Marine Oil Spill Risk in Australia

Report

Oil spills are basically chance events, their occurrences and characteristics being governed by probability distributions. Many properties of these distributions can be applied, with reasonable confidence, to the prediction of the location, number and size of oil spills around the Australian coast. The analyses described in this Report are aimed at identifying the most appropriate statistical distributions underlying oil spill occurrences in Australia, and at interpreting the results to assist the planning process. In particular, the results are used to estimate future levels and locations of chemical dispersant stockpiles.

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Bureau of Transport Economics

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FOREWORD

In 1980, the Commonwealth/State agencies responsible for the 'National Plan to Combat Pollution of the Sea by Oil' asked the then Department of Transport Australia (DoTA) to update an assessment of marine oil spill risk in Australia. The assessment was originally prepared in 1978 and was based on overseas methodology and data. On further examination, it became evident that the basis of the 1978 assessment was not appropriate to the Australian marine oil spill risk situation, and that a completely new approach should be taken.

The Coastal Services Division of DoTA (subsequently merged into the Marine Operations Division of the Department of Transport and Construction), accordingly requested that the Bureau of Transport Economics (BTE) undertake a study of marine oil spill risk in Australia.

This Report presents the results of the study, focussing on the probabilistic nature of the problem and projections of future oil spill occurrence and extent.

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SPECIAL NOTE

Following preparation of the major component of this Report, new administrative arrangements came into force in relation to the Commonwealth Transport portfolio. The previous Department of Transport Australia (DoTA) was abolished, and its surface transport components amalgamated with the previous Department of Housing and Construction, to form the Department of Transport and Construction (DTC). Subsequently in 1983, further changes to the administrative arrangements resulted in the creation of a new Department of Transport to undertake the transport function of DTC.

References to Commonwealth Departments in the Report reflect the arrangements as they existed at the time of the study, or at the time of writing, depending on the context.

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SUMMARY

Oil spills are basically chance events, their occurences and characteristics being governed by probability distributions. Many properties of these distributions can be applied, with reasonable confidence, to the prediction of the location, number and size of oil spills around the Australian coast. The analyses described in this Report are aimed at identifying the most appropriate statistical distributions underlying oil spill occurrences in Australia, and at intepreting the results to assist the planning process. In particular, the results are used to estimate future levels and locations of chemical dispersant stockpiles.

Previous work in this area relied on both data and methodology derived from overseas sources. Comparison of this overseas work with the historical situation in regard to oil spills in Australia over the past decade highlighted some apparent discrepancies. These discrepancies threw some doubt on the applicability of the overseas analysis to the Australian oil spill situation. The work done overseas also concentrated on large (catastrophic) spills, of which Australia has very few. On the other hand, an Australian Parliamentary Inquiry in 1978 found that the environmental damage caused by frequent small oil spills was often as great as, if not greater than that caused by large spills, and that not enough emphasis was attached to preventing small spills. This Report attempts to respond to the planning requirements associated with this situation by presenting the results of an analysis of oil spills of all sizes occurring in Australian waters. More specifically, the study results are directly applicable to the determination of chemical dispersant stockpile requirements.

In this study, three major types of oil spills were identified: spills occurring during the loading and discharging of oil and oil products (oil-handling spills), spills occurring during the loading of bunker fuel (bunkering spills), and spills occurring during all other ship operations such as ballasting, cleaning of tanks and so on (miscellaneous spills). Several port types were also identified in relation to their relative susceptibility to oil spills. For example, capital city ports and ports at which a refinery was located exhibited spill propensities which differed from the spill propensities of other ports.

The oil spill data analysed in the Report were obtained from the then Department of Transport Australia (DoTA) and included only those spills which had been reported to the appropriate authorities, and which occurred between 1 July 1972 and 30 June 1979 (the study period).

This study examined three primary characteristics of oil spills in Australia:

- the number of oil spills of each of the three major types, by port;
- the volume of oil spilled in each major type of spill; and
- the number of oil spills from other sources (undersea pipelines, drilling rigs and offshore platforms, and spills from ships at sea).

During the study period the average annual number of oil spills at capital city ports ranged from 12 spills at Sydney to zero spills at Darwin, and in Australia as a whole there were on average 48 spills per annum.

The results of the analyses were used to forecast the following oil spill measures for the two fiscal years 1984-85 and 1989-90 at 32 major ports:

- the average number of spills of each major type, by port;

- the range which would encompass the actual number of spills with a high probability, by port;
- the average volume spilled in each major type of spill;
- the probability that a spill of any of the major types would exceed a specific volume, by port;
- the amount of chemical dispersant which would be adequate to neutralise a specific (high) proportion of spills in each State;
- the probability that a given stockpile of dispersant would not be adequate for at least one spill in a given year in each State; and
- upper limits on the spill rates of at-sea, undersea pipeline, drilling rig and offshore platform oil spills.

The analysis of the number of oil spills by location required identification of the 'exposure' of each location to the various types of oil spills. It was initially considered that an appropriate measure of the relative levels of exposure of ports to the chance of oil spills would be provided by the numbers of shipping operations leading to the various types of spills. Unfortunately, this information was not readily available and other measures of the levels of shipping activities were used as 'exposure variables' for the various types of spills listed below:

- the volume of oil and oil products handled (oil-handling spills);
- the volume of bunker fuel loaded (bunkering spills);
- the weight of cargo handled (miscellaneous spills);
- the volume of oil and oil products transported by ship around the Australian coast (at-sea spills);
- the volume of oil transported in undersea pipelines (undersea pipeline spills);
- the number of oil wells drilled to final depth in the sea (drilling rig spills); and
- the volume of oil produced at offshore platforms (offshore platform spills).

In formulating the statistical models on which the forecasts are based it was necessary to assume that the number of oil spills and their sizes (that is, volumes spilled) followed specific probability distributions. These distributions were based on the historical situation relating to oil spills in Australian waters.

The number of spills occuring at each port was found to be related to the level of shipping activity (the exposure variable) in the port. Simple projections of the exposure variable levels were made for the three major types of spills (oil-handling, bunkering and miscellaneous spills) which occur in ports, for the years 1984-85 and 1989-90. The projections were used to illustrate the application of the oil spill models developed in the study and the resulting oil spill forecasts depend on the validity of these projections.

The spill rates appropriate to each type of spill at given ports were applied to the projections of the exposure variables at those ports to obtain forecasts of the **average** numbers of spills of each type in each port in the two years 1984-85 and 1989-90. Properties of the probability distribution governing the number of spills were then used to obtain a range on the **actual** number of spills likely to occur. These ranges are expected to encompass the actual number of spills which will occur in a particular year at a high proportion of the ports. Based on the levels of the exposure variables projected for 1984-85, the **average** numbers of spills of each type expected to occur in Australia as a whole in that year have been calculated to be 8 oil handling spills, 28 bunkering spills and 15 miscellaneous spills.

There was no evidence to indicate that the **volumes** of oil spilled in each spill were changing over time or were dependent on port type. The only characteristic with which the spill volumes appeared to be related was spill type. Average bunkering spill volumes were significantly smaller than those for the other two major types of spill. Miscellaneous spill volumes were similar on average to oil-handling spill volumes, but were much more variable.

Combining the projected average number of spills and projected average volumes spilled gave projected average total volumes of oil spilled in each Australian port in the year 1984-85. These average total volumes spilled are long-term averages. Further analysis yielded estimates of the probabilities of specific total volumes spilled in the year, and, in particular, the probabilities of **large** total volumes spilled. The probability of the occurrence of a **single** 'large' spill was also derived from the original models. That is, the spill volumes having a probability of 0.05 (or 1 chance in 20) of being exceeded were calculated for each State. It is expected that 95 per cent of the time the volumes of spills occurring in each State will be less than these large spill volumes.

The major application of these models was in the calculation of 'economic' levels of stockpiles of chemical dispersant distributed around Australia. These levels were determined by the amount of chemical dispersant required to neutralise the oil spill volume which has a probability of 0.05 (1 chance in 20) of being exceeded in a given State or Australia in a given year. Estimates of future dispersant stockpile levels for each State, based on the forecasts for the year 1984-85, ranged from 2 drums[1] of dispersant in the Northern Territory to 77 drums in New South Wales. The total requirement for Australia as a whole amounts to 281 drums of dispersant in 1984-85. These stockpile levels are based on having one stockpile in each State, refurbishing each stockpile after each spill (or at the end of the shelf life of the dispersant) and accepting a 5 per cent risk that the stockpiles are inadequate for at least one spill in the year. If the stockpiles were combined into one stockpile for the whole of Australia, only 192 drums would be required for the same risk. Transport of dispersant from such a central stockpile would of course be more expensive, and clean-up reaction times could be greater.

It is believed that the statistical models presented in this Report represent the most appropriate forms to describe both the number of oil spills which occur and the volumes spilled, and the results derived from these models represent the most comprehensive analysis of the occurrence of oil spills so far produced in the Australian context. The future levels of shipping activities (the exposure variables) presented in the Report should be regarded as plausible estimates only, and consequently the oil spill forecasts based on these projections should be considered largely as being **illustrative** of the many applications of the models. Because of the nature of the statistical models, large changes in the exposure variables are required before there is a noticeable effect in the actual number of oil spill occurrences. The future annual rates of change in the levels of the exposure variables presented in this Report are, in general, small and the forecast average numbers of oil spills exhibit the same small rates of change. Nevertheless, the average number of spills is useful for assessing the oil spill risk at a new port, or at a port for which the exposure variable levels are expected to change significantly. The forecasts have immediate application to estimating the minimum (and hence economic) levels of the dispersant stockpiles, and to planning the availability and distribution of dispersal equipment and labour.

1. One drum is approximately 200 litres of dispersant and will neutralise approximately 600 litres of oil.

CHAPTER 1—INTRODUCTION

Being an island continent, Australia is dependent economically on its sea lanes and port operations. In turn, the maritime transport activity taking place around the Australian coast produces a continual risk of pollution of the marine environment by the various forms of liquid hydrocarbons carried by ships. With the concentration of Australia's population around the coastline, and the economic and recreational use made by that population of coastal waters, the potential seriousness of marine oil pollution in these circumstances comes into focus.

Fortunately, Australia's comparatively small population has not yet generated sufficient shipping activity to produce serious sea lane congestion, with the attendant risk of collisions at sea. To illustrate the situation, the traffic density in Bass Strait, which is the busiest shipping area in Australian waters, averaged some 12 ships per day in 1978. In contrast, the Dover Straits off the United Kingdom averaged some 300 transits and 70 crossings per day in what may well be the busiest shipping area in the world. Despite such comparatively low shipping densities, particular parts of the shipping routes around the Australian coast have potential weather and navigational hazards associated with them, so that a degree of traffic management has been required. In addition, resources development and other factors have resulted in a certain degree of congestion in and around ports from which minerals are exported.

The general context of Australia's marine oil pollution potential may be summarised in terms of:

- a very long coastline, some of which is particularly vulnerable to oil pollution (for example, the Great Barrier Reef area);
- terminal operations at over 70 sea ports; and
- a wide range of port activity levels leading to possible localised and transient congestion.

Under these circumstances it becomes apparent that the absolute level of risk of oil pollution is comparatively quite small, but the consequences of an oil pollution episode or series of episodes can be very serious in both economic and social terms, depending on location. Chronic pollution (the long-term slow release of oil from repeated spills) can be serious where sensitive ecosystems may not have sufficient opportunity to recover between pollution episodes. An Australian Parliamentary Inquiry in 1978 (Australia, Parliament 1978) found that the environmental damage caused by frequent small oil spills is often as great, if not greater than that caused by large (catastrophic) spills, and that not enough significance was attached to preventing small spills or dealing with them in an environmentally acceptable way.

The general situation leading to the risk of marine oil pollution required the development of a plan which would allow a co-ordinated and rapid response to oil spills, while at the same time minimising costs. The so-called 'National Plan to Combat Pollution of the Sea by Oil'[1] has been in operation in Australia since October 1973. It represents a combined effort by Commonwealth and State Governments, with the assistance of the oil industry, to help provide a solution to the threat posed to the coastal environment by oil spills from ships.

1. This will be referred to subsequently by the shortened title 'National Plan'.

The original concept of the National Plan was to provide chemical spraying equipment and dispersant material at nine points around the Australian coastline and a central stockpile of ship-to-ship transfer equipment. Additional equipment (ship-to-ship transfer equipment, and retainment and recovery equipment) is located in Sydney for air dispatch to pollution incidents as required.

The use of the National Plan resources is based on three principles:

- oil pollution should be allowed to disperse unless it is likely to cause environmental damage;
- if oil has to be removed then physical recovery techniques should be employed in preference to chemical dispersants; and
- where such recovery techniques are not applicable, low toxicity dispersants are to be employed.

The administration, maintenance and development of the National Plan are funded by the Commonwealth Government. These costs are offset through a levy imposed on shipping using Australian ports. Furthermore, every effort is made to recover the costs of pollution removal from those responsible for causing the problem.

The Parliamentary Inquiry cited previously, pointed out that there is no economic or operational justification to equip and prepare for a major disaster which may never occur. The Inquiry's Report stated that a planned response capability was required which was able to cope with an anticipated level of oil pollution, based on the nature of shipping activity carried out in Australian waters.

In order to derive information on the resources required to maintain the National Plan in accordance with the philosophy recommended by the Parliamentary Inquiry, the Commonwealth/State and Commonwealth/Industry agencies responsible for the National Plan requested the Department of Transport Australia (DoTA) to produce an assessment of the future risks of oil spills in the marine environment. Previous work in this area relied on both data and methodology derived from overseas sources. Comparison of this overseas work with the historical situation in regard to oil spills in Australia over the past decade highlighted some apparent discrepancies. These discrepancies threw some doubt on the applicability of the overseas analysis to the Australian oil spill situation.

The Coastal Services Division (CSD) of DoTA requested that the Bureau of Transport Economics (BTE) undertake a study of marine oil pollution risks in the Australian context. This study was intended to produce a statistical analysis of Australian oil spill history. It was also designed to form the basis for an assessment of the risks of marine oil spills in the future.

It is worthwhile stressing the statistical nature of the analysis. Because oil spills are basically chance events, their occurrence and characteristics are governed by probability distributions. This, of course, implies that any predictions which are made on the basis of the statistical models[1] developed for the oil spill processes can only be expressed in terms of levels of probability that spills will occur, and that they will involve certain spill volumes. The analysis presented in this Report was aimed at identifying the most appropriate statistical distributions underlying the oil spill process in Australia, and at interpreting the results to assist the planning process.

STRUCTURE OF THE REPORT

The next section of this chapter considers the scope and objectives of the study in more detail and outlines certain constraints and basic assumptions which impinged on the

1. The term 'model', as used throughout this Report, refers to a statistical relationship taking the form of a mathematical expression. Such an expression embodies the nature of the relationship between a particular parameter and other so-called independent variables, without necessarily implying a 'cause and effect' situation.

analysis. Chapter 2 outlines the historic background of the characteristics of the oil spills analysed in this Report. It begins with an outline of the Federal legislation on oil pollution, which was designed to minimise both the number and volume of oil spills and to generate a source of funds for cleaning up oil spills which did occur. The second part of Chapter 2 presents a summary of oil spill occurrences in Australia during the period 1 July 1972 to 30 June 1979. Chapter 3 outlines the basic results of the analysis of the frequency of occurrence of oil spills of various types. Results derived from an analysis of volumes of oil spilled are also presented in Chapter 3. Chapter 4 uses the statistical models derived in Chapter 3 to project the average number and size of oil spills for the fiscal years 1984-85 and 1989-90 and illustrates the use of these projections in estimating future economic dispersant stockpile levels. Finally, Chapter 5 concludes this Report with some brief remarks on the nature and limitations of the study.

A certain amount of technical analysis is included in this Report. However, an attempt has been made to minimise this, consistent with the aim of presenting both statistical results and their application to practical situations.

STUDY OBJECTIVE

In line with the requirements to assist future development of the National Plan, the BTE developed a study designed to analyse information which would throw some light on the possible number, sizes and geographic locations of marine oil spills over the next ten years. The general aim of this exercise was to allow a ranking of individual ports and sections of the Australian coast in terms of their potential requirements for anti-pollution resources, both capital and labour.

Following an examination of the characteristics of various port operations, and of the types of spills which have occurred over the past seven to eight years, it became clear that oil spills would need to be classified into a number of categories for the purposes of analysis. The categories selected as being most appropriate for these purposes are:

- spills associated with the loading or discharging of oil and oil products in ports ('oil-handling spills');
- spills associated with bunkering operations in ports ('bunkering spills');
- spills associated with any other operations such as ballasting and tank cleaning in ports ('miscellaneous spills');
- spills outside ports, but sufficiently close to the coast to be potentially damaging ('at-sea spills');
- spills associated with drilling rig blowouts ('drilling rig blowout spills');
- spills associated with offshore platform oil production ('offshore platform spills'); and
- spills associated with undersea pipelines ('undersea pipeline spills').

Having defined these spill categories, the analysis aimed at answering a number of questions in relation to each category, as appropriate. Although lack of suitable statistical information precluded the analytical treatment of each of the above categories in equal depth, the questions which the study has attempted to address are outlined below.

- Given the volume of oil handled at a port in a certain time period, how many oil-handling spills may occur, and how much oil may consequently be spilled through this mechanism in that time period?
- Given the volume of bunker fuel loaded at a port in a certain time period, how many bunkering spills may occur, and how much oil may consequently be spilled through this mechanism in that time period?
- Given the total weight of cargo handled at a port in a certain time period, how many miscellaneous spills may occur, and how much oil may consequently be spilled

through this mechanism in that time period?

- Given the volume of oil handled, volume of bunker fuel and total weight of cargo handled at all ports in Australia in a certain time period, how many spills may occur and how much oil may be spilled in any group of ports (for example, in all the ports in one State or all the ports in Australia)?
- What are the minimum dispersant stockpile levels which guarantee that a specified proportion of spills can be accommodated?

It must be stressed that the questions posed above relate to statistical or chance events, and hence the responses to these questions can only be formulated in statistical or probabilistic terms. In particular the aim has been to provide 'expected value'[1] information as well as information which indicates the likely upper limits to the numbers and sizes of spills in specific time periods.

ASSUMPTIONS AND BACKGROUND

In this study, all ports and sections of the coast were assumed to be equally vulnerable to oil pollution. As will be discussed later, ports were grouped into a number of categories based on the nature of particular ports. However, factors such as weather, tide and seabed conditions were not treated as independent factors. These factors were assumed to be implicit in the historic spill data and were not expected to change significantly in the future. Futhermore, specific analysis of these environmental factors was precluded since, in most cases, they were not recorded in the spill reports.

The study was concerned only with spills of persistent oils[2]. Within the limits previously noted, all spill volumes which have the potential to pollute were considered. The regions of interest in terms of pollution potential were all ports, all sections of the Australian coast (including Norfolk Island and Christmas Island) and all reefs and islands within Australian internal and territorial waters.

A basic assumption which was necessary in the study was that the level of oil spill risk was proportional to some measure of shipping activity. This (plausible) assumption was necessary to permit the analysis to be useful in assessing future spill risks, given the expected level of future shipping activity. One such measure of activity is the number of handling operations; such a measure of activity is referred to in a technical sense as an 'exposure variable' in the context of a situation involving exposure to risk. Unfortunately, complete data on the number of operations were not available for any of the spill types and were not expected to be available in the future. Other measures of shipping activity include the weight of cargo handled, number of ships entering the port and the volume of oil handled. Earlier studies, in particular those by Devanney and Stewart (1974), have shown a general relationship between the number of oil spills and the volume of oil handled. In the present study, the exposure variables used to estimate spill rates applicable to the previously-defined spill categories were taken as the volume of oil handled at a particular port[3], the volume of bunker fuel loaded at a port[4], and the total weight of cargo handled at a port[5]. Historical data for these exposure variables are graphed, together with values for their future levels, in Appendix I. The treatment of other types of spills, mentioned previously in this chapter, is discussed later.

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1. This refers essentially to the average results. For example, it may be determined that a port is expected to have **on average** n spills in a given year. However, the **actual** number of spills at that port in the specified year may be greater or less than n.
2. This refers to oils with a density in excess of around 0.82 kilograms/ litre. Lighter oils present less of a pollution problem since they tend to disperse or evaporate rapidly.
3. For the estimation of handling spills.
4. For the estimation of bunkering spills.
5. For the estimation of miscellaneous spills.

