over recent years.
- The trends in the commercial fishery have been monitored in recent years using the logbook system. This is important as the Australian Bureau of Statistics data does not distinguish between catches in Peel Inlet and Harvey Estuary, yet these parts of the system are hydrologically distinct and have responded differently to nutrient enrichment. It is therefore recommended that the present logbook system be continued.
- Little data is yet available on the distribution and abundance of the juvenile stages of the western king prawn in the estuary. However a detailed study of the ecology of this species recently began and this should continue to be strongly supported because of the importance to the fishery.

THE COMMUNITY RESPONSE

A survey was conducted during March 1985 with the objectives of:

- determining local and regional views on the algal problem and what should be done;
- providing input to an Environmental Review and Management Programme (ERMP) for the management strategy;
- determining the views of professional fishermen, local residents, and daily, weekly and longer term tourists on what constitutes an acceptable estuary.

Components of the survey

The survey involved two components:

- an interview survey with 155 randomly selected respondents in Mandurah and adjacent areas, of whom 99 were interviewed by telephone and 56 were interviewed face-to-face in holiday homes, caravan parks and motels;

- five group discussions with groups of up to ten people representative of selected community interest groups associated with the Peel Inlet and Harvey Estuary.

The interview survey was conducted over the weekend of 1-3 March 1985, while the group discussions were conducted on 9 and 10 March 1985. In most cases no clear distinction emerged between most people's perception of the algal problem in general and the growth and accumulation of weed and the *Nodularia* blooms in particular.

Full details of the survey are provided in Appendix 4.

Summary of findings of the attitudinal survey

The main findings of the household survey are summarized below:

- There is a strong indication that natural environment attributes and the casual, friendly lifestyle are the main aspects which respondents like about the Mandurah area.
- Mosquitoes, traffic problems and canal developments were all identified (without prompting) ahead of the algal problem of the estuary as matters which concerned people about living in or visiting Mandurah.
- There is considerable and frequent recreational use of the estuary for both passive and active recreation, particularly prawning, crabbing, fishing and boating.
- There is a clear identification that there are problems which adversely affect the recreational use of the estuary, with the principal problem being related to the weed accumulation and the smell associated with it.
- 95% of respondents who had identified or acknowledged that the algal problem existed thought that it was 'very serious' or 'fairly serious'.
- The main ways in which the algal problem affects people are its smell or stench and its adverse effects on crabbing and fishing.
- Almost 100% of respondents who had identified or acknowledged that algae were a problem thought that something should be done about this problem.
- State Government was the most frequently mentioned authority which respondents thought should be responsible for taking some action about the problem.
- Almost three-quarters of respondents thought that the existing programme to encourage farmers to change their methods of applying agricultural fertilizer (a low-cost/long-term solution) was acceptable in varying degrees.
- More support was expressed for the high-cost/immediate solution than for the low-cost/long-term solution.
- There is considerable support for the expenditure of more than $25 million to improve water quality in the estuary relative to other claims upon State Government expenditure.

Thus of the 155 respondents, a total of 133 (or 86%) indicated that they thought algae were a problem in the Peel Inlet or Harvey Estuary, and only 14% did not acknowledge or identify this problem. Of the 133 respondents who did identify or acknowledge that there was a problem with weed growth, most (128 respondents) identified it without prompting, which is a clear indication of the extent of the perception of the problem by the general public in the Mandurah area.

Farmer's field day to discuss fertilizer practices.

Summary of Group discussion sessions

Group discussions were held with representatives of the following:

- Falcon Progress Association
- John Street, Coodanup, Residents
- Peel Preservation Group
- Mandurah Professional Fishermen's Association
- Southern Estuary Progress Association

The range of issues summarized by the various groups is discussed below. This summary of issues moves from the general to the particular but the order does not necessarily reflect the relative priority of an issue as many of the issues overlap.

Perceptions of issues associated with living in the Mandurah area

Both the mosquito problem and the algal problem were identified by various members of the groups as being the most significant problems in the Mandurah area. The mosquito problem appeared to be a more universal, but seasonal problem than the algal problem, which was seen as having localized but significant effects.