The ports analysed in this study were those ports which handled at least 500 tonnes of cargo in at least one year over the period 1 July 1972 to 30 June 1979[1]. There were no oil spills recorded in the study period at the small ports omitted from the analysis and the assumption is made that no spills will occur at a port which handles less than 500 tonnes of cargo in a year.

The weight of oil and oil products handled was obtained from DoTA (1981) and was converted to volume using appropriate density factors. These factors were only approximate because of the varying detail with which each port recorded the **type** of product moving through that port. The weight of cargo handled at each port was obtained from the same DoTA publication.

Data on the volume of bunker fuel delivered at each port were obtained from five oil companies. These five companies accounted for 85 per cent of the bunker fuel market. Unfortunately, some of these companies provided figures for only two or three years out of the eight years intended for analysis, and the only years for which all of the companies provided information were the calendar years of 1979 and 1980. Hence, part of the analysis of the bunkering spill risk was based on data for only one year, as oil spill data were available only up to 1979 at that stage.

In a large number of cases the reports of oil spills did not record the particular shipping operation which was being performed at the time of the spill. In these cases DoTA officers deduced the type of spill from other recorded facts such as type of fuel spilled, clean-up costs and times, the type of vessel involved and the location of the spill.

In many cases, the **amount** of oil or oil product spilled also was not recorded. In this study, analyses were undertaken using the information that was recorded. It was thus assumed that for those instances in which the quantity spilled was not recorded the amount spilled followed the same pattern (or more precisely, probability distribution) as the recorded spills in the same category ('oil-handling', 'bunkering' or 'miscellaneous').

The type of petroleum product spilled, cause of the spill (other than the operation being performed at the time), duration, environmental conditions, response procedure, costs and so on were not specifically considered in the study, since the information relating to these aspects was not available on any consistent basis.

For each of the types of oil spill mentioned previously, certain alternative approaches to the analysis of the expected number of oil spills were considered. These approaches ranged from an aggregation of the statistical oil spill data and the exposure variable data over all ports to produce one overall oil spill rate, to the specific consideration of the data from each port individually. Neither of these two extremes was regarded as satisfactory. Aggregating information from all ports would produce a result which ignored the different operational characteristics of various ports and would not allow any differentiation in the assessment of risks at individual ports. On the other hand, insufficient data were available on a port by port basis for each port to be treated individually.

Further examination revealed that an approach between these extremes was likely to produce the most appropriate results. Ports could be grouped by port type and the resulting spill rates for the groups of ports could be used for any port expected to be in each group in the future. This approach gives more realistic results than one based on an aggregation over all ports, and at the same time is convenient to apply. Hence, a statistical model based on this approach was developed for each spill type. Projections of characteristics of future oil spills at a port then depend upon that port being grouped correctly, although it was not expected that many ports would change in their operational characteristics sufficiently to require their re-classification into another group.

1. 'The period 1 July 1972 to 30 June 1979' will be referred to subsequently by the shortened title 'the study period'.

CHAPTER 2—LEGISLATIVE AND HISTORICAL BACKGROUND

This chapter begins with an outline of the legislation administered by DoTA on oil pollution in Australian waters, from the *Navigation Act* 1912 to the recent (1981) Protection of the Sea Acts. The second part of the chapter broadly reviews statistical information on oil spill occurrences in Australia for the period 1 July 1972 to 30 June 1979. The data analysed in this study were collected over a period during which the earlier Pollution of the Sea by Oil Acts 1960 and 1972, were administered. The oil spill occurrence patterns presented in this chapter may change in the future under the new (1981) Act.

OVERVIEW OF FEDERAL LEGISLATION ON OIL POLLUTION

The Department of Transport Australia (DoTA) has been responsible for administering several pieces of legislation on oil pollution in Australian waters. These are:

- part VII A of the *Navigation Act* 1912;
- *Pollution of the Sea by Oil Act* 1960;
- *Pollution of the Sea by Oil (Shipping Levy) Act* 1972; and
- *Pollution of the Sea by Oil (Shipping Levy Collection) Act* 1972.

The successor to DoTA, the Department of Transport and Construction (DTC), will be administering the 1981 Protection of the Sea legislation package which will replace all the marine pollution legislation currently administered by DTC. The package incorporates the following Acts:

- *Protection of the Sea (Civil Liability) Act* 1981;
- *Protection of the Sea (Discharge of Oil from Ships) Act* 1981;
- *Protection of the Sea (Powers of Intervention) Act* 1981;
- *Protection of the Sea (Shipping Levy) Act* 1981;
- *Protection of the Sea (Shipping Levy Collection) Act* 1981; and
- *Navigation (Protection of the Sea) Amendment Act* 1981.

This package of legislation received Royal Assent in April 1981 and it is envisaged that part of the legislation will be proclaimed towards the end of 1982.

The Department of Home Affairs and Environment operates the *Beaches, Fishing Grounds and Sea Routes Protection Act* 1932-66. The Bureau of Customs collects the shipping levy authorised by the Pollution of the Sea by Oil (Shipping Levy) and (Shipping Levy Collection) Acts.

The State Governments for the most part have legislation which mirrors the Federal legislation for waters in their State within the three-mile limit.

The Navigation Act gives the Minister for Transport and Construction powers to prevent or deal with oil escaping from ships into Australian coastal waters, the coast or reefs. Fines, depending on quantity of oil on board the ships, range from $2000 to $8000 on the ship's owner. Expenses in cleaning any oil leaked into the sea are recoverable from the owner with a maximum liability constraint. These Navigation Act provisions took effect late in 1970 and there have been no changes to the levels of the maximum fines that can be imposed. The 1981 Amendment to the Act will repeal the provisions relating to civil liability and intervention on shipping casualties. The areas these provisions are concerned with will be given extended application by operation of the *Protection of the Sea (Civil Liability) Act* 1981 and the *Protection of the Sea (Discharge of Oil from Ships) Act* 1981.

The *Protection of the Sea (Civil Liability) Act* 1981 is based on the concept of ensuring that adequate compensation is available where pollution damage occurs, on land or in Australian waters, when oil escapes or is discharged from a ship carrying a bulk oil cargo or where expenses are incurred to prevent pollution damage. The Act provides for the owners of bulk oil cargo ships to limit their liability for pollution damage by maintaining insurance cover. The ship owners' liability would be limited to an amount determined by the size of the ship.

The *Protection of the Sea (Powers of Intervention) Act* 1981 will give the Commonwealth Government the power to intervene in a situation which has caused or threatens to cause an oil pollution incident. The intervention powers also extend to incidents involving certain other noxious substances.

The Pollution of the Sea by Oil Act came into force in 1962 (and was amended in 1965 and 1972 taking effect in 1967 and 1973, respectively) and made it an offence to pollute prohibited parts[1] of the sea by oil. It also allows a surveyor to board a ship in Australian waters for various purposes. Initially, the maximum fine for discharging oil into the sea was £1000 ($2000) on both the owner and master of the ship. However, in 1973 these fines were raised to a maximum of $50 000 on the owner and master. Hindering a ship's surveyor in his duties was an offence initially punishable by a maximum fine of £100 ($200) but this also was increased in 1973 to $2000.

The *Protection of the Sea (Discharge of Oil from Ships) Act* 1981 has repealed and replaced the *Pollution of the Sea by Oil Act* 1960. Two important provisions that are incorporated into this Act are improved protection for the Great Barrier Reef and the imposition of limits on the size and location of cargo tanks in tankers. This new Act also doubled the maximum penalty for an unauthorised discharge of oil to $100 000 for a corporation. The penalty for an individual remained at $50 000.

There have been very few court cases under the 1962 and subsequent legislation. Reasons for the lack of prosecutions include the fact that a spillage in the sea under Federal jurisdiction is more difficult to detect than a spillage in Australian ports or State waters. Australian courts to date have tended not to impose heavy fines on those convicted under the legislation.

The Bureau of Customs collects the shipping levy on behalf of the Department of Transport and Construction, which currently administers the legislation under which it is collected. The Acts were assented to in 1972 and allowed for a **maximum** levy of 4 cents per ton[2] of the ships tonnage per quarter. The legislation which took effect in 1972 set the levy at 1 cent per ton per quarter. The levy rate was reduced to 0.8 cents per ton per quarter as from 1 October 1976. The levy was subsequently increased to 2 cents per ton per quarter from 1 July 1981 and more recently a **minimum** levy of $10 per ship per quarter was set. This took force from 1 October 1982.

The amount raised by the levy is closely related to the actual cost of operating the National Plan, including costs that cannot be recovered from the polluter. The National Plan provides stockpiles of equipment to deal with oil pollution, whether in Commonwealth or State waters, in several locations around Australia.

HISTORICAL OIL SPILL OCCURRENCES

The previous section briefly reviewed the legislation that has been in place governing marine pollution since 1912. This section presents statistical information on oil spills which occurred in Australian ports in the seven years of the study period (1 July 1972 to

1. Prohibited parts of the sea are those parts within 50 miles of the 'nearest land' (as defined in the legislation).

2. A 'register ton'.

30 June 1979) and hence which occurred during the period of the 1960 and 1972 legislation. The analyses which formed the basis of this study related to these spills.

The information supplied by DoTA indicated that 334 oil spills occurred in ports during this period and only one spill occurred at sea. Using the information reported to DoTA on each of the occurrences in ports, the 334 spills were categorised as handling spills (occurred during the loading or discharging of crude oil or crude oil products), bunkering spills (occurred during bunkering operations) or miscellaneous spills (occurred in situations other than those mentioned above). Handling spills accounted for 17 per cent of the total number of spills, bunkering spills accounted for 58 per cent and miscellaneous 25 per cent. These oil spill data are given in detail in Appendix II.

Figure 2.1 shows the trend, over the period 1 July 1972 to 30 June 1980, of the number of occurrences of the three types of spills, for Australia as a whole. The number of handling spills remained steady at an average of approximately eight per annum, while the number of bunkering spills decreased and the number of miscellaneous spills increased. The compensating movements exhibited by the numbers of bunkering and miscellaneous spills may be due to the nature of the categorisation of these types of spills, in that trimming, cleaning fuel tanks and so on were taken as miscellaneous spills, but are in fact often performed in conjunction with bunkering operations.

In the analysis which follows, ports were classified as capital city or non-capital city ports. The capital city ports are the Port of Sydney (does not include Botany Bay), the Port of Melbourne, the Port of Brisbane, the Port of Port Adelaide, the Port of Fremantle (includes Kwinana) the Port of Hobart and the Port of Darwin.

Oil-handling spills

The information supplied by DoTA indicated that 55 oil-handling spills occurred in the study period, representing around 17 per cent of the total number of spills in this period. Approximately eight such spills occurred per year on average. Figure 2.2 shows the location of the 55 spills. Table 2.1 gives the total number of oil-handling spills, volume of oil handled[1] and spill rates by port for the study period.

It was expected that the volume of oil handled would be a good measure of the exposure of a port to the risk of oil handling spills. The reasonably stable spill rates (spills per gigalitre of oil handled) across the ports and further analysis in Chapter 3 supported this hypothesis. Further, the number of spills at a port was positively correlated with the volume of oil handled at that port. However, the ports represented in Table 2.1 encompass a wide range of levels of oil-handling activity. The nature of these handling activities may be different from port to port and the spill risk processes are also likely to differ. The non-capital city ports at which a refinery was located (such as Botany Bay, Geelong, Westernport and Port Stanvac) in general had lower oil-handling spill rates than capital city ports at which a refinery was located. Ports not associated with a refinery either reported no oil-handling spills or suffered high spill rates (as a result of the effect of a single spill and a comparatively small volume of oil handled). To compensate for the many factors which may affect the oil-handling spill rate at a port, the ports were homogenously grouped, as above, for the analysis in Chapter 3 of the expected number of spills at a port. Table 2.1 also shows the average volume of oil spilled per spill at ports for which at least one spill had volume recorded. The overall average volume spilled for those oil-handling spills for which spill volume was recorded in the study period, was 2545 litres. The average volume spilled per spill at individual ports was very variable.

Bunkering spills

The information supplied by DoTA indicated that in the study period 194 spills occurred during bunkering operations. This number of spills represented 58 per cent of

1. Complete data by type of oil product were unavailable. The volume of oil handled referred to in this section is the volume of crude oil and any liquid petroleum product.

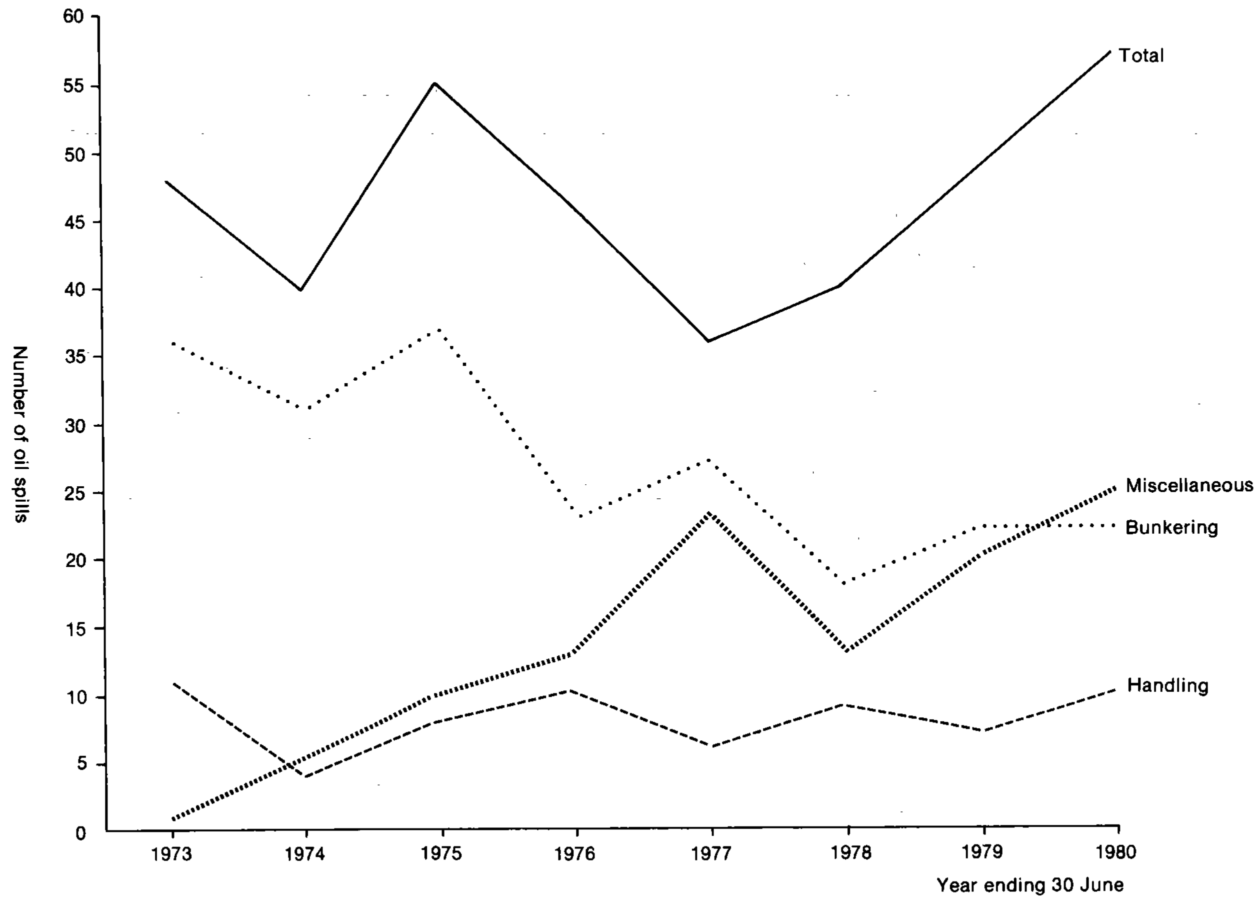

Figure 2.1 Annual numbers of oil spills in Australia: 1 July 1972 to 30 June 1980

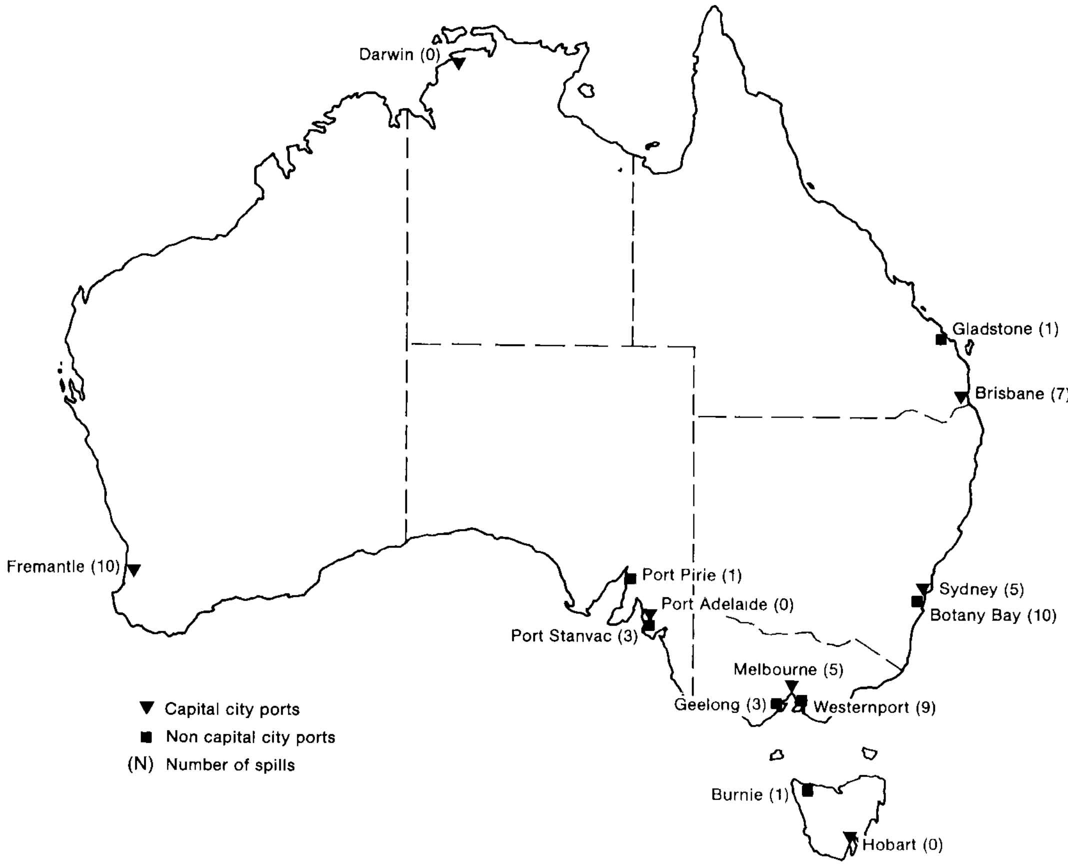

Figure 2.2 Location of oil-handling spills: 1 July 1972 to 30 June 1979

TABLE 2.1—CHARACTERISTICS OF OIL-HANDLING SPILLS BY PORT[a], 1 JULY 1972 TO 30 JUNE 1979

Port	*Number of spills*	*Volume of oil handled (gigalitres[b])*	*Spill rate[c]*	*Average volume[d] spilled (litres)*
		New South Wales		
Sydney	5	39.84	0.126	648
Botany Bay	10	82.10	0.122	1 799
Newcastle	—	14.22	—	—
Port Kembla	—	8.24	—	—
		Victoria		
Melbourne	5	20.71	0.241	na
Geelong	3	27.48	0.109	183
Portland	—	2.54	—	—
Westernport	9	81.00	0.111	554
		Queensland		
Brisbane	7	44.05	0.160	9 480
Cairns	—	2.15	—	—
Gladstone	1	5.11	0.195	22 800
Townsville	—	6.43	—	—
		South Australia		
Port Adelaide	—	3.91	—	—
Port Stanvac	3	27.38	0.110	985
Port Pirie	1	2.80	0.359	1 364
		Western Australia		
Fremantle	10	57.93	0.173	632
Barrow Island	—	14.38	—	—
Dampier	—	2.23	—	—
Wyndham	—	2.58	—	—
		Tasmania		
Hobart	—	3.46	—	—
Burnie	1	1.87	0.535	34
Launceston	—	2.04	—	—
		Northern Territory		
Darwin	—	3.13	—	—
Gove	—	2.95	—	—
		Australia		
Remaining 33 ports[e]	—	19.28	—	—
All ports	55	477.80	0.115	2 545

a. Ports which handled at least one thousand tonnes of oil or oil products during at least one year in the period.
b. One gigalitre is one thousand million litres.
c. Defined as the number of spills per gigalitre of oil handled.
d. Where recorded.
e. Total for 33 ports (each of which recorded volumes of less than 1.82 gigalitres).

the total number of all spills recorded in that period. Approximately 28 bunkering spills occurred each year on average. Figure 2.3 shows the location of these 194 spills. Table 2.2 shows the number of bunkering spills, the volume of bunker fuel loaded and the spill rates by port for 1979[1].