All groups were quite unflattering in their opinions of the Mandurah Shire Council, perceiving that the Council acted only in the interests of the business community and, to a lesser extent, the residential community in Mandurah itself. The groups considered that the Council ignored the needs of residential areas outside of Mandurah itself and of special interest groups such as the professional fishermen. Opposition to canal development by members of the groups and related local issues such as the closure of Leighton Road seemed to underlie negative attitudes to the Mandurah Shire Council.

Perceptions of cause of the algal problem

Within all groups the view was expressed that damming the rivers (upstream of the Inlet and Estuary) was a contributing factor to the problem. This view was expressed more categorically than any 'blame' on the fertilizer practices of farmers. The damming of the rivers was seen as preventing adequate flushing of the estuary and thus contributing to the problem.

Perceptions of effects of the algal problem

The smell, adverse effects on recreational usage of the estuary (especially fishing, prawning and crabbing) and the aesthetic unpleasantness were the main effects mentioned by the residents' discussion groups. More severe localized effects such as the tarnishing of metal and the belief that the smell made some people ill were also mentioned, along with the likely effects on tourism of the deterioration of the Mandurah area's prime environmental asset.

Some groups also expressed the opinion that the effects of the algal problem were reflected in depressed land values and the inability to sell properties at realistic or expected prices.

The professional fishermen's group identified effects of direct and adverse economic consequence to them, to the excessive growth of *Nodularia* rather than the weed. Such effects included decreased availability of some species of fish and crustacea and operational effects such as weed getting tangled in nets and motors.

Perceptions of solutions to the algal weed problem

With the exception of the professional fishermen's group, the members of the other four groups were generally strongly in favour of the proposed Dawesville Channel and were vocal in their support for this measure to be undertaken as soon as possible.

There was some scepticism expressed that this solution would actually be implemented as some participants believed that the Government would baulk at the measure. Whilst most participants were keen to see the Channel implemented as the only real solution to the algal/weed problem, many tempered their enthusiasm with cautions about ensuring that adequate studies were done beforehand to try and predict the success and effects of this option.

There was general support for initiatives to date — the weed harvesting program and the fertilizer modification program — but participants perceived these as not really getting to the cause of the problem. Implicit in much of the discussion, and explicit in some instances, was the view that the general public relied for the solution on 'experts' and 'Government' and that the public was somewhat removed and remote from the process of arriving at and implementing a decision. While most groups acknowledged that they generally received enough information about the studies and investigations, there was some feeling expressed that the information released was repetitious and that the whole process was not moving quickly enough towards resolution. Most members of the discussion groups were not opposed to the idea of well-planned canal developments at the sides of the Dawesville Channel.

The professional fishermen's group was strongly opposed to the proposed Dawesville Channel because they considered that proper dredging of the existing entrance channel at Mandurah would provide adequate flushing, while the Dawesville Channel would adversely affect professional fishing in the estuary. It would reduce the catch of commercial species of fish and crustacea and the greater tidal range would affect operational aspects of fishing.

PLANNING ISSUES

The possible construction of a new channel to the ocean near Dawesville also provides the opportunity, in the creation of prime real estate adjacent to the channel, for some exciting developments. Such developments also have the potential to recover in sales a portion of the capital expenditure which must be committed for the channel construction.

Two exercises have been undertaken at a preliminary level to assess these possibilities:

- preparation of a concept plan;
- a baseline valuation of the available land adjacent to the channel.

The concept plan

A preliminary concept plan has been prepared by Ralph Stanton Planners. In summary, the findings of the exercise are as follows:

- The general area within which the channel is proposed has for many years been attractive as a holiday and retirement venue. Recent trends have been towards an intensification of holiday, tourist, semi-rural and residential developments, with a growing level of sophistication. The advent of the proposed channel could increase the demand for these uses by opening new opportunities in boating-related tourism and recreation and in holidaymaking generally.
- In terms of the landform and ecology of the site, opportunities for the construction of recreational marine facilities (already inherent in the land) would be greatly enhanced. Care would need to be taken in the planning and management of coastal and estuary foreshores, but, taken overall, the increased scope for public recreation will be considerable.
- The ownership of the majority of the land in the study area is in private hands, much of it undeveloped and in the control of a single landowner. To the south of the area the bulk of the land remains unalienated and is reserved for various public purposes, the most significant of which is the Caddadup recreation and camping reserve. This suggests that the proposed channel alignment could form a logical boundary between mainly public land uses to the south and generally private development to the north of this channel. Development in both these locations should be designed to maximize the benefits arising from the introduction of the channel.
- The effects of the channel, if it is designed to advantage, can be highly beneficial. With the exception of two houses, no existing developments will be directly threatened by the proposal — although existing roads and services will require modification. The local authority town planning scheme will require amendment in due course, subject to the usual statutory town planning procedures.
- The opportunities presented and the constraints identified have been supplemented by a series of planning principles and objectives guiding the preparation of the plan. These include:
    - the provision of large public recreation areas along water frontages and elsewhere;
    - the inclusion of appropriate coastal and waterway management controls and recognition of the environmental capacity of the site;
    - the shaping of landform through the disposal of spoil to create settings for recreation, resort, residential and other uses, taking advantage of the opportunities presented by channel construction;
    - the provision of sites for land uses appealing to a wide cross-section of the community, in particular within a marine atmosphere;
    - the relocation of incompatible land uses where possible.
- The range of land use types which could be accommodated within these criteria include:
    - boating facilities of a variety of kinds and purposes;
    - residential and holiday accommodation of many descriptions, from short-stay requirements at the lower end of the market through to permanent and semi-permanent needs, and including everything from camping and chalet areas through Rottnest-type units to motel/hotel accommodation of varying quality and price;
    - commercial facilities — local shops, taverns, boat servicing, etc.
- In preparing the plan a conceptual approach has been adopted, the plan indicating only one of several possible responses to these requirements. Later modifications (or even substantial recasting) of the plan may arise due to changes in the channel alignment, ownership considerations, market forces, local authority or departmental requirements, or to any of a number of other factors without damage to the basic principles adopted.

Conclusions

It is clear that the proposed channel would create a new focus of activity and interest in the region and a rare opportunity for public and private waterfront recreation facilities to be developed. Whatever plan is adopted, development should occur in a coherent fashion with a maritime theme.

With the new channel forming a division between generally private development to the north and generally public land to the south, new opportunities are available to create maximum benefit:

- to the public, through the provision of recreation and boating facilities and through the availability of a wide variety of holiday accommodation in a unique harbourside atmosphere;
- to the present landowners, through the prospect of new development opportunities;

- to the local area, through these same opportunities, and
- to the state, through the added tourism potential of the plan.

The valuation exercise

Estimates of the value of the existing land were made. In addition, a valuation was made of the land as it might be affected by the Dawesville Channel and a simplified version of the above concept plan. The summary of findings of this study indicates that:

- the value of the land as it stands is $2,400,000
- the potential profit arising from a 'base line' single residential development would be of the order of $2,000,000, conditional upon the assumptions made in the report and excluding any social or community benefits.

This indicates that there is an even greater potential arising from the preliminary concept plan and should a decision be made to construct the Dawesville Channel, then the plan could be investigated, from cost/benefit, timing and management points of view.

A scene on the Serpentine River.

CHAPTER 7

RECOMMENDATIONS FOR MANAGEMENT OF THE PEEL-HARVEY ESTUARY

OBJECTIVES FOR MANAGEMENT

The report 'Management of Peel Inlet and Harvey Estuary' (DCE Bulletin 170, 1984), which was endorsed by the Government, stated the principal objective for management to be:

'. . . to reduce the algal nuisance to acceptable levels without further damage to the estuarine environment'.

This was to be accomplished without causing loss of production of the estuarine fishery or of agriculture in the catchment.

An acceptable level of algal abundance was defined as:

- *Nodularia* blooms should not occur more frequently than once in five years on average
- weed should not foul beaches near populated areas.

Studies carried out in 1984 confirm that in the short term (3-5 years) this objective can only be accomplished by the combination of management measures of the recommended strategy.

RECOMMENDED STRATEGY FOR MANAGEMENT

This strategy has the twofold objective of controlling the algal nuisance, as long as it persists, and of preventing its continuance. The **control measures** aim to ameliorate the nuisance caused by weed accumulating on the shores and the **preventive measures** aim to progressively reduce the amount of phosphorus available for algal growth to about 30% of the present level.

Principal control measures

Continue, and if necessary modify and expand the present measures to control the weed nuisance near populated areas.

Supplementary control measures

Complete the present studies of algicides to determine their effectiveness to prevent ***Nodularia*** blooms and to determine the risks associated with the use of algicides.

Investigate the possibility of using nitrate to clear up the macroalgal problem quickly.