For bunkering spills, the measure of exposure to spill occurrences was taken to be the volume of bunker fuel loaded at a port. The number of spills was positively correlated with the volume of bunker fuel loaded. Although data for a single year were insufficient to make generalisations, it appeared that capital city ports experienced the lowest bunkering spill rates (an average of 10 spills per gigalitre of bunker fuel loaded). Other ports tended either to experience higher rates (due to the influence of a single spill) or to have reported no bunkering spills at all. The overall spill rate was dominated by the capital city data and was 11 spills per gigalitre of bunker fuel loaded. Further analysis which is detailed in Chapter 3, showed that there was not enough information to justify grouping the ports according to different bunkering spill rates.

The average volume spilled per bunkering spill for the study period was 729 litres. This was much smaller than the average volume spilled per oil- handling spill in the same period (2545 litres). Furthermore, the average volumes spilled per bunkering spill were not as variable as those for handling spills.

Miscellaneous spills

Information supplied by DoTA indicated that during the study period 85 spills occurred in ports during operations which were neither bunkering nor oil loading/discharging operations. These miscellaneous spills were caused, in the main, by bad maintenance and human error (whilst ballasting and trimming). They represented 25 per cent of all spills during the period, and, approximately 12 such spills occurred per year, on average. Figure 2.4 shows the location of these 85 spills. Table 2.3 gives the total number of miscellaneous spills, the weight of cargo handled, the average volume spilled per spill and the spill rates, by port, for the study period. The weight of cargo handled was obtained from DoTA (1981 and earlier issues).

The measure of exposure to miscellaneous spills was taken as the total weight of cargo handled. The number of miscellaneous spills and the weight of cargo handled were positively correlated across the ports. There were however obvious differences in the miscellaneous spill rates for various types of ports. Ports which handled heavy mineral products, such as Dampier, Newcastle and Port Kembla, experienced comparatively low spill rates while those ports which handled small quantities of mainly general cargo, such as Thevenard, Cairns and Rockhampton, experienced comparatively high spill rates. Again, these high spill rates often tended to result from a single spill being reported in conjunction with a relatively small weight of cargo handled. The capital city ports (defined previously) experienced spill rates in the middle range with the exception of Brisbane, which experienced a spill rate which was approximately double the average for the other capital city ports. These homogenous port groupings were used in the analysis of the expected number of spills at a port in Chapter 3.

The average volume spilled per miscellaneous spill (19 785 litres) was much higher than the average for either handling spills (2545 litres) or bunkering spills (729 litres). This high average for miscellaneous spills was influenced markedly by one very large spill of 800 000 litres in Newcastle in October 1974.

Other spills

During the study period there were no reported spills in Australian waters of persistent oil from undersea pipelines, drilling rig blowouts or off-shore platforms, nor from at-sea groundings or collisions. However, in March 1970 an at-sea spill occurred when the

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1. As noted in Chapter 1, comprehensive data on bunker fuel sales on a port-by-port basis were available only for 1979. Since data on these sales formed the basis for the exposure variable used in the bunkering spill analysis, the analysis had to be restricted to this particular year.

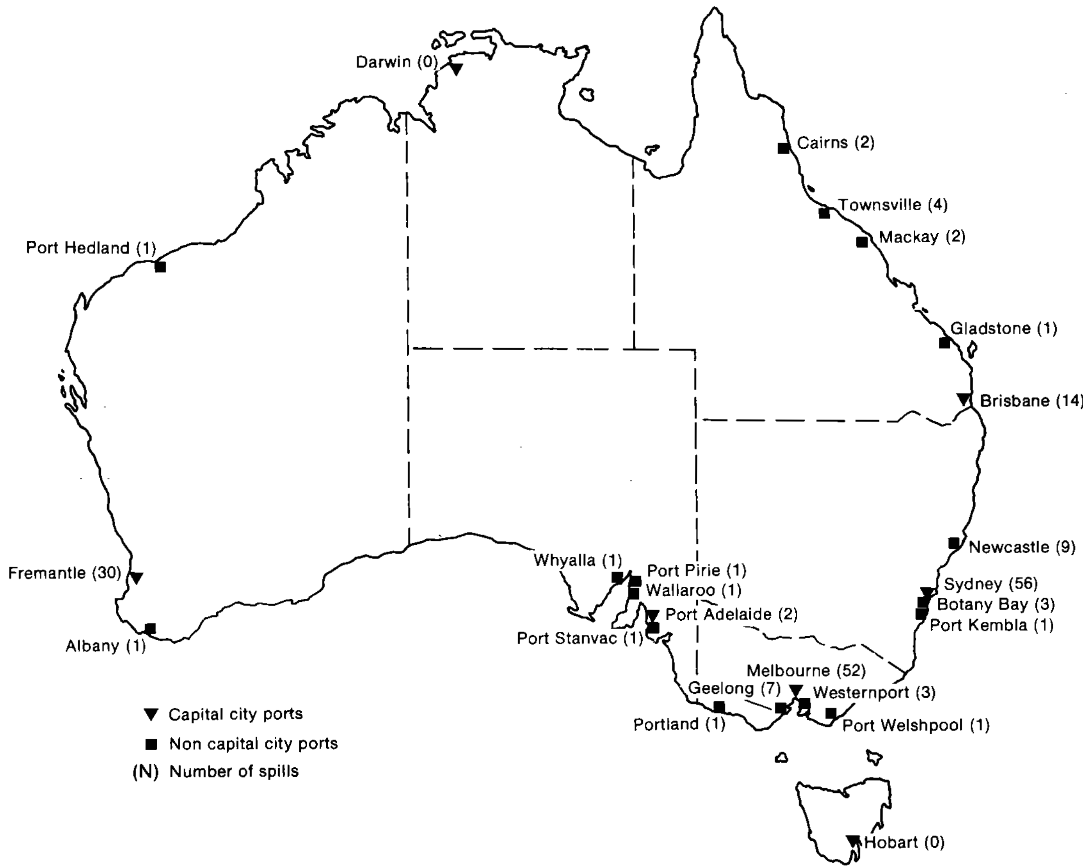

Figure 2.3 Location of bunkering spills: 1 July 1972 to 30 June 1979

Oceanic Grandeur ran aground in the Torres Strait spilling approximately 2000 tonnes of crude oil.

Very little analysis can be performed on these types of spills in the Australian context. Overseas data, in particular from UK and USA, were not considered to be appropriate because of the lower shipping densities around the Australian coastline relative to the shipping densities experienced in those countries[1]. Some attempt is made in Chapter 3 to estimate upper bounds on the spill rates for these types of spills in Australia.

TABLE 2.2—CHARACTERISTICS OF BUNKERING SPILLS BY PORT[a], 1979

Port	*Number of bunkering spills*	*Volume of bunker fuel (megalitres[b])*	*Spill[c] rate*	*Average[d] volume spilled (litres)*
		New South Wales		
Sydney	8	453.5	0.018	120
Botany Bay	1	—[f]	—	90
Newcastle	1	101.3	0.010	40
		Victoria		
Melbourne	4	469.7	0.009	na
Westernport	1	37.7	0.027	na
		Queensland		
Brisbane	—	52.2	—	—
		South Australia		
Port Adelaide	1	74.6	0.013	455
		Western Australia		
Fremantle	4	628.9	0.006	na
Albany	2	5.0	0.398	116
Port Hedland	1	1.3	0.746	na
		Tasmania		
Hobart	—	37.7	—	—
		Northern Territory		
Darwin	—	10.6	—	—
		Australia		
Remaining ports[e]	—	246.8	—	—
All ports	23	2 083.3	0.011	138

a. Capital city ports as well as other ports which reported at least one bunkering spill in 1979.
b. One megalitre is one million litres.
c. Refers to the number of spills per megalitre of bunkering fuel loaded.
d. Where recorded.
e. Total for the remaining eight ports which supplied bunker fuel in 1979.
f. Bunkering fuel was available on a restricted basis. No sales were reported by the companies servicing Botany Bay, however one spill occurred and was ascribed to bunkering operations.

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1. Of course navigational conditions also are markedly different in the three situations, and these also influence oil spill risks.

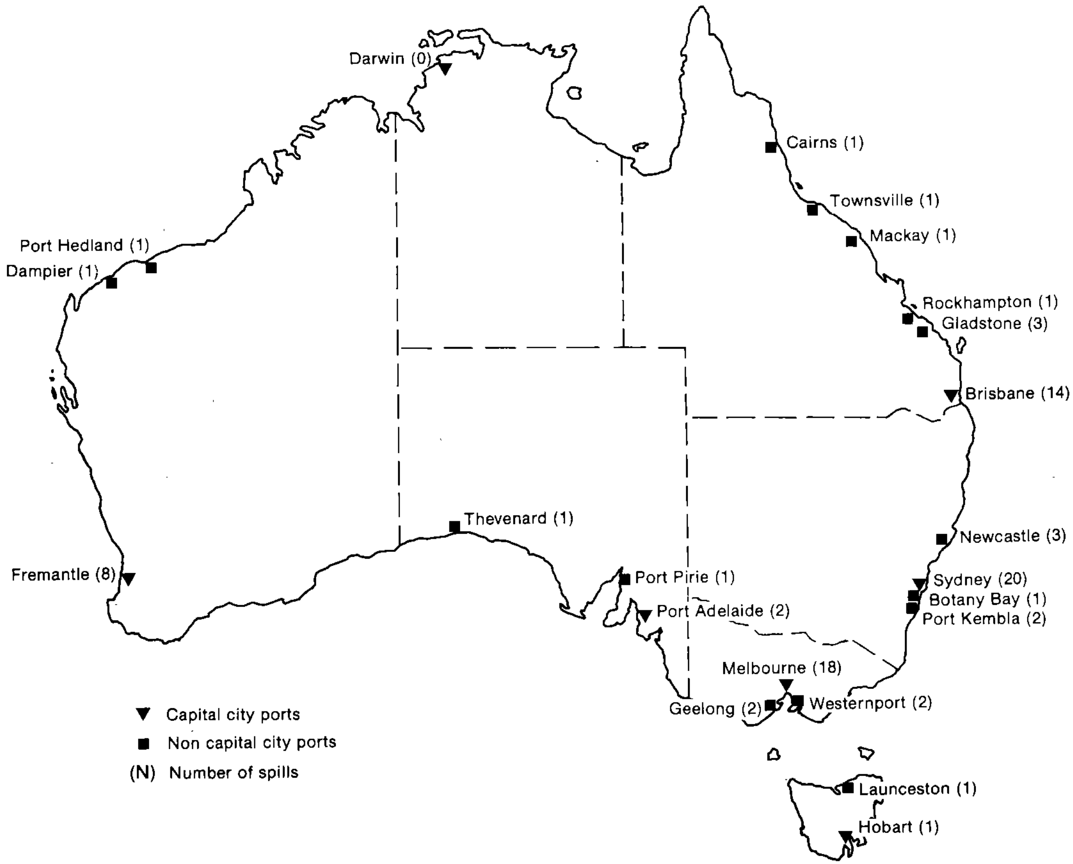

Figure 2.4 Location of miscellaneous spills: 1 July 1972 to 30 June 1979

TABLE 2.3—CHARACTERISTICS OF MISCELLANEOUS SPILLS BY PORT[a], 1 JULY 1972 TO 30 JUNE 1979

Port	*Number of spills*	*Weight cargo handled (megatonnes)*[b]	*Spill*[c] *rate*	*Average volume spilled*[d] *(litres)*
		New South Wales		
Sydney	20	140.0	0.143	200
Botany Bay	1	65.6	0.015	20
Newcastle	3	119.9	0.025	400 000
Port Kembla	2	110.9	0.018	500
		Victoria		
Melbourne	18	119.0	0.151	na
Geelong	2	39.1	0.051	na
Westernport	2	77.5	0.026	40
		Queensland		
Brisbane	14	57.6	0.234	3 040
Cairns	1	5.3	0.189	18
Gladstone	3	105.1	0.029	na
Mackay	1	8.0	0.125	na
Rockhampton	1	1.3	0.795	227
Townsville	1	15.1	0.066	568
		South Australia		
Port Adelaide	2	25.3	0.079	1 840
Port Pirie	1	8.8	0.114	855
Thevenard	1	5.3	0.190	na
		Western Australia		
Fremantle	8	117.2	0.068	248
Barrow Island	1	11.7	0.086	na
Dampier	1	230.9	0.004	1 160
		Tasmania		
Hobart	1	20.8	0.048	na
Launceston	1	22.0	0.045	450
		Northern Territory		
Darwin	—	6.1	—	—
		Australia		
Remaining 54 ports[e]	—	751.1	—	—
All ports	85	2 063.5	0.041	19 785

a. All ports which handled at least one thousand tonnes of cargo during at least one year in the period.
b. One megatonne is one million tonnes.
c. Refers to the number of spills per megatonne of cargo handled.
d. Where recorded.
e. Total for 54 ports.

Comparison of spills by type

Spill rates for the three types of spills cannot be compared because of the different exposure variables used in each case. Bunkering and handling spill rates could be compared although the operations involved are different. In the study period there were on average 11 bunkering spills for every gigalitre of bunker fuel loaded compared to approximately 11 oil-handling spills (strictly 11.5 spills) for every 100 gigalitres of oil handled. The difference could arise from the number of operations involved, there being fewer **operations** involved in handling a quantity of oil than in loading the same quantity of bunker fuel, but could also result from differences in loading equipment, techniques and manpower skills.

The average volumes spilled per spill were affected by small numbers of comparatively large spills. An alternative measure, the median, is useful for comparing typical spill volumes for the three types of spill. The median spill volume is the volume which is exceeded in exactly half of the spills.

Median spill volumes for handling, bunkering and miscellaneous spills were, respectively, 420 litres, 165 litres and 185 litres. Proportionally, the number of spills involving a 'large' spill volume was higher for handling spills than for the other two spill types.

CHAPTER 3—DETAILS OF OIL SPILL ANALYSES

For each of the oil spill types introduced in Chapters 1 and 2, two basic statistical models are derived. These models provide:

- an assessment of the relative frequency with which an oil spill will occur at a particular port; and
- an assessment of the volume of oil or oil product which will be spilled (given that a spill occurs).

It must be emphasised that both the frequency of spill and the volume spilled are statistical quantities, and hence are only capable of being described in statistical terms. In this chapter, the discussion of the various spill types revolves around the probability distributions which have been found to represent the historical spill information[1] most satisfactorily. Explanations of the implications of these probability distributions are also included.

In many areas throughout this Report, **non-integer** average spill numbers will be discussed, although the number of actual spills can only be **integer.** It is worth stressing at this stage that non-integer spill numbers derived from the models refer to **theoretical** averages, from which the statistical chances of particular (integer) numbers of spills can be derived.

OIL-HANDLING SPILLS

Frequency distribution

As previously mentioned the number of spills which occur at a port may depend on the type of oil and oil products handled, the equipment used for loading and discharging, and the expertise of the personnel involved as well as to the volume of oil and oil products handled. In order to account in some way for the first three of these factors, ports were grouped into the three groups[2] indicated in Chapter 2. These groups are defined in detail in Table 3.1.

Table 3.1 also gives the spill rates for the three groups of ports, defined as the number of oil-handling spills per volume of oil and oil products handled at the ports over the study period.

The ports in Group 1 were expected to have two general types of handling spills; one type involving the handling of large volumes of crude oil and products and the other type involving the handling of small quantities of oil products. These ports experienced much higher spill rates than ports in the other two groups. This indicated that the high level of activity at these ports, possibly combined with the interaction of general cargo and refinery operations, produces an increased risk of occurrence of oil spills. Group 2 ports were expected only to experience one general type of handling spill, associated with the handling of large quantities of crude oil and products. The average spill rate for these ports was lower than that for ports in Group 1. The ports in Group 3 represented mainly importers of small quantities of many different oil products for consumption at the port or distribution to nearby centres. Ports in this group were expected to have

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1. The historical spill information analysed in this study is given in detail in Appendix II.
2. As noted subsequently, statistical tests were performed which showed that these three port groups exhibited different levels of spill risk.

spills associated with these types of handling operations, and had the lowest average spill rate of the three groups.

The frequency of occurrence of spills in a given period was found to be described by a Poisson distribution with an average number of spills obtained by multiplying the appropriate spill rate by the volume of oil handled during the same period (the 'exposure variable'). Although this statistical distribution applies for any time period, it has been applied on an annual basis in all analyses described in this Report. Appendix III provides technical details of the Poisson distribution, and describes how this model can be used to obtain probabilities of various numbers of spills at a specific port or for a group of ports.

To illustrate the application of this type of model, consider a Group 1 port which handles 20 gigalitres of oil annually. The spill rate is 0.166 spills per gigalitre (from Table 3.1) and the average number of spills per annum is therefore 3.32. It can be indicated (Appendix III) that, for this average number of spills, the probability of three or more spills occurring is 0.65, and hence the probability of fewer than three spills occurring at that port in a year is 0.35.

A test was carried out to determine whether the statistical processes governing the oil spills were significantly different at ports in each of the three groups mentioned above. If this test had indicated that there were no significant differences among the three groups of ports, the information from all ports could have been 'pooled', with no distinction being made among ports in any of the groups. In practice, the test indicated that there were very significant differences between the three groups and that it was necessary to consider the individual spill rates for each of the port groups separately.

Spill volume distribution

For the study period the average volume spilled per oil-handling spill, the number of oil-handling spills and the volume of oil handled are given in Table 3.2, for those ports at which the volume of at least one oil spill was recorded in the period. These data were analysed to investigate relationships between spill volume (given that a spill occurred) and the number of spills and the volume of oil handled. It was indicated in Chapter 2 that handling, bunkering and miscellaneous spill volumes exhibited different characteristics, and that it was necessary to analyse each type separately.

An estimate of the amount of oil spilled was recorded for only 40 of the 55 handling spills which were reported. Analysis of the available information indicated no statistically significant correlation between the average volume of oil spilled per spill at a port and the volume of oil handled at the port. Further, there was no statistically significant correlation between the average volume spilled per spill and the number of spills. Since no significant relationship between spill volume and other characteristics associated with the oil-handling operations could be found, the oil-handling spill volume data were treated as observations from a single statistical distribution, and goodness-of-fit tests showed that they were well described by the 'lognormal' distribution. Four other statistical distributions were examined but these produced inferior results in comparison with the lognormal distribution outlined above. Appendix IV gives the results of the estimation procedure.

The estimated lognormal distribution was used as the statistical model for spill volumes, and the expected frequencies of occurrence of various oil spill volumes were calculated and are given in Table 3.3. Actual results derived from the oil spill volume data are also shown in Table 3.3 for comparison. An average spill volume of 2044 litres may be calculated from this model. This compares reasonably with the data from the actual spills, for which the average volume spilled (in spills for which volume was recorded) is 2545 litres.

The difference between the model average and the actual average arises from the technique used to calibrate the statistical model. The technique used (maximum likelihood estimation) ensures that the probability of the occurrence of each spill

TABLE 3.1—OIL-HANDLING SPILL RATES BY PORT GROUP, 1 JULY 1972 TO 30 JUNE 1979

Group	*Type*	*Ports included*	*Number of spills*	*Oil handled (gigalitres)*[a]	*Spill rate*[b]
1	Capital city ports which handle large amounts of general cargo and which encompass at least one oil refinery	Fremantle Brisbane Melbourne Sydney	27	163	0.166
2	Non-capital city ports which include at least one oil refinery and handle oil and oil products primarily	Botany Bay Geelong Westernport Port Stanvac	25	218	0.115
3	Other ports	All other ports which handled at least 1000 tonnes of oil products in at least one year during the period 1 July 1972 to 30 June 1979	3	97	0.031
	All ports		55	478	0.115

a. One gigalitre is 10^9 litres.
b. Refers to the number of spills per gigalitre of oil handled.