Principal preventive measures

Reduce the input of phosphorus to the estuary by continuing the programme to modify agricultural practices on the coastal plain.

Increase the loss of nutrients to the sea by construction of the Dawesville Channel.

Supplementary preventive measures

Continue to monitor the effect of the programme to modify agricultural practices, on the input of phosphorus to the estuary.

Continue the study of the potential of a change in land use on the coastal plain, from pasture to forestry production, to reduce the input of phosphorus to the estuary.

Evaluate the effect of further clearing and extensions to drainage on the coastal plain, on input of phosphorus to the estuary and to make recommendations for long-term management.

Continue the current studies on control of nutrient release from point sources (piggeries, sewage, etc.).

Acquire the land required for development of the channel immediately. (A further two years will be required before channel works can begin because of the need to prepare detailed plans and estimates and a complete environmental assessment through the ERMP process.)

Continue and, if necessary, expand the monitoring of the estuary to assess the effect of the management strategy.

IMPLEMENTATION OF THE RECOMMENDED STRATEGY

It is further recommended that an interdepartmental steering committee, co-ordinated by DCE, be formed to advise the Government on the implementation and ongoing management of these measures.

THE MANDURAH CHANNEL

While not part of the recommended strategy, the proposed enlargement of the Mandurah Channel would contribute to achieving the management objective by increasing the flushing of phosphorus from Peel Inlet to the sea.

WHAT THESE MANAGEMENT MEASURES CAN ACHIEVE

Weed control

Weed harvesting, at the present level of effort, has the potential only to ameliorate the worst features of the weed problem — accumulation and decomposition of algae on the shores of the estuary adjacent to populated areas. Harvesting, on any practicable scale, is unlikely to have any significant effect on the excess of plant nutrients in the estuary, and in consequence on the growth of weed or *Nodularia.*

There are indications that more of the existing weed harvesting equipment will be needed to keep the beaches free of weed to an acceptable degree. Also, there is a need to replace sand that is being lost from beaches during weed removal operations.

Catchment management measures

The results of the 1984 fertilizer management programme have confirmed that agronomic measures have the potential to reduce the input of phosphorus to the estuary by 20-40% over a period of three to five years. Because of the store of phosphorus in the estuarine sediments this may not immediately reduce the frequency or intensity of *Nodularia* blooms and alone will not eliminate them. It is also to be expected that the sediment phosphorus store will support growth of weed for a considerable period.

It must be emphasized that catchment measures alone will not solve the algal problem in the short term.

However, depending on the rate at which the soil phosphorus store is depleted, there will be a progressive reduction in input of phosphorus to the estuary and, in consequence, a reduction in intensity of the algal problems. Continued implementation of the fertilizer programme and the introduction of other land use changes may, over many years, reduce algal abundance to 'acceptable levels'.

The Dawesville Channel

The results of the modelling studies have confirmed that the Dawesville Channel will improve flushing of the estuary to the extent that, in combination with the other measures, the management objective will be achieved within five years.

The improved flushing will about halve the retained phosphorus, and it will make the estuarine water more saline and so less favourable for *Nodularia* growth. Blooms will cease, except perhaps in exceptional circumstances or in the southern end of Harvey Estuary.

However, there may be an increase in weed growth for some years; this is because the improved flushing will result in clearer water while there is still a considerable supply of phosphorus available from the surface sediments.

The Mandurah Channel

Enlargement of the Mandurah Channel will improve flushing and reduce the retention of phosphorus in Peel Inlet and so contribute to a reduction of weed growth but, as with the Dawesville Channel, improved clarity of the water is likely to allow a short-term increase in weed growth. It will have little effect on retention of phosphorus in Harvey Estuary and consequently will have only a minimal impact on the *Nodularia* problem there.

Mandurah Channel enlargement carried out in conjunction with the Dawesville Channel development would yield a greater improvement in estuarine flushing than would result from the Dawesville Channel alone.

Algicides

Use of these is envisaged only as a possible short-term solution to the *Nodularia* problem. Preliminary tests have not been encouraging as yet.

Nitrate

Application of nitrate to the surface sediment is thought to have the potential to rapidly reduce the phosphorus available for algal growth. No detailed investigation has yet been made, but if found to be practicable it could be valuable as a short-term measure to reduce algal growth.