TABLE 3.2—OIL-HANDLING SPILL VOLUMES BY PORT GROUP[a], 1 JULY 1972 TO 30 JUNE 1979

Group	*Type*	*Port*	*Average volume spilled (litres)*	*Number of spills*[b]	*Volume of oil handled (gigalitres)*
1	Capital city refinery ports[c]	Sydney	648	4	39.8
		Brisbane	9 480	5	44.1
		Fremantle	632	9	57.9
	Combined ports[a]	3 093	18	141.8	
2	Non-capital city refinery ports	Botany Bay	1 799	9	82.1
		Geelong	183	3	27.5
		Westernport	554	4	81.0
		Port Stanvac	985	3	27.4
	Combined ports[a]	1 153	19	218.0	
3	Other ports	Gladstone	22 800	1	5.1
		Port Pirie	1 364	1	2.8
		Burnie	34	1	1.9
	Combined ports[a]	8 066	3	9.8	
	All ports[a]		2 545	40	370.0

a. Ports for which at least one spill volume was recorded.
b. Spills for which an estimate of the volume spilled was recorded.
c. No volumes were recorded for oil spills of any type which occurred in the port of Melbourne. Instead areas of pollution were recorded, but this information could not be used in this study.

volume in the model is the closest approximation to the actual probability of occurrence, based on historical data. This approximation is achieved at the expense of tolerating some discrepancy in average spill volume. In the context of this study, and recognising the fact that statistical models can only be approximations to the 'true' distributions, this trade-off was regarded as appropriate.

TABLE 3.3—OIL-HANDLING SPILLS; DISTRIBUTION OF THE VOLUME SPILLED AND COMPARISON OF EXPECTED WITH ACTUAL RESULTS

Amount spilled (litres)	*Actual number of spills for which volume was recorded*	*Per cent of spills*	
		Expected[a]	*Actual*
Less than 50	4	8.7	10.0
50 or more but less than 100	4	8.4	10.0
100 or more but less than 500	15	33.3	37.5
500 or more but less than 1 000	5	15.9	12.5
1 000 or more but less than 5 000	8	25.2	20.0
5 000 or more but less than 30 000	3	7.8	7.5
30 000 or more	1	0.7	2.5
	40[b]	100.0	100.0

a. Derived from the statistical distribution fitted to the data.
b. Only 40 of the 55 handling spills had the spill volume estimates recorded.

BUNKERING SPILLS

Spill frequencies

The bunkering activities at the ports in Table 2.2 covered a wide range, from the supply of small quantities of bunker fuel for small pleasure craft to the supply of very large quantities for large container ships. In an attempt to account for the differences in the nature of various bunkering operations and other factors associated with port operations, the ports were initially categorised into four groups:

- capital city ports near which oil refineries were located;
- other capital city ports;
- non-capital city ports which were primarily oil refinery ports; and
- all other ports.

As noted previously, considerable difficulty was experienced in obtaining data on the exposure variable to be used in analysing bunkering spills and the bunkering data supplied by the oil companies were reasonably complete and consistent for only one year (1979 calendar year) in the study period for which consistent spill data were available. Analysis of bunkering spills by port group was carried out initially from these data[1].

1. Clearly this is hardly a satisfactory situation. Given that bunkering spills constitute the majority of spills recorded, it is important to have more detailed information on the exposure variables than has been available so far.

Spill rates for each group of ports were calculated using the number of spills in the calendar year 1979 and the volume of bunker fuel loaded at the ports in the same year. The results are not given here due to the confidentiality of the bunker fuel data. A statistical test to determine the necessity for using individual spill rates for the four groups of ports defined above was carried out and the results showed that the groups did not have statistically different spill rates[1]. From a statistical point of view, based only on data for the calendar year 1979, there was therefore no justification for distinguishing among the port groups defined above, and hence a single overall average bunkering spill rate was assumed for all ports.

In order to increase the amount of information used to estimate the bunker spill rate, data for total Australian consumption of bunker fuel (AIP 1980) for the study period were used together with the total number of bunkering spills for this period. The total consumption for this period was 18159 megalitres and 194 bunkering spills occurred in that period, resulting in an estimate for the bunkering spill rate of 0.011 spills per megalitre of bunker fuel loaded. This estimate is coincidentally numerically equal (to three decimal places) to the spill rate obtained for the 1979 port data, given in Table 2.2.

As for oil-handling spills, the distribution of the number of bunkering spills occurring in one year at any port is represented by a Poisson probability distribution, with an average number of spills per annum given by the spill rate multiplied by the annual volume of bunker fuel throughput (in megalitres) at the port.

The probability of a specified number of spills occurring can be obtained using the calculations summarised in Appendix III. Details in Appendix III can be used in a similar way to that previously described for oil-handling spills. For example, if a port loads 700 megalitres of bunker fuel in a year, the average number of spills expected to occur is 7.7 spills. From Appendix III it can be shown that the probability of 10 or more spills occurring at that port in the year is 0.25 (that is, this situation would occur during one year in four, on average).

Spill volumes

For this part of the analysis, the 194 bunkering spills which occurred in the study period were examined, and the 112 spills for which estimates of the spill volume were recorded were analysed. Table 3.4 gives the actual frequencies of particular amounts spilled in bunkering spills.

As in the case of oil-handling spills, the available information indicated that there was no significant correlation between the average volume spilled per spill and the number of bunkering spills at a port. The volume of bunker fuel throughput by port for 1979 was also not significantly correlated with the average volume spilled per spill. Since no significant relationships between bunkering spill volume and other characteristics could be established from the available data, a single statistical distribution was developed to represent the data relating to these volumes.

The lognormal distribution provided the best fit to the bunkering spill volume data. Results of the estimation procedure are given in Appendix IV.

Table 3.4 also shows the relative frequencies of occurrence of particular ranges of spill volume as obtained from this model. Details of the calculation of these probabalities are provided in Appendix IV. The average spill volume calculated from the lognormal distribution is 612 litres with 95 per cent of spills being less than 2367 litres in volume. For the **actual** spills which occurred during the period analysed, the average amount spilled per spill was 729 litres and 95 per cent of spills were found to be less than 2275 litres in volume. The model results compared very favourably with the actual results. The discussion presented in the previous section (indicating the philosophy adopted in

1. Again the paucity of the data must be emphasised. If a more comprehensive time series on bunker fuel consumption had been available for analysis, it is possible that differences among the port groups could have been established.

calibrating the derived statistical distribution using the data from actual spills) also applies here.

TABLE 3.4—BUNKERING SPILLS; DISTRIBUTION OF THE VOLUME SPILLED AND COMPARISON OF EXPECTED WITH ACTUAL RESULTS

Amount spilled (litres)	*Actual number of spills for which volume was recorded*	*Per cent of spills*	
		Expected[a]	*Actual*
Less than 50	35	25.8	31.3
50 or more but less than 100	15	15.1	13.4
100 or more but less than 500	37	35.5	33.0
500 or more but less than 1 000	9	10.6	8.0
1 000 or more but less than 5 000	13	11.2	11.6
5 000 or more but less than 15 000	2	1.5	1.8
15 000 or more	1	0.3	0.9
	112[b]	100.0	100.0

a. Derived from the statistical distribution fitted to the data.
b. Only 112 of the 194 bunkering spills had the spill volume estimates recorded.

MISCELLANEOUS SPILLS

Spill frequencies

The total weight of cargo handled at a port (DoTA 1981 and earlier issues) was used as the most suitable exposure variable for miscellaneous spills. The number of spills, total cargo handled and spills per megatonne of cargo handled have previously been given in Table 2.3.

The analysis of miscellaneous oil spills incorporated the numbers of miscellaneous spills by port in the study period (85 spills) and the total weight of cargo loaded and discharged by port for the same period.

Ports which handled heavy bulk cargo would have fewer ships entering per megatonne of cargo handled than ports which handled lighter cargo and hence relatively fewer opportunities for a spill to occur per megatonne of cargo handled. For this reason, the ports were categorised into four groups in an attempt to minimise the variation in the weight of cargo handled per ship in the ports in each group. In this categorisation, Group 1 comprised ports in the capital cities. The measure used to group the non-capital city ports was based on their degree of mineral cargo specialisation. It involved the weight of mineral cargo[1] associated with a single industry (DoTA 1981 and earlier issues) as a per cent of the total weight of cargo handled for the fiscal year 1978-79. Group 2 was the 'least specialised' group for which the mineral cargo comprised less than 50 per cent of total cargo handled; Group 3 was the 'specialised' group with

1. Woodchip cargo was included in this category, as an unpublished study indicated that weight of woodchip cargo per vessel entering was in the same range as weight of mineral cargo per vessel entering. For the same reason sand and crude oil were included.

mineral cargo comprising between 50 and 85 per cent and Group 4 was the 'highly specialised' group with mineral cargo comprising more than 85 per cent of total cargo handled. The four groups are given in Table 3.5 together with the total number of spills, total cargo handled and group spill rates.

The spill rates were calculated from the number of miscellaneous spills during the seven-year study period and the total weight of cargo handled in the same period for all ports in each group.

A statistical test was carried out to determine whether the spill rates relating to the four groups of ports were statistically different. The test indicated that the four rates were significantly different, and it was therefore necessary to consider the individual spill rates for each of the port groups separately.

Brisbane appears to have been out of line with the other capital city ports in that its miscellaneous spill rate for the study period (0.234 spills per megatonne of cargo handled) was greater than that of any other capital city port (these latter rates ranging from zero to only 0.151). The projected number of spills for Brisbane for the fiscal year 1979-80, using the overall spill rate for capital cities and the actual exposure variable levels for Brisbane in that year, was 3.2 spills and was close to the actual number of spills (two spills) for that period, whereas its historical annual average was five spills per year. This further indicates that, for the study period, Brisbane behaved in a significantly different way to the other capital city ports.

TABLE 3.5—MISCELLANEOUS SPILL RATES BY PORT GROUP, 1 JULY 1972 TO 30 JUNE 1979

Group	*Type*	*Ports included in the group (codes)*[a]							*Number of spills*	*Cargo handled (megatonnes*[b]*)*	*Spill rate*[c]
1	Capital city ports	201	301	401	501	601	701	801	63	486	0.130
2	Non-capital city ports —least specialised	204	302	403	506	602	702				
		205	303	404	508	604	703				
		208	304	408	509	608	704				
		209		409	510	609	705				
		211		410	511	610	706				
				411	514	611	708				
				413	516	614					
				414					7	168	0.042
3	Non-capital city ports —specialised	202	305	402	502	605					
		206		412	503						
		207			515						
					517				10	454	0.022
4	Non-capital city ports —highly specialised	203		405	504	603	707	802			
		210		406	505	606		803			
		212		407	507	607		804			
				415	512	612					
					513	613					
						615			5	956	0.005
	All ports								85	2064	0.041

a. Port names associated with these codes are given in Appendix V.
b. One megatonne is 1 million tonnes.
c. Refers to the average number of spills per megatonne of cargo handled.

With Brisbane omitted from the analysis, the frequency of occurrence of miscellaneous spills at a specific port, in a given period, can be shown to follow a Poisson distribution with an average number of spills calculated from the appropriate spill rate and the weight of cargo handled at the port in the same period. Again Appendix III gives the details of this probability model. No reasons were apparent for the fact that the distribution representing miscellaneous spill occurrences in other ports did not represent the occurrences of these spills in Brisbane. In the absence of additional information, it was decided not to treat Brisbane separately in the total analysis. However, its apparent divergence from the situation with respect to miscellaneous spills in other similar ports should be noted.

To illustrate the application of the probability model to miscellaneous spill risk analysis, consider a hypothetical port, in the 'least specialised' group (Group 2), which handles 10 megatonnes of cargo in a year. The average number of spills expected to occur would be 0.42, and it can be shown (Appendix III) that with this average number of spills, the probability that at least one spill occurs in the year is 0.33. This implies that at least one miscellaneous oil spill occurs during one year out of every three on average.

Spill volumes

Spill volumes were recorded for only 42 of the 85 miscellaneous spills reported in the study period. The 42 recorded volumes are analysed in this sub-section. As for handling and bunkering spills, the average spill volumes by port were not strongly correlated with either the exposure variable or spill frequency. Hence, spill volumes were treated as observations from a single statistical distribution and the statistical distribution which represented the data most accurately was, once again, the lognormal. The consistency with which the lognormal distribution described the three types of spill volumes indicated the suitability of this distribution for these variables. Appendix IV gives the results of the estimation procedure.

The frequency distribution of the spill volumes for miscellaneous spills, given in Table 3.6, shows both the actual frequency of spills and the frequency calculated from the lognormal distribution. Appendix IV provides further technical details of this statistical distribution.

Using the lognormal distribution as the model for spill volumes, the average amount spilled is 2964 litres, with 95 per cent of spill volumes being less than 9060 litres. The actual spills indicated an average amount spilled per spill of 19785 litres, with 95 per cent of these spills being less than 11 400 litres in volume.

The average volume of the actual spills is very much larger than that derived from the best statistical model found, while the spill volumes at the 95 percentile compare reasonably well. The actual average was influenced significantly by the inclusion of the one large spill (800 000 litres) which occurred in 1974. Use of the statistical model calibration technique, discussed in the previous sections, resulted in this large spill having only a small influence on the average spill volume estimated from the model. As noted previously, this technique estimates the probability of the occurrence of spills in the various volume classes with more precision than it estimates the average volume spilled.

SPILLS AT SEA

The number of spills at sea was assumed to be related to the volume of oil and oil products transported near the Australian coast. Estimates of these volumes could only be obtained indirectly from available sources. To carry out this estimation certain assumptions were required.

It was assumed that exports and imports of oil and oil products would be handled **once** at terminals (ports) and that domestic production shipped around the coast would be handled **twice** at ports[1]. Thus, the total amount of these commodities transported near the coast was estimated by:

Imports + Exports + ½ (Total volume handled at ports − Imports − Exports)

For the period 1 January 1970 to 30 June 1979 it was estimated that some 403 gigalitres of oil were transported near the coast. The volumes imported and exported[2] were obtained from the Australian Institute of Petroleum (AIP 1980) and the total volume handled was obtained from DoTA (1981 and earlier issues).

As noted in Chapter 2 only one spill occurred at sea during the period from 1 January 1970 to 30 June 1979, *Oceanic Grandeur.* On the basis of this limited observation period, the average spill rate is one spill per 403 gigalitres or 0.0025 spills per gigalitre transported. Unfortunately, this estimated spill rate has very little statistical significance as it is based on only one observed spill. As an example of the use of this average spill rate, if in one year 60 gigalitres of oil and oil products were transported around the coast the average number of at-sea spills expected to occur would be 0.15. On this basis it can be shown (Appendix III) that the probability of at least one spill occurring as a result of the transport of this volume would be 0.13. That is, at least one spill would occur approximately during one year in eight on average.

A more useful estimate of the at-sea oil spill risk is the upper confidence limit on the spill rate. The spill rate is increased hypothetically from zero until it reaches a value which, if true, would infer that the observed situation was an unlikely event. This maximum level is called the upper confidence limit and is the maximum spill rate which is **just** consistent with the occurrence of the observed situation.

TABLE 3.6—MISCELLANEOUS SPILLS; DISTRIBUTION OF THE VOLUME SPILLED AND COMPARISON OF EXPECTED WITH ACTUAL RESULTS

Amount spilled (litres)	*Actual number of spills*	*Proportion of spills*	
		Expected[a]	*Actual*
		(per cent)	
Less than 50	13	27.6	30.1
50 or more but less than 100	6	10.9	14.0
100 or more but less than 500	12	27.0	27.9
500 or more but less than 1 000	6	10.3	14.0
1 000 or more but less than 5 000	2	16.0	4.7
5 000 or more but less than 15 000	3	5.2	7.0
15 000 or more	1	3.0	2.3
Total	43[b]	100.0	100.0

a. Derived from the statistical distribution fitted to the data.
b. Only 43 of the 85 miscellaneous spills had the spill volume estimates recorded.

1. Once during loading and once during unloading.
2. LPG not included.

The observed situation of at-sea spills was one spill in a period during which 403 gigalitres of oil was transported. If the spill rate was as high as 0.012 spill per gigalitre, the probability of no more than one spill in 403 gigalitres (as observed) is 0.05 (5 per cent). This spill rate (0.012) is the upper 95 per cent confidence limit. The upper 90 and 95 per cent confidence limits on the at-sea spill rates are given in Table 3.7.

UNDERSEA PIPELINE, DRILLING RIG BLOWOUT AND OFFSHORE PLATFORM SPILLS

Exposure variable data for these types of spills were available for the nine-year period 1 January 1970 to 30 December 1978. The undersea pipelines in Australia which are treated in this study are the crude oil pipelines from the offshore drilling platforms in Victoria. Undersea pipelines for the loading and discharging of oil and oil products at refineries are not included here because data for the relevant exposure variables were not available.

The volume piped undersea in Australia[1] in the period was 170 gigalitres.

During the same period there were a total of 381 off-shore wells drilled[2] in Australia and the production from offshore platforms was 170 gigalitres (total Victorian production, as for the volume piped undersea).

There were no spills of the above three types in the nine-year period and consequently average spill rates cannot be estimated in the usual way, although upper confidence limits on the spill rates can be calculated. As the true spill rate increases the probability of no spills occurring (given the exposure variables levels) decreases. Since no spills did occur in the nine-year period (and hence the probability of this event cannot be very low) upper limits can be placed on the spill rates. Table 3.7 gives the upper 90 and 95 per cent confidence limits on the spill rates for these types of spills.

The limiting spill rates can be used to estimate future spills provided it is noted that these estimates represent the highest probable spill rates. That is, using a 95 per cent limit as the spill rate infers that the occurrence of zero spills in the period 1 January 1970 to 30 December 1978 was a one in 20 chance event.

Illustrative examples

To illustrate the application of the estimates presented in the previous sub-sections, the following **hypothetical** example is discussed.

If, during a particular year, 30 gigalitres of oil were piped under the sea, 50 offshore wells were drilled and 25 gigalitres of oil were produced at offshore platforms, the average numbers of spills of each type which would occur at the 95 per cent confidence level are 0.54 undersea pipeline spills, 0.40 drilling rig blowout spills and 0.45 offshore platform spills[3]. These averages are calculated using the 95 per cent upper limit for each spill rate. The historical data **could not** support rates higher than these 95 per cent limits. On this basis, 1.4 spills of one or more of these types would occur **on average** during the year considered. This can be shown (Appendix III) to yield a probability of 0.25 that **none** of these types of spills will occur during that year.

If in the same year 60 gigalitres of oil was transported by ship near the coast, a further 0.72 at-sea spills would occur, on average (using the upper 95 per cent at-sea spill rate).

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1. Equivalent to the total Victorian production.
2. Wells which reached final depth in the period (AIP 1980).
3. These averages are **long-term averages** and imply that approximately one pipeline spill occurs every two years, one drilling rig spill occurs every 30 months, and one platform spill occurs every 27 months. The averages are based on spill rates which imply that the observed situation was a one in 20 chance event, and therefore they are upper limits on the average number of spills which would occur.

TABLE 3.7—AT-SEA, UNDERSEA PIPELINE, DRILLING RIG BLOWOUT AND OFFSHORE PLATFORM SPILLS; UPPER CONFIDENCE LIMITS ON SPILL RATES

Type of spill	*Period beginning 1 January 1970 and ending*	*Exposure variable level*	*Exposure variable units*	*Number of spills*	*Upper confidence[a] limit on spill rate*	
					90 per cent	*95 per cent*
At-sea	30 June 1979	403	Gigalitres transported by ship near coast	1	0.010	0.012
Undersea pipeline	30 December 1978	170	Gigalitres piped undersea	—	0.013	0.018
Drilling rig blowout	30 December 1978	381	Offshore wells drilled to final depth	—	0.006	0.008
Offshore platform	30 December 1978	170	Gigalitres produced at offshore platforms	—	0.013	0.018

a. Number of spills per unit of the exposure variable.

VALIDATION AND APPLICATION OF OIL SPILL MODELS

Appendix VI shows the results obtained by applying the statistical models derived in this chapter to 1979-80 exposure variable data. The resulting projections of the numbers and volumes of oil spill occurrences are compared with the actual numbers and volumes of oil spills which occurred in 1979-80. The comparisons support the validity of the derived statistical models.

The models which have been presented in this chapter do not allow for a trend over time in the spill rates or in the average volumes spilled. The new oil spill legislation outlined in Chapter 2 may cause a change in either the parameters of the above models, the type of model which best describes the past data, or both. The relevant data for future years should be examined as they become available and the models changed or recalibrated, as necessary.

Appendix VI also discusses the application of the basic models presented in this chapter to the calculation of risk of a spill of a specific volume. Specifically, the calculation of the risk of a very large spill occurring is discussed and the actual results are compared with the model results for the fiscal year 1979-80.

CHAPTER 4—PROJECTION OF OIL SPILL OCCURRENCES AND ECONOMIC LEVELS OF DISPERSANTS

The Parliamentary Inquiry (Australia, Parliament 1978) cited previously, observed that there is no economic or operational justification to equip and prepare for a major spill disaster which may never occur. The Inquiry's report stated that a planned response capability was required which was able to cope with an anticipated level of oil pollution, based on the nature of shipping activity carried out in Australian waters.

This chapter presents estimates of future oil spill occurrences and applies these estimates to the determination of chemical dispersant stock levels which are economically appropriate for given levels of spill risk. It will be recalled from Chapter 1 that the use of chemical dispersants is often an important operational factor during implementations of the National Plan. In the subsequent discussion, stockpile levels are related to specific levels of 'risk'. In the context of this Report, 'risk' refers to the risk of having insufficient resources on hand to deal effectively with a spill of a particular size. As discussed below, two levels of risk are discussed—the one per cent and five per cent chances, respectively, that a spill will occur which exceeds the resources (in this case dispersants) readily available to neutralise it. These two levels are commonly used in risk studies as standard benchmarks, though of course the analysis can be applied to other levels of risk.

The models so far developed were applied to projected exposure variable data (Appendix I) to produce future estimates, for both of the fiscal years 1984-85 and 1989-90, of the following parameters:

- the average number of spills at each port;
- confidence limits on the actual number of spills to be expected;
- probabilities of spills of a specific size; and
- probabilities that the total volume spilled in all spills at a port exceeds a specific value.

Projections of the average numbers of spills for intermediate years between these two fiscal years could be calculated by linear interpolation. This assumes that the exposure variable projections are linear and maintain the same relative proportions. This technique, however, should not be applied to spill probabilities, or to confidence limits as these measures are not linearly related to the exposure variable data. In the latter situations the models must be applied to projections of the exposure variables for the particular years for which estimates are required.

EXPOSURE VARIABLE PROJECTIONS

The scenarios presented in Appendix I are not intended to represent definitive forecasts. They should be regarded as representing a set of plausible assessments of future levels of the relevant exposure variables, and as such are useful for illustrating the application of the statistical oil spill models developed in this study. Any alternative set of scenarios for volume of oil handled, volume of bunker fuel loaded and weight of cargo handled can be used to produce similar projections of future oil spill risks. Appendix I presents the projected levels of the exposure variables in diagrammatic form.

Volume of oil handled

Using information based on the Department of National Development and Energy (DND&E) ten-year forecasts of the demand for petroleum fuels (DND&E 1981), DoTA provided high and low estimates for the volumes of oil and oil products likely to be handled at each port in the fiscal years 1984-85 and 1989-90. Most likely estimates of the volume of oil handled were taken as the average of the high and low values for the respective years.

Weight of cargo handled

DoTA provided high and low estimates for the amount of cargo handled at each port in 1984-85 and 1989-90. As before, for the purpose of applying the models, estimates of the most likely weight of cargo handled were taken to be the average of the high and low values.

Volume of bunker fuel loaded

The oil companies, from which bunker fuel sales were sought, supplied data for varying periods of time, and were in the main unable to supply projections of future bunker fuel sales. The two years for which complete data were available were the calendar years 1979 and 1980.

The lack of adequate historical data on bunkering fuel loaded made it impossible to identify any trends in bunker fuel sales by port. However, it was considered that the change in the volume of total cargo handled would represent a reasonable proxy for the trend in bunker fuel sales. This consideration is based on the fact that the demand for bunker fuels is dependent upon the number of ships using a port, and the volume of cargo handled has been used in this study as a proxy for this preferred (but unavailable) exposure variable.

The assumption was made that the ratio of the volume of bunker fuel sales to the weight of total cargo handled would remain constant. The ratio of bunker sales to cargo handled in 1979-80 (for each port which loaded bunker fuel) was multiplied by the projected cargo handling figures for that port in 1984-85 and 1989-90 (detailed above) to yield bunker fuel sales estimates for those respective years.

The adjusted volumes of bunker fuel loaded by port in 1984-85 and 1989-90 are given in Appendix I.

PROJECTIONS OF SPILL FREQUENCIES

Tables 4.1 and 4.2 give the projected number of oil spill occurrences, based on the models in Chapter 3 and the exposure variable projections described above for 1984-85 and 1989-90, respectively.

In general, the projections of the exposure variables indicate a small upward trend and this is reflected in the projections of oil spill occurrences. The oil spill occurrence projections are generally within the range of the occurrences observed over recent years. Consequently, if the projections for the exposure variables were to reflect reality, the occurrences of oil spills during the next 10 years will follow a similar pattern to that observed in recent years.

CONFIDENCE LIMITS ON THE ACTUAL NUMBER OF SPILLS

As stressed previously, the specific numbers of spills which will actually occur in the future can only be discussed in terms of probabilities. These probabilities depend on the projected average numbers of spills. For each of these projected averages, the probability of specific numbers of spills occurring can be obtained as described in Appendix III. Table 4.3 shows the confidence limits within which the actual number of spills at each port can be expected to fall with a 'high' probability (confidence).

TABLE 4.1—PROJECTIONS OF OIL SPILL OCCURRENCES[a] BY SPILL TYPE AND PORT[b], 1984-85

Port	Type of spill: Handling	Bunkering	Miscellaneous	Total spills[c]
New South Wales				
Sydney	0.94	5.26	2.98	9.2
Botany Bay	1.35	0.07	0.25	1.7
Newcastle	0.07	1.21	0.49	1.8
Port Kembla	0.04	1.65	0.42	2.1
State total[d]	2.41	8.20	4.17	14.8
Victoria				
Melbourne	0.54	6.04	2.38	9.0
Geelong	0.49	1.12	0.29	1.9
Portland	0.01	0.06	0.04	0.1
Westernport	1.39	0.32	0.25	2.0
State total[d]	2.43	7.54	2.98	13.0
Queensland				
Brisbane	1.14	0.72	1.28	3.1
Cairns	0.01	0.06	0.03	0.1
Gladstone	0.02	0.04	0.09	0.2
Hay Point	—	—	0.10	0.1
Mackay	—	0.06	0.05	0.1
Townsville	0.03	0.23	0.11	0.4
Weipa	—	—	0.06	0.1
State total[d]	1.22	1.11	1.80	4.1
South Australia				
Port Adelaide	0.02	1.02	0.57	1.6
Port Stanvac	0.45	0.33	0.07	0.9
Port Pirie	0.01	—	0.06	0.1
Whyalla	—	—	0.30	0.3
State total[d]	0.49	1.37	1.09	2.9
Western Australia				
Fremantle	1.31	8.78	2.57	12.7
Albany	—	0.11	0.06	0.2
Barrow Island	0.06	—	—	0.1
Bunbury	—	0.01	0.12	0.1
Dampier	0.01	—	0.26	0.3
Geraldton	—	—	0.06	0.1
Port Hedland	—	0.02	0.27	0.3
Port Walcott	0.01	—	0.11	0.1
State total[d]	1.43	8.93	3.52	13.9

TABLE 4.1—PROJECTIONS OF OIL SPILL OCCURRENCES[a] BY SPILL TYPE AND PORT[b], 1984-85 (Cont)

	Type of spill			
Port	*Handling*	*Bunkering*	*Miscellaneous*	*Total spills*[c]
Tasmania				
Hobart	0.02	0.43	0.42	0.9
Burnie	—	—	0.09	0.1
Devonport	—	—	0.06	0.1
Launceston	—	0.06	0.18	0.2
State total[d]	0.04	0.50	0.77	1.3
Northern Territory				
Darwin	0.02	0.20	0.13	0.3
State total[d]	0.03	0.20	0.18	0.4
Australia				
All ports[d]	8.07	27.85	14.51	50.4

a. Based on average numbers of spills for the year under consideration.
b. Only ports with a projected average number of all spills of at least 0.05 are listed.
c. Totals are rounded to one decimal place.
d. These totals are for all ports considered in the region and are therefore not exactly equal to the column totals.

Because numbers of spills are represented by discrete variables, precise 90 and 95 per cent confidence limits cannot be obtained. Hence limits which contain the actual number with 90 per cent confidence or higher have been presented.

ECONOMIC DISPERSANT STOCKPILE LEVELS

One application of the projected numbers of spills relates to the calculation of economic stockpiles[1] of oil dispersant chemicals. These calculations require estimates of the spill volumes which are exceeded only a certain proportion **of the time**[1] (time-based risk levels) or estimates of the spill volumes which are exceeded in only a certain proportion **of spills** (spill-based risk levels), given the projected levels of the exposure variables in 1984-85. These spill volumes are given in Tables 4.4 and 4.5 and can be used, in conjunction with a relationship between spill volume and the amount of dispersant required to neutralise that volume, to calculate the level of dispersant to be stockpiled at each port. For example, from the spill volume which is exceeded only 1 per cent of the time, the number of barrels of dispersant required to neutralise that volume can be calculated. This amount of dispersant is the minimum (and hence economic) amount required to ensure that only one year in 100 years the stockpile will be inadequate. Appendix VII gives the formula for these calculations and the results for the 1 and 5 per cent risk levels are shown for time-based and spill-based risks in Tables 4.4 and 4.5, respectively.

These stockpile levels would infer the acceptance of a given degree of risk of having insufficient dispersant to accommodate spill volumes exceeding a certain amount and are dependent on the acceptable risk level. A higher acceptable risk level results in a lower level of chemical dispersant.

1. The analysis in this section assumes that the stockpiles are refurbished to the calculated economic level immediately after any dispersant is used. They are calculated on the basis of their adequacy to neutralise a single spill rather than a number of spills in a given time period.

TABLE 4.2—PROJECTIONS OF OIL SPILL OCCURRENCES[a] BY SPILL TYPE AND PORT[b], 1989-90

Port	Type of spill: Handling	Bunkering	Miscellaneous	Total spills[c]
New South Wales				
Sydney	0.94	5.64	3.20	9.8
Botany Bay	1.35	0.07	0.27	1.7
Newcastle	0.07	1.37	0.55	2.0
Port Kembla	0.04	1.82	0.46	2.3
State total[d]	2.42	8.91	4.52	15.8
Victoria				
Melbourne	0.56	6.29	2.48	9.3
Geelong	0.51	1.24	0.32	2.1
Portland	0.01	0.07	0.05	0.1
Westernport	1.42	0.33	0.26	2.0
State total[d]	2.51	7.92	3.12	13.6
Queensland				
Brisbane	1.19	0.78	1.39	3.4
Cairns	0.01	0.06	0.03	0.1
Gladstone	0.03	0.04	0.10	0.2
Hay Point	—	—	0.12	0.1
Mackay	—	0.06	0.06	0.1
Townsville	0.03	0.26	0.12	0.4
Weipa	—	—	0.07	0.1
State total[d]	1.28	1.20	1.98	4.5
South Australia				
Port Adelaide	0.02	1.12	0.63	1.8
Port Stanvac	0.45	0.34	0.07	0.9
Port Pirie	0.01	—	0.06	0.1
Whyalla	—	—	0.34	0.4
State total	0.49	1.48	1.19	3.2
Western Australia				
Fremantle	1.28	0.97	2.92	14.2
Albany	—	0.12	0.07	0.2
Barrow Is	0.06	—	—	0.1
Bunbury	—	0.01	0.16	0.2
Dampier	0.01	—	0.35	0.4
Esperance	—	—	0.05	0.1
Geraldton	—	—	0.07	0.1
Port Hedland	—	0.03	0.34	0.4
Port Walcott	0.01	—	0.17	0.2
State total[d]	1.40	10.15	4.15	15.7

TABLE 4.2—PROJECTIONS OF OIL SPILL OCCURRENCES[a] BY SPILL TYPE AND PORT[b], 1989-90 (Cont)

Port	Type of spill: Handling	Bunkering	Miscellaneous	Total spills[c]
		Tasmania		
Hobart	0.02	0.44	0.44	0.9
Burnie	—	—	0.10	0.1
Devonport	—	—	0.06	0.1
Launceston	0.01	0.07	0.21	0.3
State total[d]	0.05	0.53	0.83	1.4
		Northern Territory		
Darwin	0.02	0.21	0.15	0.4
State total[d]	0.03	0.21	0.20	0.4
		Australia		
All ports[d]	8.18	30.40	15.99	54.6

a. Based on average numbers of spills for the year under consideration.
b. Only ports with a projected average number of all spills of at least 0.05 are listed.
c. Totals are rounded to one decimal place.
d. These totals are for all ports in the region and are therefore not exactly equal to the column totals.

Example

The difference between time-and spill-based risk levels can be illustrated with an example involving the two ports, Port A which has 20 spills on average each year and Port B which has only 2 spills. At the 5 per cent time-based risk level both ports have inadequate stockpile levels for one year in every 20 years, this being approximately one spill in every 400 spills at Port A and one spill in every 40 spills at Port B. At the 5 per cent spill-based risk level both ports have inadequate stockpile levels for one spill in every 20 spills, which is once a year at Port A and only once every 10 years at Port B.

In determining the amount of dispersant to be stockpiled at each site, some appropriate balance needs to be arrived at between the cost of the dispersant (which has only a limited storage life) and the risk which can be accepted of having insufficient dispersant to deal adequately with a particular oil spill. It is not within the scope of this report to explore the level of risk which can be tolerated. However, the application of the results developed previously will be illustrated under certain **assumptions** regarding tolerable risk levels.

Time-based risk levels

Table 4.4 shows the number of drums of dispersant which is sufficient to combat all spills in each State for both 99 and 95 per cent of time (years) respectively at the levels of exposure variables projected for 1984-85. These estimates assume that one drum of dispersant will neutralise 600 litres of spilled oil, and are derived directly from the 'maximum' spill volumes also shown in Table 4.4. The stockpile levels are dependent on the absolute number of spills of each type which occur, and consequently States with larger projected numbers of spills will require larger stockpiles.

TABLE 4.3—CONFIDENCE LIMITS[a] FOR PROJECTED NUMBERS OF SPILLS BY PORT[b], 1984-85 AND 1989-90

Port	1984-85 Lower limit (numbers of spills)	1984-85 Upper limit (numbers of spills)	1984-85 Confidence (per cent)	1989-90 Lower limit (numbers of spills)	1989-90 Upper limit (numbers of spills)	1989-90 Confidence (per cent)
New South Wales						
Sydney	5	14	90	5	15	92
Botany Bay	—	3	91	—	3	91
Newcastle	—	4	96	—	4	95
Port Kembla	—	4	94	—	4	92
Victoria						
Melbourne	5	14	90	5	14	90
Geelong	—	4	96	—	4	94
Westernport	—	4	95	—	4	95
Queensland						
Brisbane	1	6	92	1	6	91
Gladstone	—	1	98	—	1	98
Townsville	—	1	94	—	1	94
South Australia						
Port Adelaide	—	3	92	—	4	96
Port Stanvac	—	2	94	—	2	94
Whyalla	—	1	96	—	1	94
Western Australia						
Fremantle	8	19	90	9	21	91
Albany	—	1	98	—	1	98
Bunbury	c	c	91	—	1	98
Dampier	—	1	96	—	1	94
Port Hedland	—	1	96	—	1	94
Port Walcott	—	—	91	—	1	98
Tasmania						
Hobart	—	2	94	—	2	94
Launceston	—	1	98	—	1	96
Northern Territory						
Darwin	—	1	96	—	1	94
Australia						
All ports[d]	38	62	92	42	67	92

a. Ranges are inclusive.
b. Only ports with more than 0.1 projected total spills in 1989-90 are listed.
c. There is a 91 per cent chance of zero spills.
d. For all ports, not just those listed in the table.

Spill-based risk levels

Table 4.5 shows the number of drums of dispersant which is sufficient to combat both 99 and 95 per cent of the spills respectively in each State. These stockpile levels are independent of the absolute number of spills and are only dependent on the proportions of each type of spill. Ports with higher projected proportions of handling and miscellaneous spills relative to bunkering spills will require higher stockpile levels to achieve the same levels of risk of being unable to respond adequately to a particular spill.

TABLE 4.4—SPILL VOLUMES WHICH ARE EXCEEDED ONLY ONE AND FIVE PER CENT OF THE TIME AND AMOUNTS OF DISPERSANT REQUIRED TO ACHIEVE ASSOCIATED RISK LEVELS BY STATE, 1984-85

		Spill volumes[b] (litres)		*Amount of dispersant (drums)[c]*	
State	*Projected average numbers of spills of all types[a]*	*Exceeded 1 per cent of time*	*Exceeded 5 per cent of time*	*Sufficient for 99 per cent of time*	*Sufficient for 95 per cent of time*
New South Wales	14.8	151 000	46 000	252	77
Victoria	13.0	123 000	38 000	205	63
Queensland	4.1	83 000	23 000	138	38
South Australia	2.9	55 000	14 000	92	23
Western Australia	13.9	132 000	39 000	220	65
Tasmania	1.3	37 000	8 000	62	13
Northern Territory	0.4	9 000	1 000	15	2
Australia	50.4	349 000	115 000	582	192

a. Based on exposure variables projected for 1984-85.
b. Spill volumes calculated to the nearest one thousand litres.
c. Assumes that, on average, 600 litres of oil are neutralised by one drum of dispersant and is rounded to the nearest whole number.

TABLE 4.5—SPILL VOLUMES WHICH ARE EXCEEDED IN ONLY ONE AND FIVE PER CENT OF SPILLS AND AMOUNTS OF DISPERSANT REQUIRED TO ACHIEVE ASSOCIATED RISK LEVELS BY STATE, 1984-85

		Spill volumes[b] (litres)		*Amount of dispersant (drums)[c]*	
State	*Projected average numbers of spills of all types[a]*	*Exceeded 1 per cent of spills*	*Exceeded 5 per cent of spills*	*Sufficient for 99 per cent of spills*	*Sufficient for 95 per cent of spills*
New South Wales	14.8	19 900	4 700	33	8
Victoria	13.0	18 600	4 600	31	8
Queensland	4.1	27 900	6 600	47	11
South Australia	2.9	23 100	5 300	39	9
Western Australia	13.9	17 600	4 200	29	7
Tasmania	1.3	29 000	5 900	48	10
Northern Territory	0.4	38 100	8 100	64	14
Australia	50.4	20 000	4 700	33	8

a. Based on exposure variables projected for 1984-85.
b. Spill volumes calculated to the nearest one hundred litres.
c. Assumes that, on average, 600 litres of oil are neutralised by one drum of dispersant and is rounded to nearest whole number.

Stockpile turnover

Oil dispersant has a shelf life which is not known precisely but is estimated to be between two and eight years, depending on storage conditions. The rate at which the dispersant stock is used, therefore, is also of interest since an excess stockpile could be wasted if it is not used within the period of its shelf life.

The statistical distributions formulated in Chapter 3 can be used to estimate the turnover rate of the dispersant stock at a port.

The total expected volume of oil spilled at each port in a given period (in this case a year), can be calculated using the expected numbers of spills of each type and the average volumes spilled in each type of spill. The total expected volume of oil spilled in each State is the sum of the volumes for each port in the State.

The projected total volumes for each State for 1984-85 are given in Table 4.6, together with the number of drums of dispersant required to neutralise these volumes of oil. From these figures the average number of years in which the stockpile in each State will be completely replaced can be calculated. These turnover times are given in Table 4.6 for both the time-based and spill-based one per cent risk levels.

Comparison of current stockpile levels with those given in Table 4.6 indicates that the stockpile turnover times shown in Table 4.6 are much shorter than those pertaining at present. Thus, for example, if the stockpile levels of Table 4.6 were adopted, wastage due to chemical deterioration of dispersant would be reduced.