Monitoring the catchment management measures

Continued monitoring of the effect of these measures on the release of phosphorus to drainage is essential to ensure that they achieve the anticipated reduction in input to the estuary.

Recommended study group on clearing and drainage

Further clearing and extension to drainage on the coastal plain has the potential to add significantly to the input of phosphorus to the estuary. It is important to assess accurately what the increase will be and how it can best be prevented.

Point sources of phosphorus

Point sources, such as piggeries, produce waste nutrients in quantities similar to those entering the estuary from agricultural drainage. It is important to ensure that measures to prevent this additional input are devised and implemented where necessary.

Changes in land use

Alternative land uses such as forestry have the potential to contribute to the long-term reduction in phosphorus input to the estuary, by reducing phosphorus losses from the land. Preliminary studies show that planting with *Eucalyptus globulus* (for wood chipping) on appropriate soils may provide an economic return, but cash flow problems may exist for farmers. Reduction in phosphorus input to the estuary could be up to 40%.

Monitoring the estuary

While every effort has been made to foresee how the estuary will respond to the proposed management measures, it is impossible to predict with certainty all the changes to such a complex ecosystem. It is essential to continue and, where appropriate, expand the present monitoring before, during and after implementation of the proposed management measures.

TIME SCALES AND COSTS

The recommended strategy aims to reverse the deterioration of the estuarine environment by reducing the amount of phosphorus available to aquatic plants. Deterioration has been progressive over the last 30 years or more and it is not possible to predict with certainty how rapidly it can be reversed, more particularly because of the unpredictability of rainfall and the consequent input of phosphorus to the estuary.

Table 7.1 summarizes the timing for implementation of the recommended management measures and also enlargement of the Mandurah Channel. Figure 7.1 indicates the effect these measures are expected to have on the frequency of *Nodularia* blooms. As indicated above, the reduction in weed growth will be a slower process which cannot be predicted reliably.

The basic cost of the Dawesville Channel proposal is $31 million (including land acquisition costs) and the cost for the Mandurah Channel enlargement is about $3.1 million. Detailed engineering for the two projects would cost $445,000. The supplementary management measures, weed control, measures associated with modifying agricultural practices, and monitoring the effects of management on the estuary — all involve ongoing costs. These will be budgeted for by the appropriate Departments.

LONG-TERM BENEFITS OF THE RECOMMENDED STRATEGY

It is expected that the recommended strategy will achieve the management objective within five years. This means the early cessation of massive *Nodularia* blooms and a progressive reduction in weed abundance to the point at which it will no longer be a nuisance. It will also make the estuary a healthier and more attractive environment, less vulnerable to harm as the result of natural events or adverse human influences.

In the longer term (20-100 years) the Dawesville Channel especially will have the effect of reversing the natural processes which, by progressively sealing off the estuary from the ocean, have resulted in a gradual change in the estuarine environment, as has occurred in other estuaries of the south-west. This change has made the estuary vulnerable to damage from pollution and use and abuse generally.

The generally healthy condition of the Swan River estuary, despite the large urban area surrounding it, must be attributed principally to the good tidal flushing that resulted from dredging Fremantle Harbour in the 1890s and to current measures to restrict the input of pollutants. Construction and maintenance of the Dawesville Channel will similarly increase flushing and protect the shallow water of the Peel-Harvey estuary from the adverse effects, direct and indirect, which a similar great increase in population pressure will impose on it over the next 100 years.