TABLE 4.6—ANNUAL AVERAGE VOLUME OF OIL SPILLED AND TIME FOR TURNOVER OF DISPERSANT STOCKPILES FOR A ONE PER CENT RISK LEVEL BY STATE, 1984-85

State	Annual average total volume of oil spilled (litres)	Dispersant required (drums)	Time-based risk		Spill-based risk	
			Stockpile (drums)	Turnover (years)	Stockpile (drums)	Turnover (years)
New South Wales	22 300	37.2	252	7	33	0.9
Victoria	18 410	30.7	205	7	31	1.0
Queensland	8 510	14.2	138	10	47	3.3
South Australia	5 070	8.5	92	11	39	4.6
Western Australia	18 820	31.4	220	7	29	0.9
Tasmania	2 670	4.5	62	14	48	10.7
Northern Territory	610	1.0	15	15	64	64.0
Australia	76 390	127.3	582	5	33	0.3

CHAPTER 5—CONCLUDING REMARKS

Although it is believed that the statistical models presented in this Report represent the most appropriate forms to describe both oil spill occurrences and volumes spilled, incomplete and inadequate data at the time of carrying out the analysis has certainly presented some difficulty in calibrating these models. In particular, the analysis of bunkering spills cannot be regarded as satisfactory since complete data for analysing the frequency of occurrence of such spills by port became available for only one particular year.

The lack of robust forecasts of future maritime activity around the Australian coastline has certain implications for the ability to use the statistical models presented in this Report for projecting future spill risks. For this application, assessments are required of future levels of appropriate exposure variables based on future maritime activity in order to estimate future oil spill occurrence frequencies. Based on experience in regulating and monitoring coastal shipping activity, DoTA made available estimates of possible future trends in levels of oil-handling, bunkering and cargo handling activities. These levels should be regarded as plausible estimates only, and consequently the oil spill occurrences projected on the basis of these estimates should be considered largely as being illustrative of the types of application of the models.

Because of the nature of the statistical models which represent the occurrence of oil spills, large changes in the exposure variable are required before there is a noticeable effect in the number of oil spill occurrences. The dependence of the number of oil spills on the exposure variable levels can be highlighted in a comparison of ports with very different exposure variable levels. The future annual rates of change in the levels of the exposure variables presented in this Report and used as a basis for projections of oil spill occurrences are, in general, small (of the order of 1 or 2 per cent average increase or decrease, per annum) and the resulting projected **average** number of oil spills shows the same small annual rate of change. The projected range, which is 'likely' to include the actual number of oil spills which will occur, is large compared to the projected change in the **average** number of spills. For example, if all the exposure variable levels increased by 4 per cent per annum from 1 July 1980 to 30 June 1990, the **average** number of spills projected for the year 1989-90 is 72 spills. However the statistical analysis presented in this Report indicate that there is a 95 per cent chance that the actual number of spills to occur in that year will be between 55 and 89 spills. It is instructive to point out that this range also encompasses the actual number of spills which occurred in 1979-80 (57 spills).

The scenarios presented in this Report relating to the future levels of the exposure variables assume a much lower level of shipping activity in 1989-90 than this hyopthetical example. The corresponding 95 per cent confidence range applicable to oil spills under these scenarios extends from 42 to 67 spills in that year, and the corresponding projected average number of spills for 1980-90 is 55. Nevertheless, the average number of spills is useful for assessing the oil spill risk at a new port, or at a port for which the exposure variable levels are expected to change significantly.

A more useful measure of future oil spill risk is the size of the spill which is not very likely to be exceeded. The size of this 'largest likely' spill was used in this Report to calculate the amounts of chemical dispersant needed to be stockpiled in each State. The projections of each measure of oil spill risk depend entirely on future trends in the exposure of variable levels. Due to the small variations in the assumed future levels of these variables, the projections presented in this Report basically reflect the oil spill situation currently and in the recent past.

In spite of the deficiencies which have been noted, it is believed that the results presented in this Report represent the most comprehensive analysis of the statistical characteristics of oil spills so far produced in the Australian context. Basically, the methodology which has been established will allow additional data to be incorporated fairly readily, should such data become available. In addition, the results can be applied to the assessment of future oil spill risk, given the acceptability of the future estimates presented in Appendix I or the availability of more accurate projections of the appropriate exposure variables. This risk assessment can then be used to estimate the levels of stockpiles of chemical dispersant required, and to plan the future availability and distribution of dispersal equipment and labour.

APPENDIX I—ASSESSMENTS OF FUTURE EXPOSURE VARIABLE TRENDS

Figures I.1 to I.66 show time-series plots of the exposure variables considered in this Report, together with estimates of the future trends in the levels of these variables to the year ending 30 June 1990.

The sources of the data presented in the graphs in this appendix are discussed in Appendix VI.

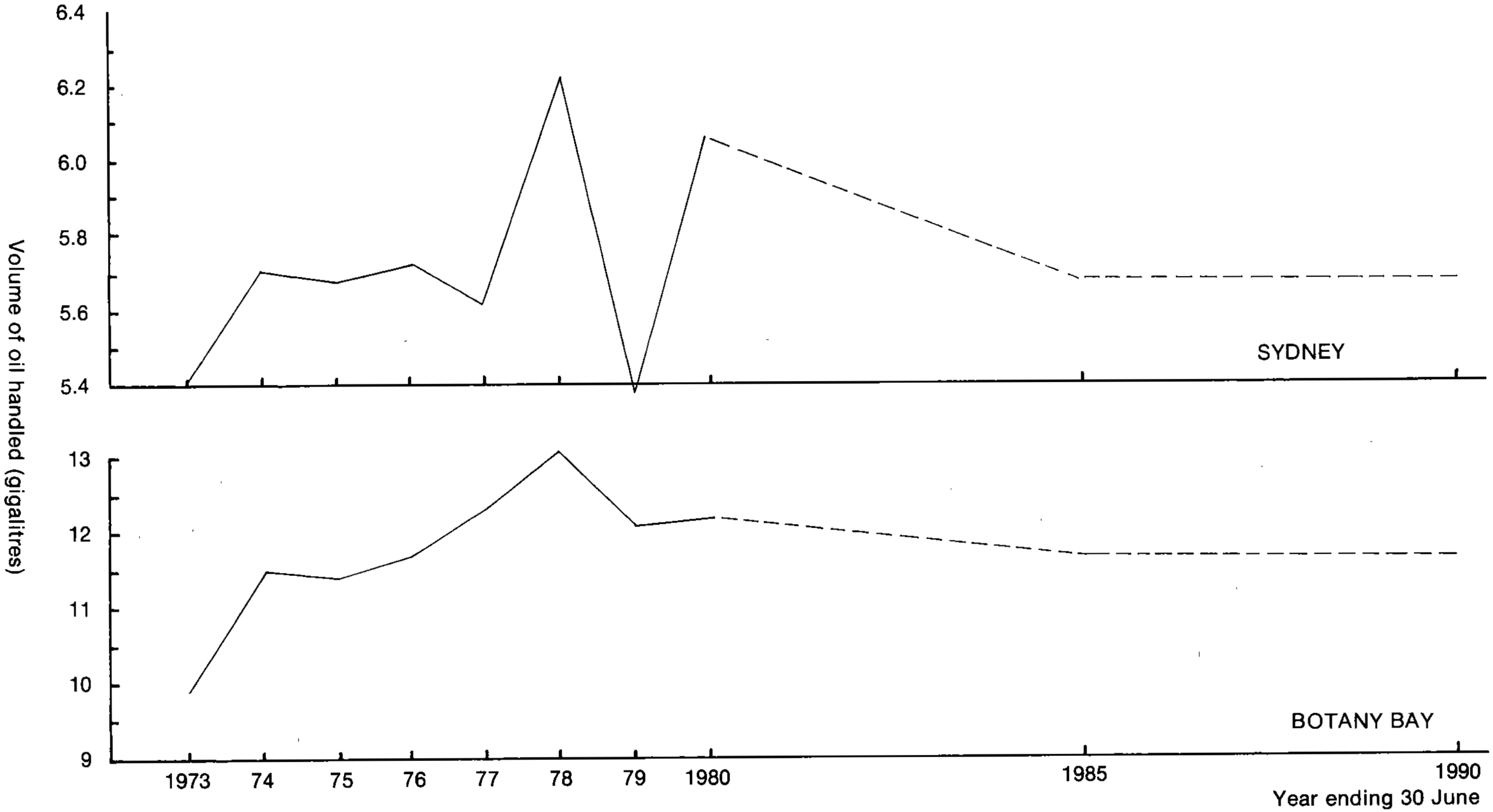

Figure I.1 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Sydney and Botany Bay

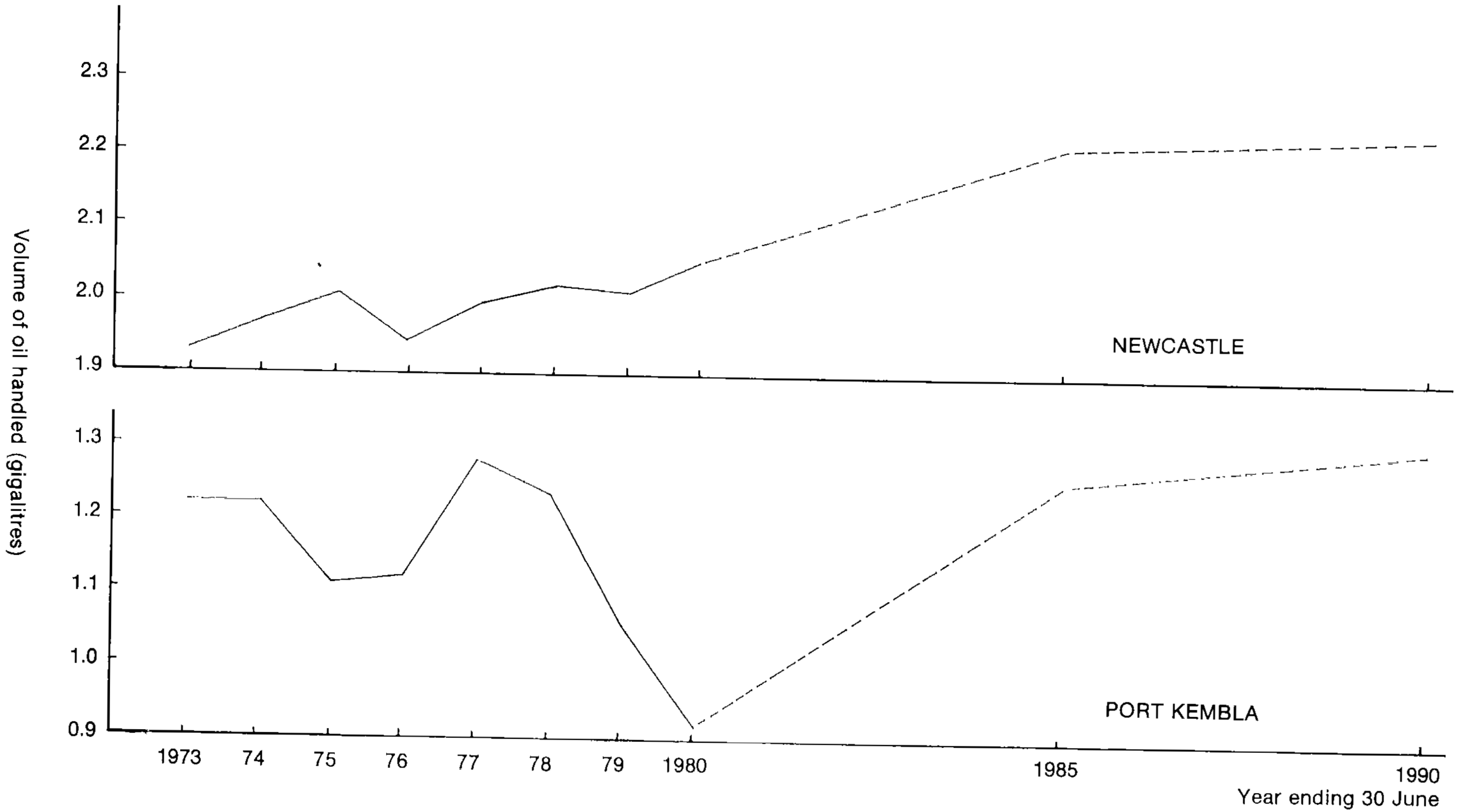

Figure I.2 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Newcastle and Port Kembla

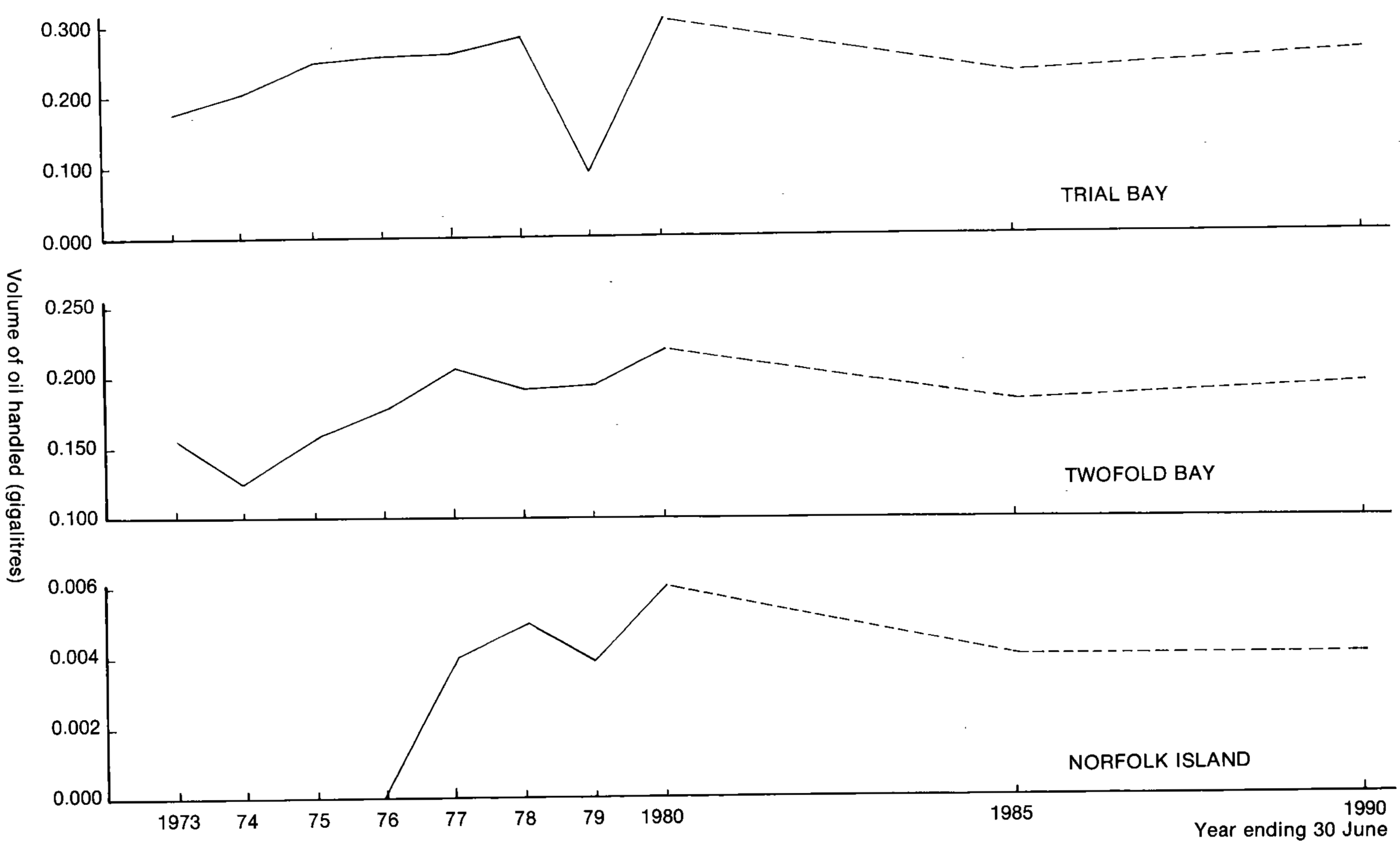

Figure I.3 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Trial Bay, Twofold Bay and Norfolk Island

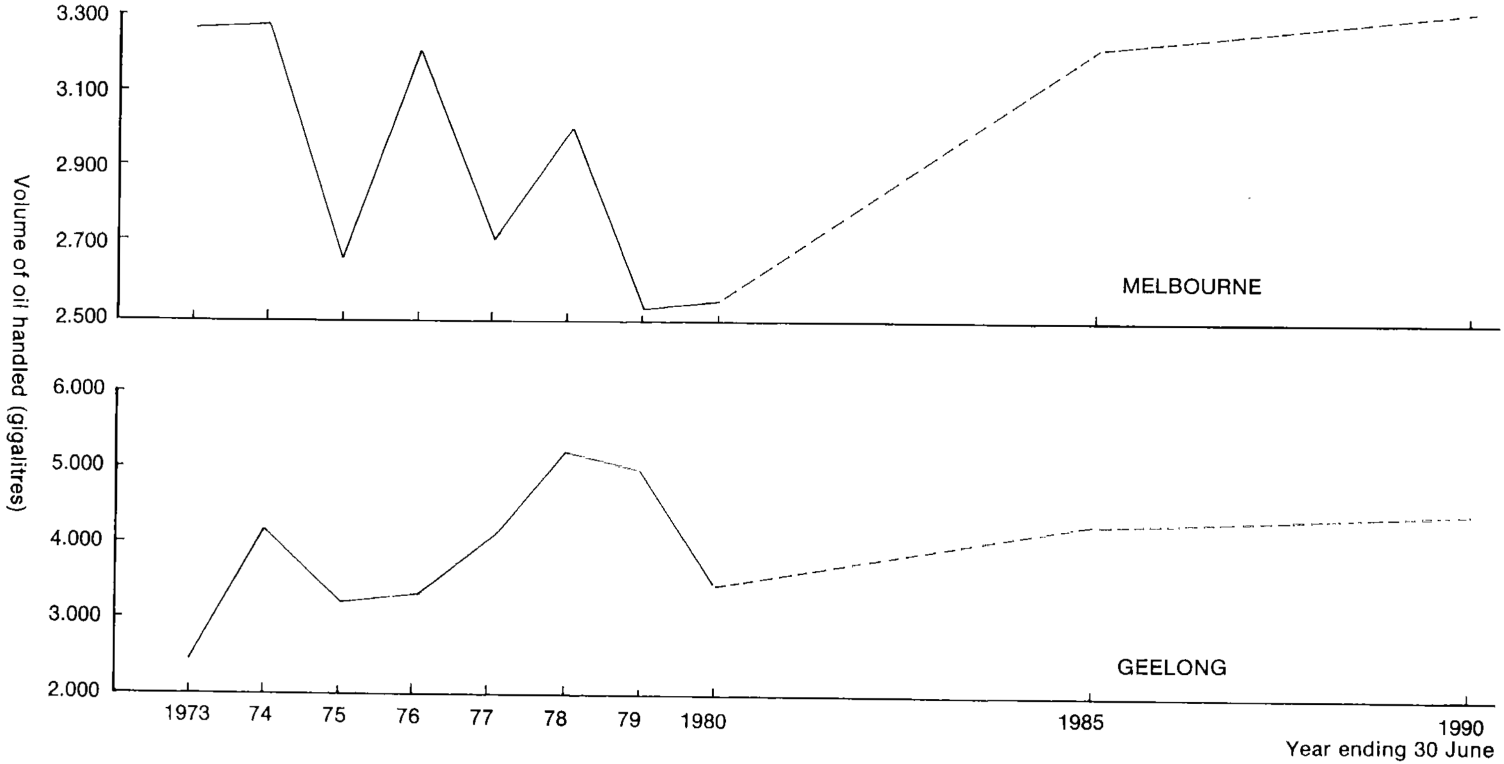

Figure I.4 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Melbourne and Geelong

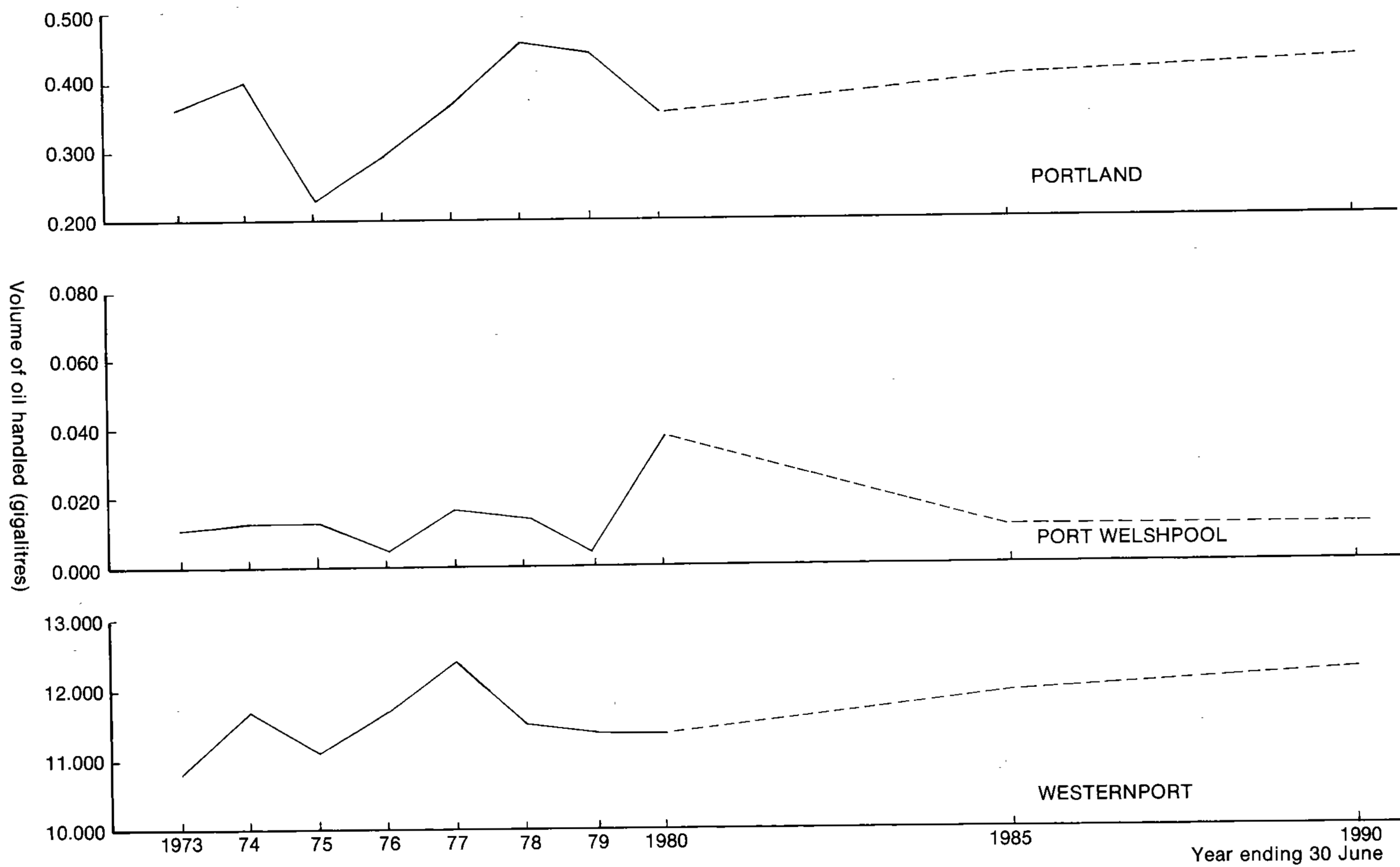

Figure I.5 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Portland, Port Welshpool and Westernport

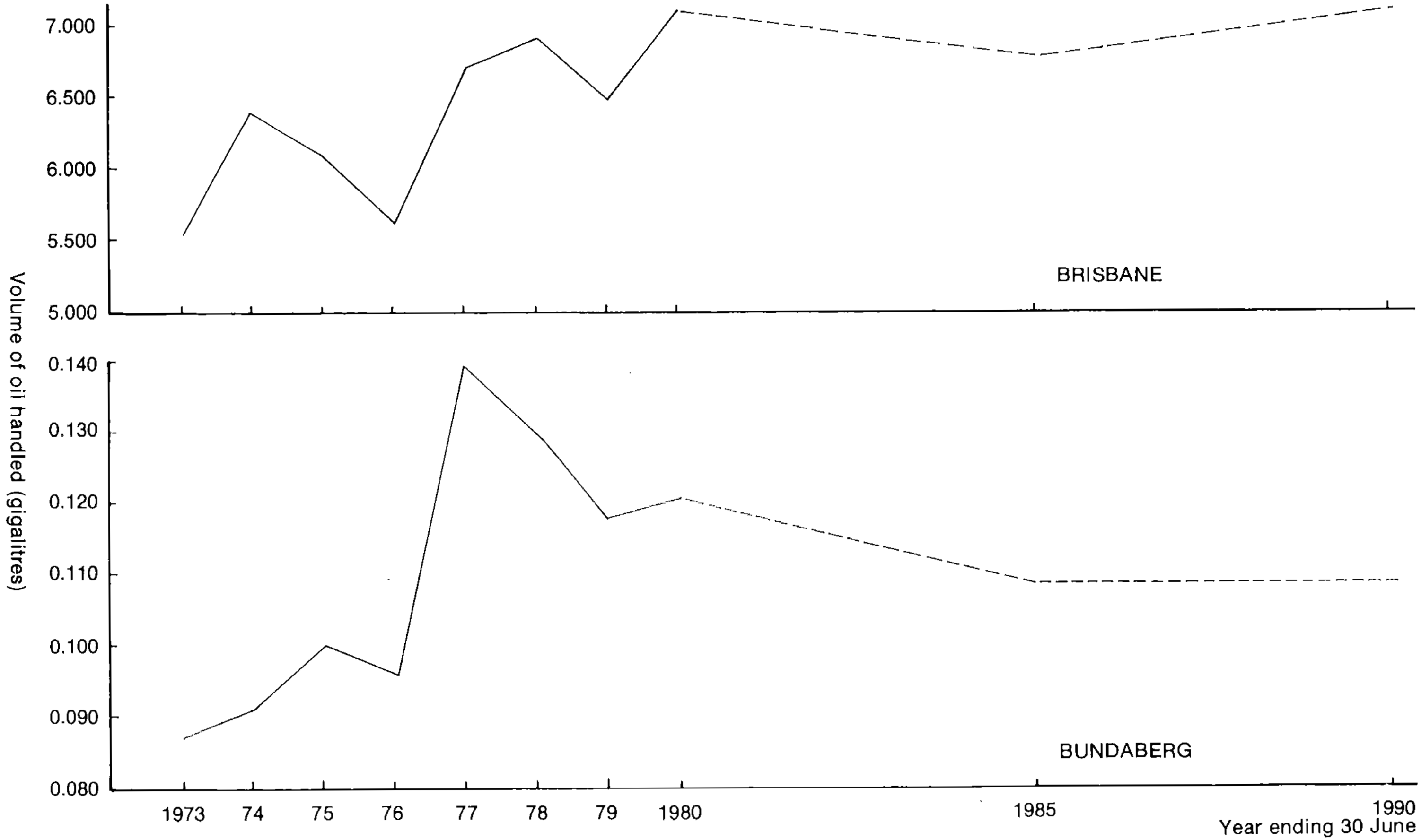

Figure I.6 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Brisbane and Bundaberg

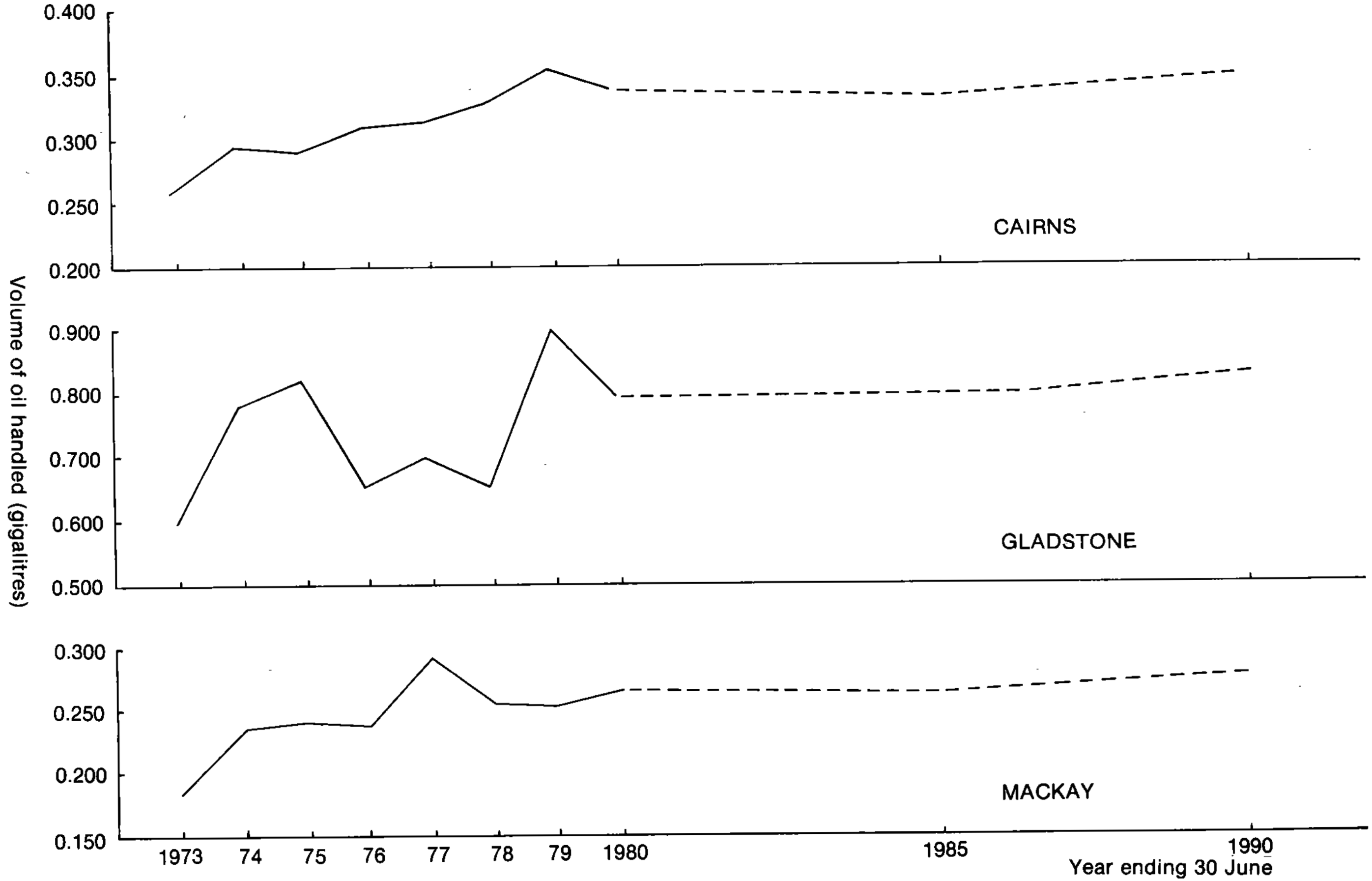

Figure I.7 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Cairns, Gladstone and Mackay

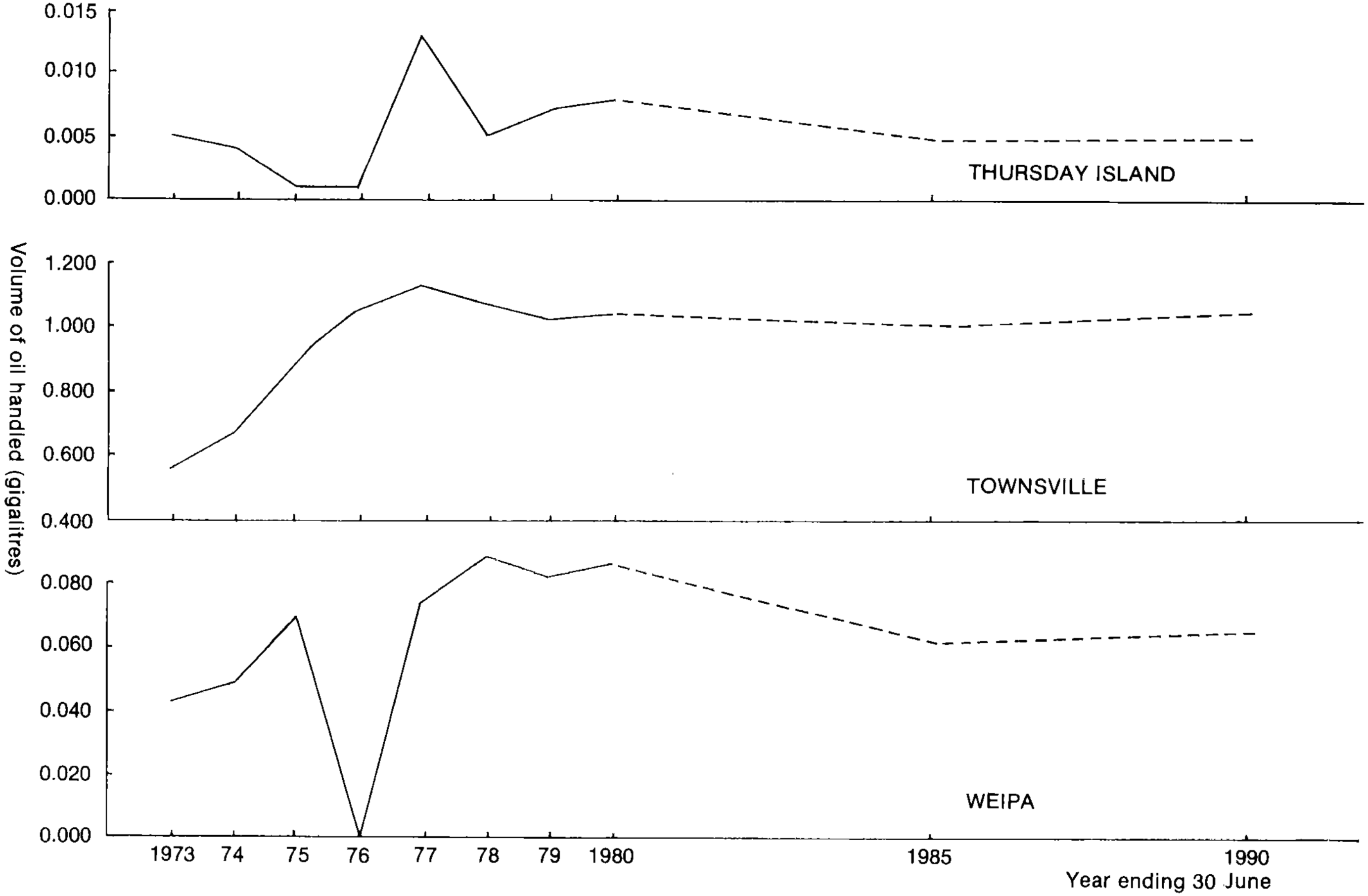

Figure I.8 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Thursday Island, Townsville and Weipa

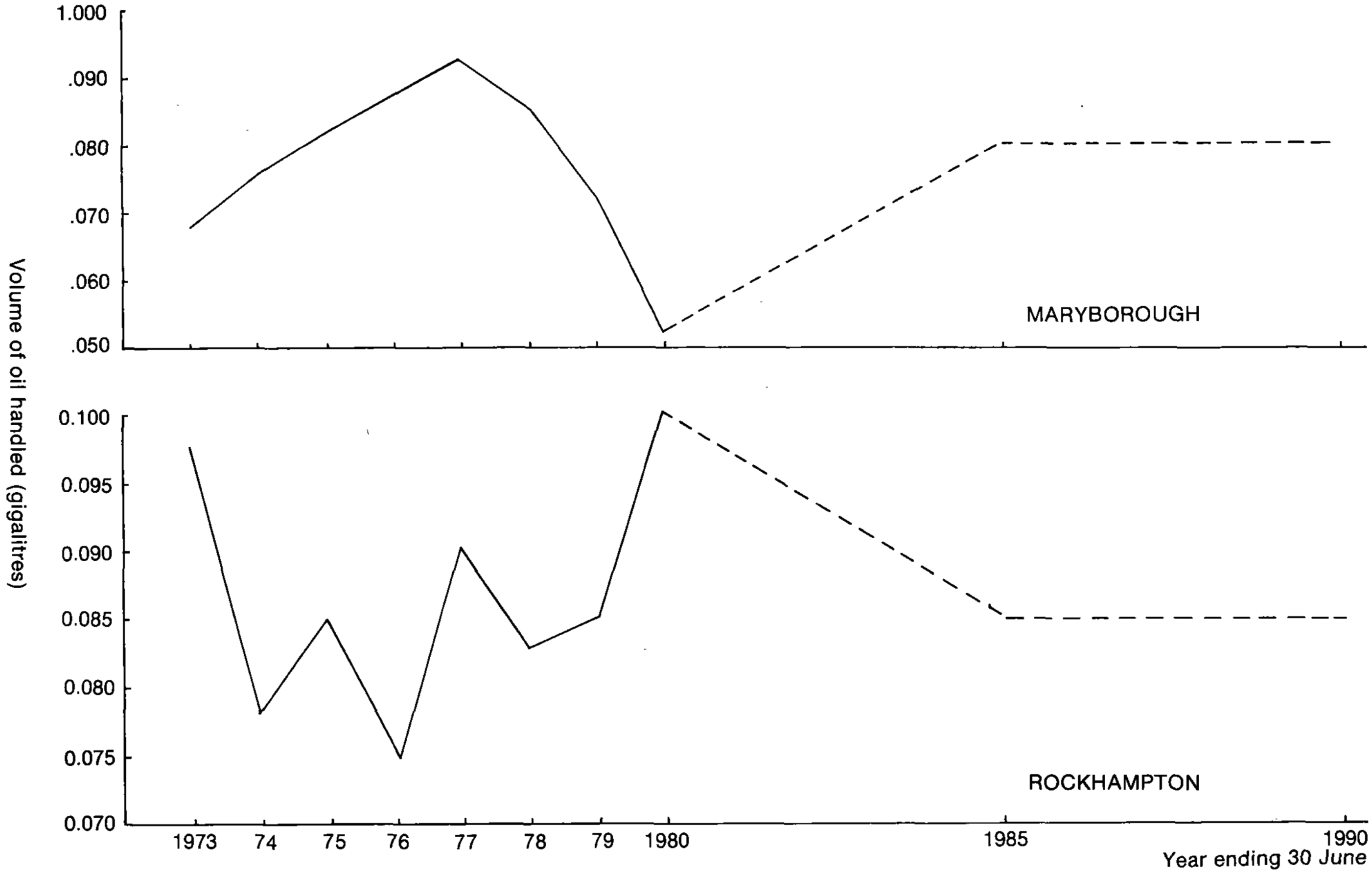

Figure I.9 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Maryborough and Rockhampton

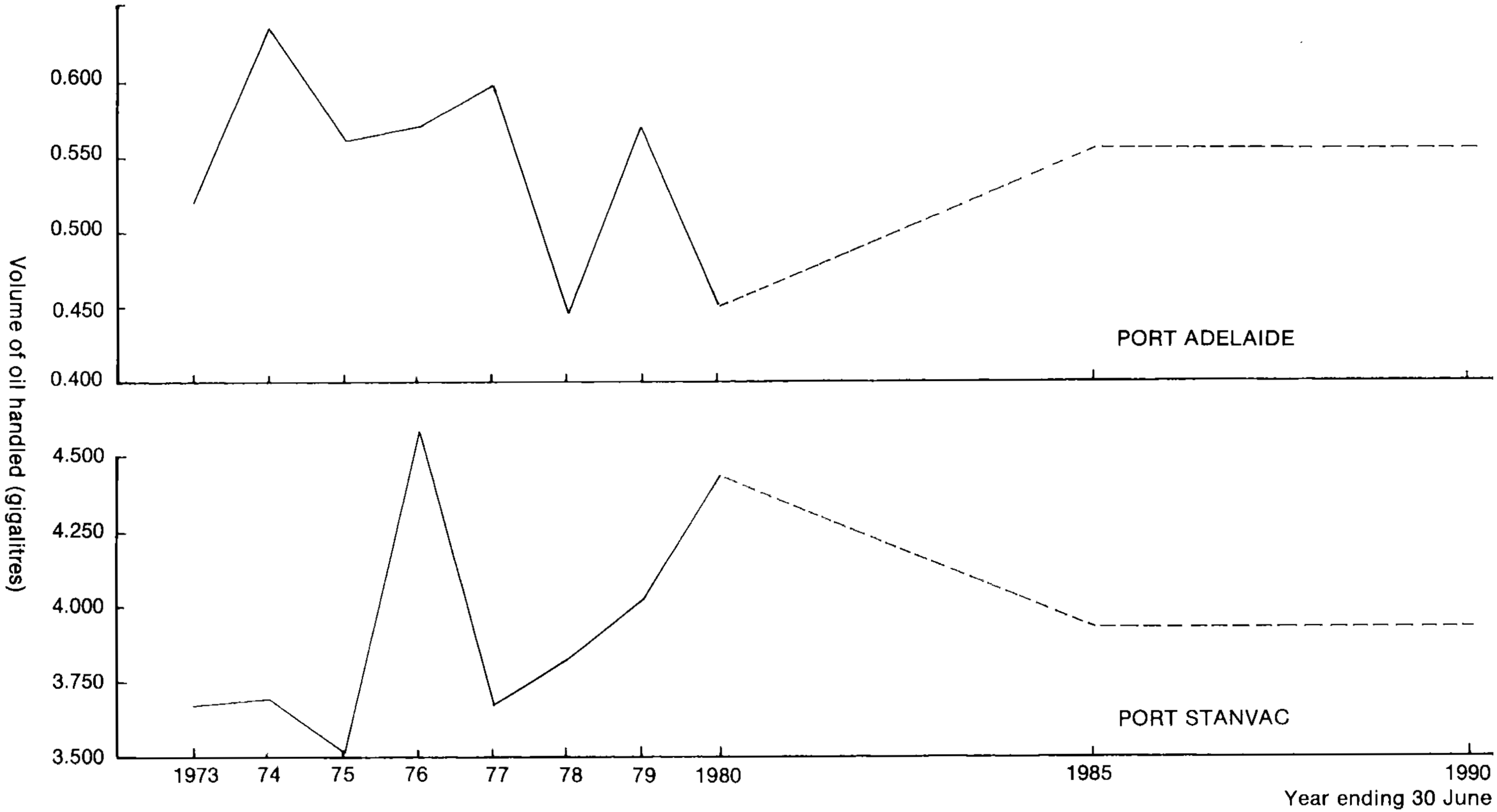

Figure I.10 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Port Adelaide and Port Stanvac