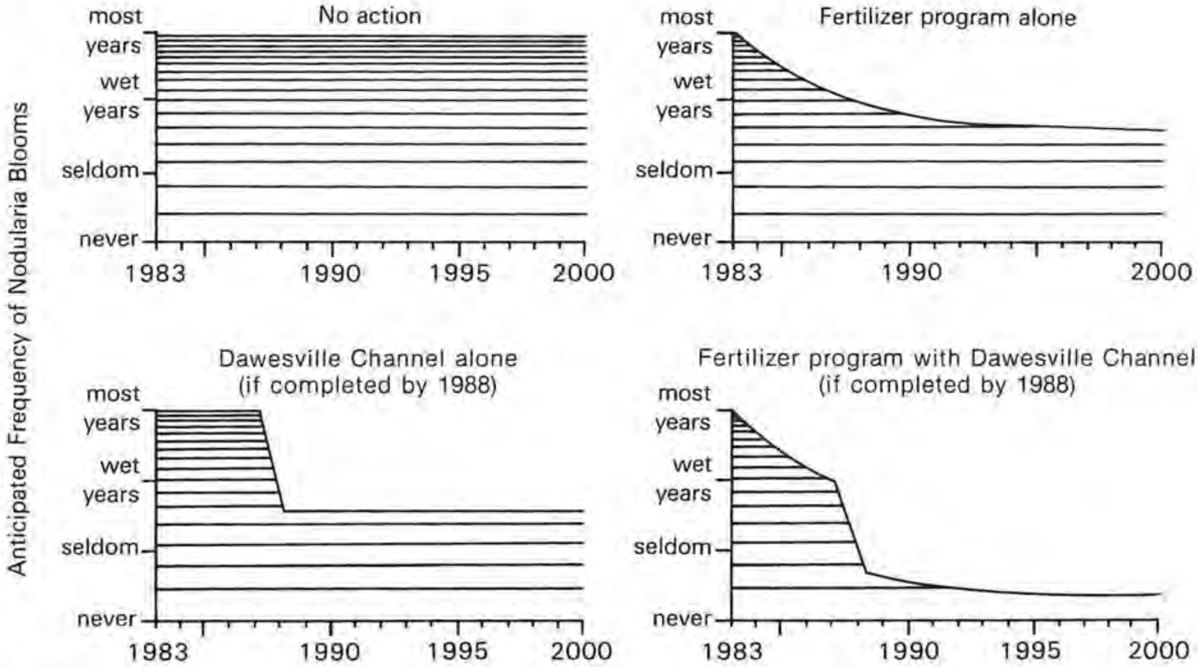
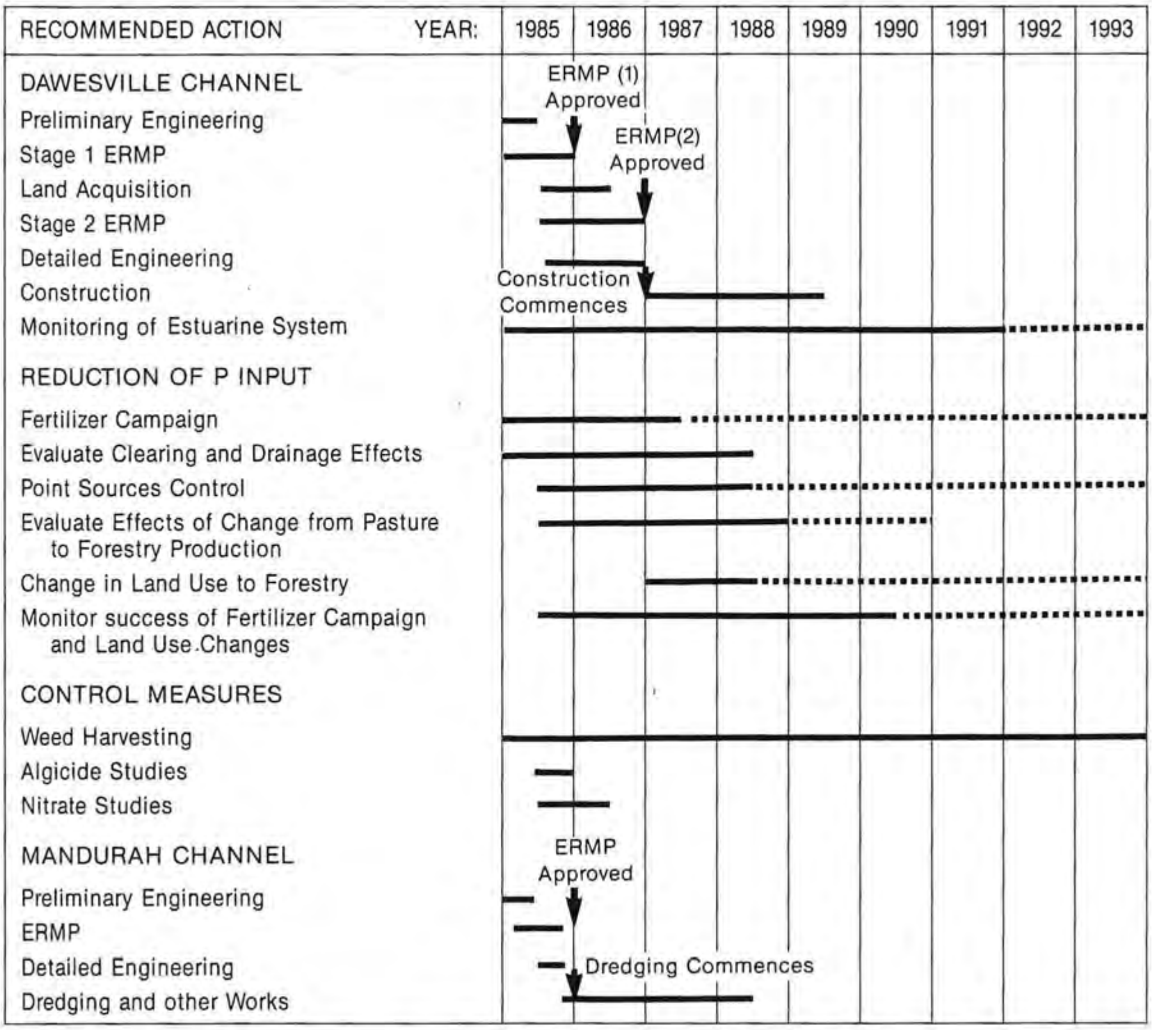


Figure 7.1 Anticipated effects of management measures on *Nodularia* blooms.

Table 7.1 Recommended timetable for estuary management.



PEEL-HARVEY ESTUARINE SYSTEM STUDY

APPENDICES TO REPORT NUMBER 14

Appendix

1. **The Background to Management**
   Department of Conservation and Environment, Bulletin 241, January 1986
    1. Physical features of the estuary by E.P. Hodgkin
    2. Biological features of the estuary by E.P. Hodgkin
    3. The source of the nutrients by P.B. Birch
2. **The Response of the Biota to the Proposed Management Measures** by K. Hillman
   Department of Conservation and Environment, Bulletin 242, January 1986
3. **Management of the Estuary: Proceedings of Symposium, February 1985**
   Department of Conservation and Environment, Bulletin 195, July 1985
4. **Report on Mandurah Attitudinal Survey** by H. Weston and R.E. Black
   Department of Conservation and Environment, Bulletin 235, August 1985

TECHNICAL REPORTS IN BULLETIN 195

CATCHMENT MANAGEMENT STUDIES

Plot and small catchment studies of phosphorus leaching to surface drainage in response to superphosphate, New Coastal Superphosphate and nil fertilizer treatments. N.J. Schofield, P.B. Birch, G.G. Forbes, K.W. McAlpine, G.M. Bott and P.D. Piesse.

The phosphorus discharged by groundwater to the Peel Inlet – Harvey Estuary system, Western Australia. A.C. Deeney.

Peel-Harvey estuary study groundwater studies, site specific. E. Bettenay, D.H. Hurle and M.I. Height.

Long term phosphorus losses from deep grey sands and duplex soils. G.P.S. Ritchie, D.M. Weaver and G.C. Anderson.

FERTILIZER MODIFICATIONS CAMPAIGN

Management of agricultural phosphorus losses from the soils of the Peel-Harvey catchment. J.S. Yeates, P.T. Arkell, W.K. Russell, D.M. Deeley, C. Peek and D. Allen.

Nutrient loading into the Peel-Harvey estuary. P.B. Birch, G.G. Forbes and G.M. Bott.

POTENTIAL OF SUPPLEMENTARY MANAGEMENT MEASURES

The application of bauxite residue to reduce phosphate loss in the Peel-Harvey catchment. D.J. Glenister.

Control of rural point sources in the Peel-Harvey catchment. J. Chambers and T. Wrigley.

Control of clearing and drainage in coastal plain catchments of the Peel-Harvey estuary. P.B. Birch.

ENGINERING MEASURES

Peel-Harvey estuarine system – Phase 3 study: Investigations into the Dawesville Channel option. M. Paul and I.M. Hutton.

Modelling studies of Dawesville Channel-Harvey Estuary. G. Tong.

RESPONSE OF THE BIOTA

Macroalgal growth, phytoplankton biomass, zooplankton populations and the role of the sediments; present trends and possible effects of the proposed effects of the proposed Dawesville Channel. R.J. Lukatelich.

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