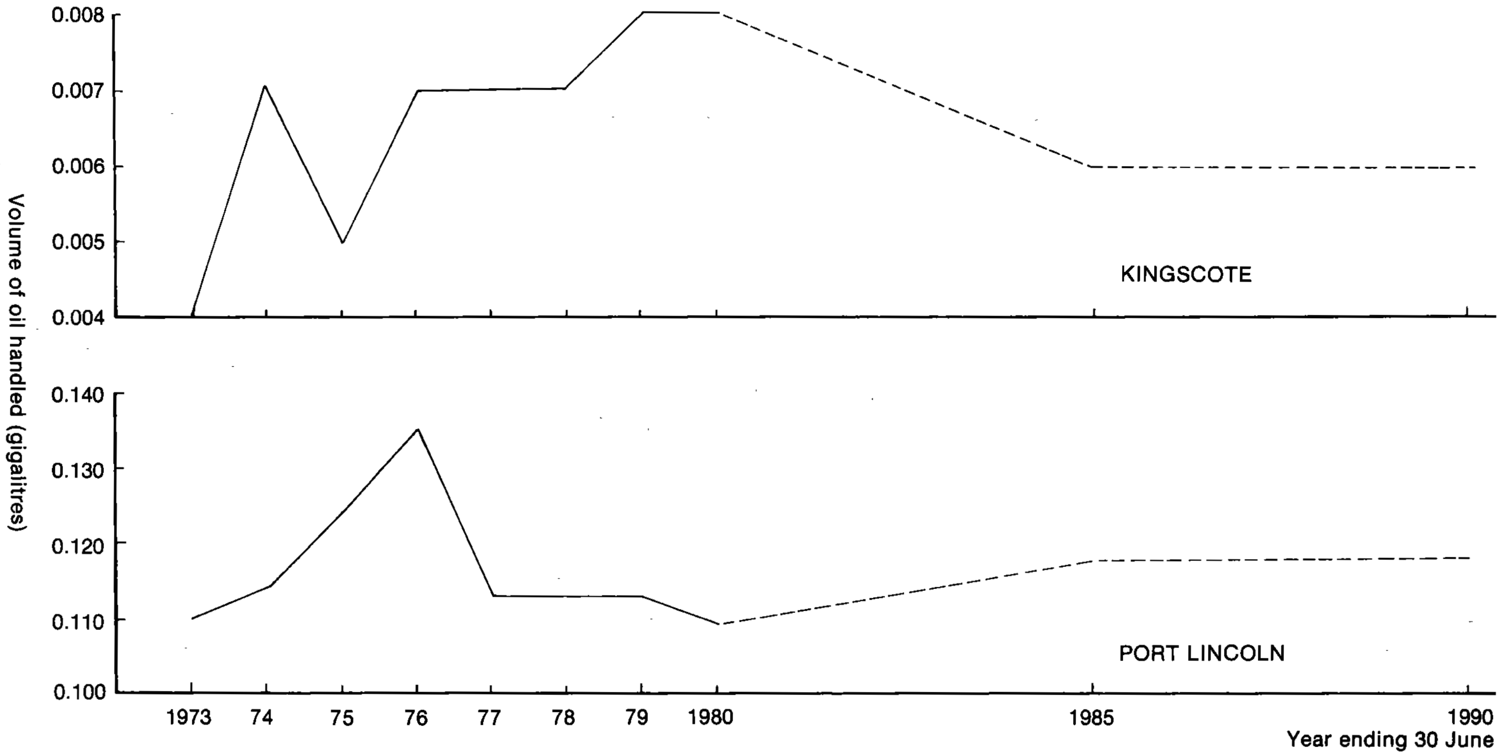

Figure I.11 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Kingscote and Port Lincoln

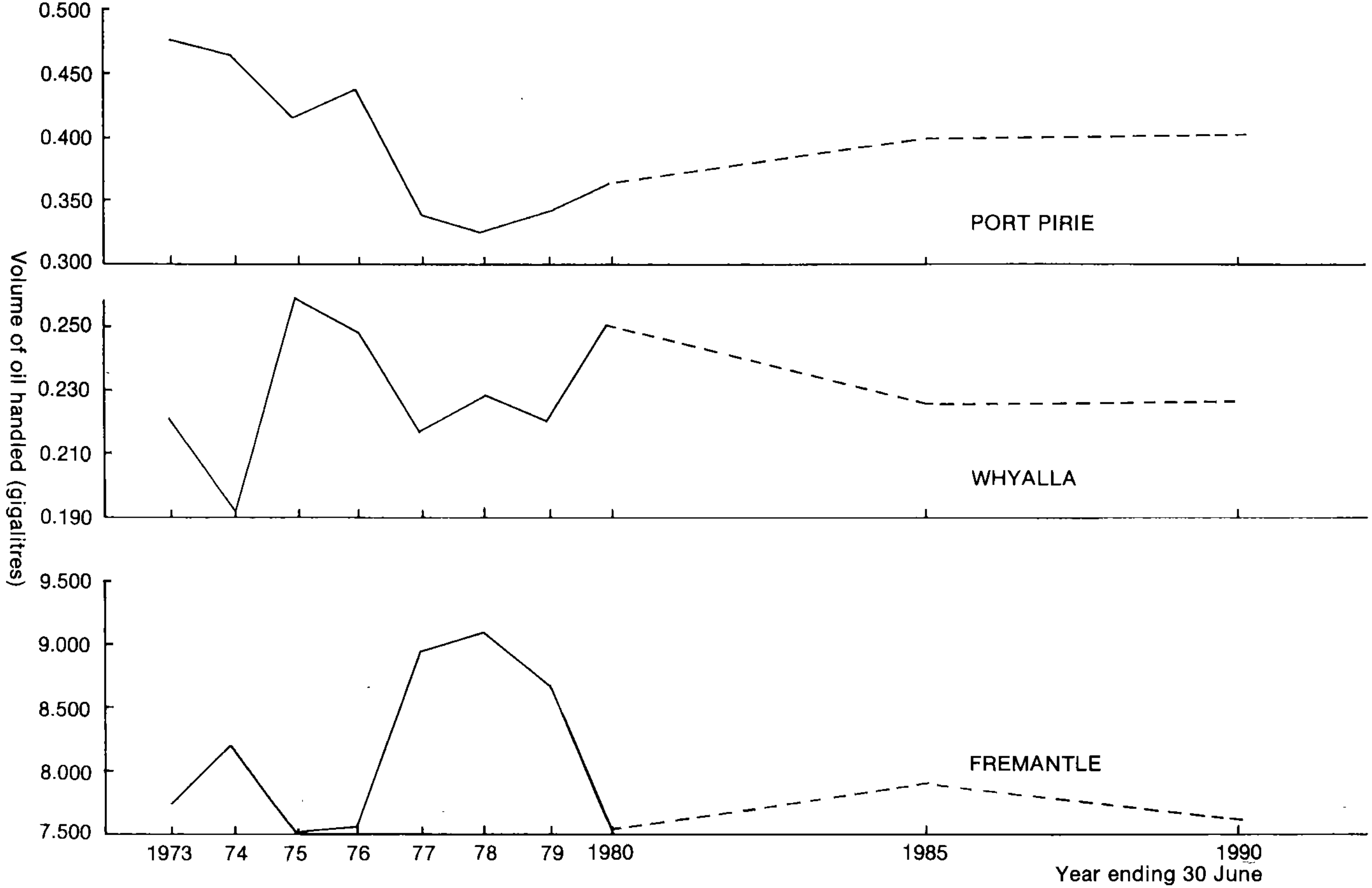

Figure I.12 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Port Pirie, Whyalla and Fremantle

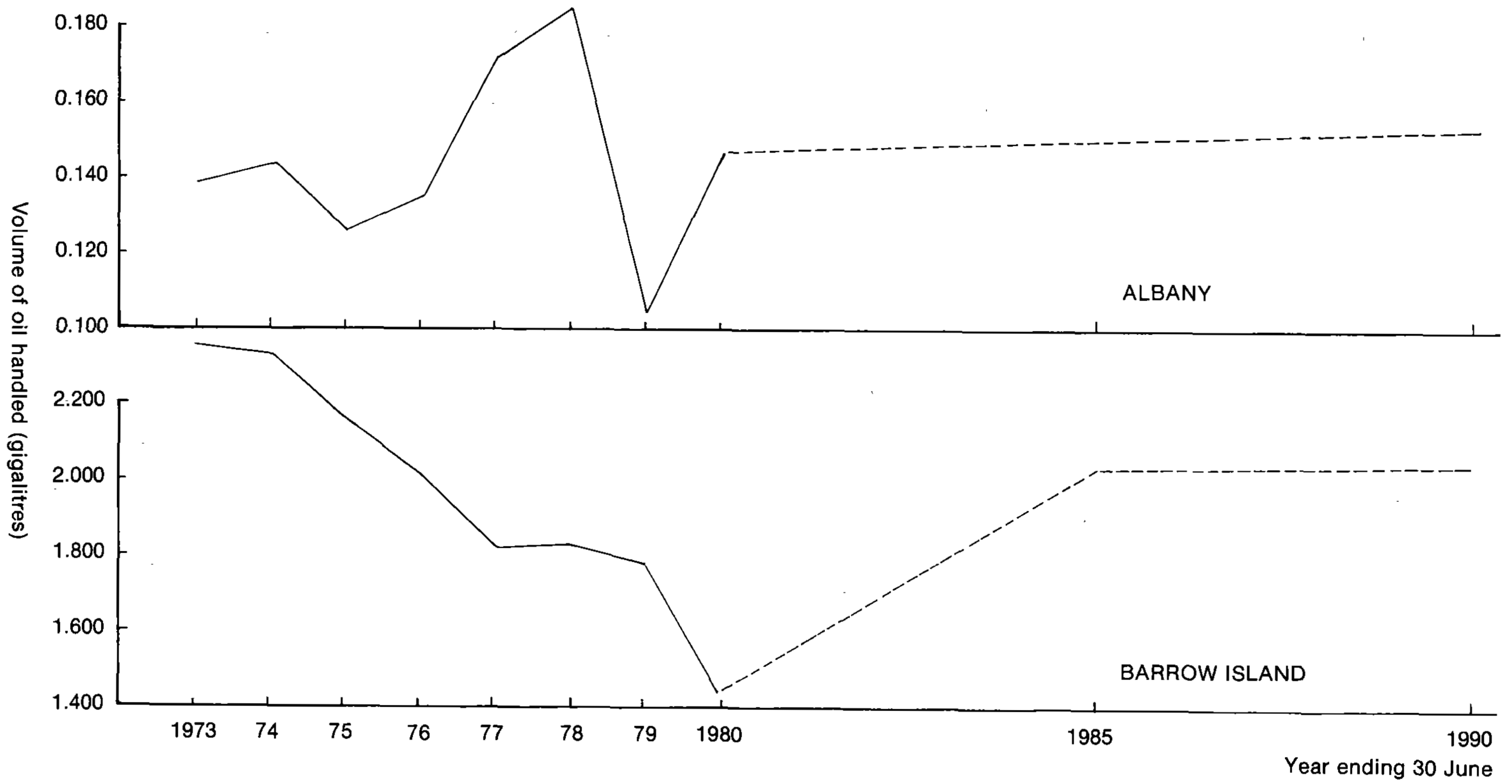

Figure I.13 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Albany and Barrow Island

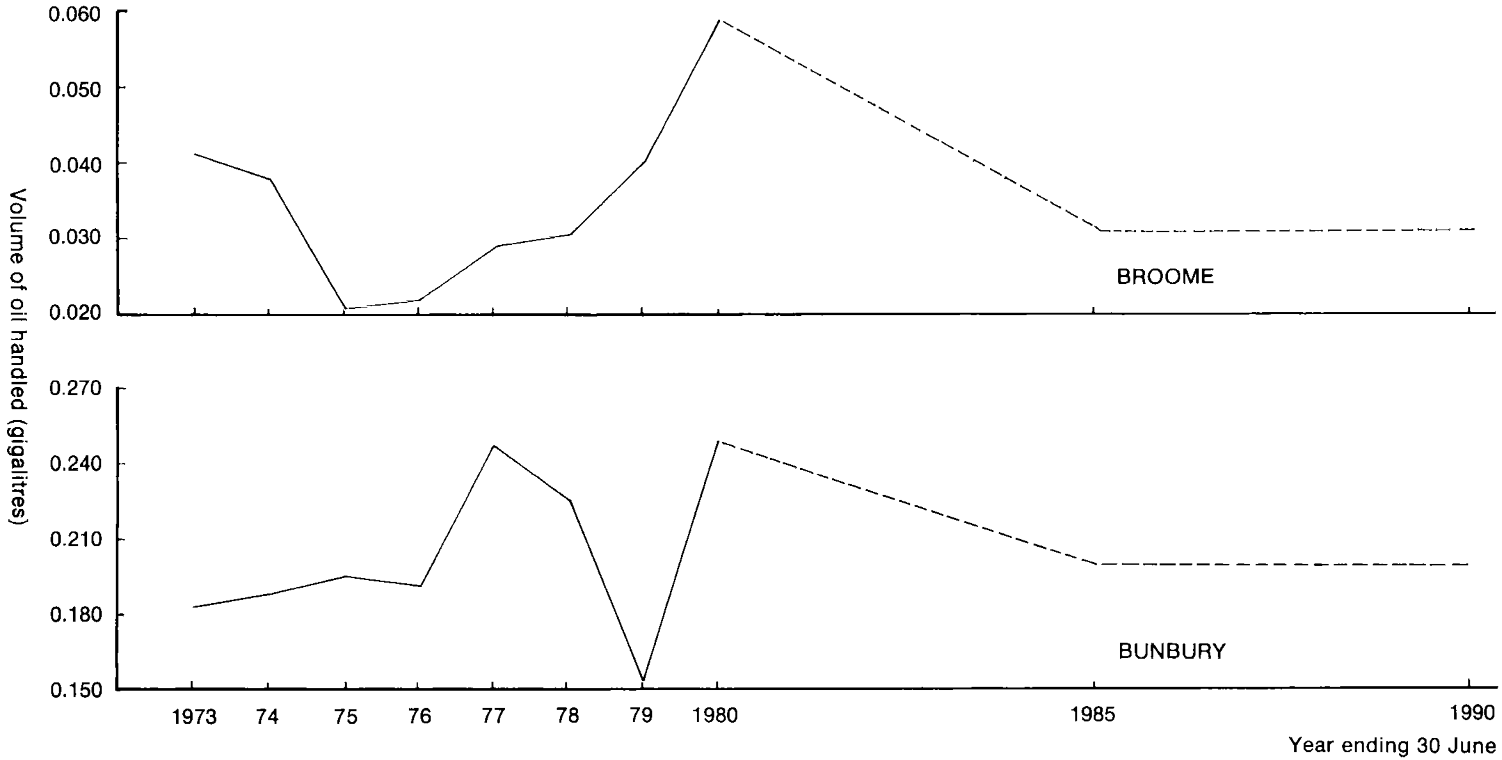

Figure I.14 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Broome and Bunbury

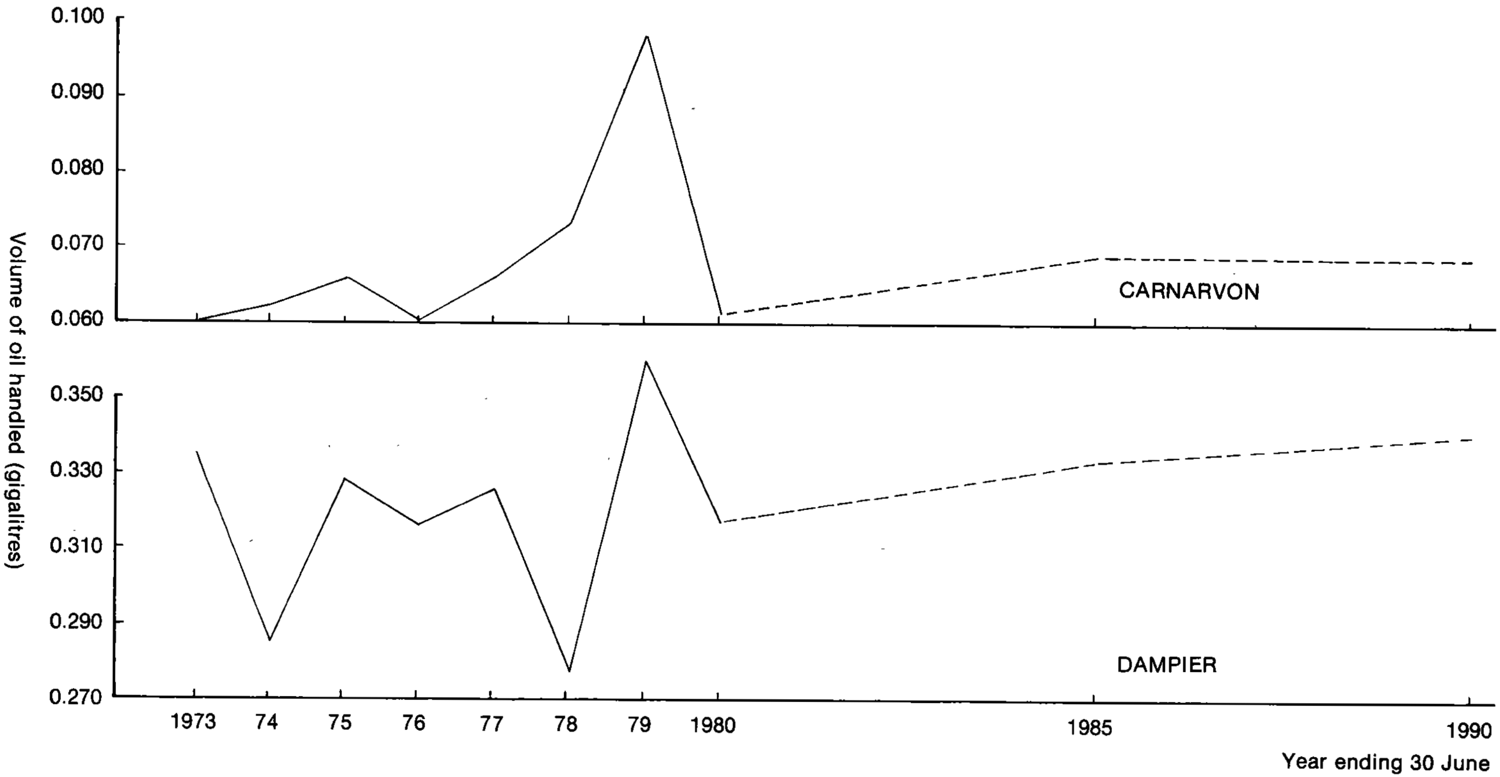

Figure I.15 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Carnarvon and Dampier

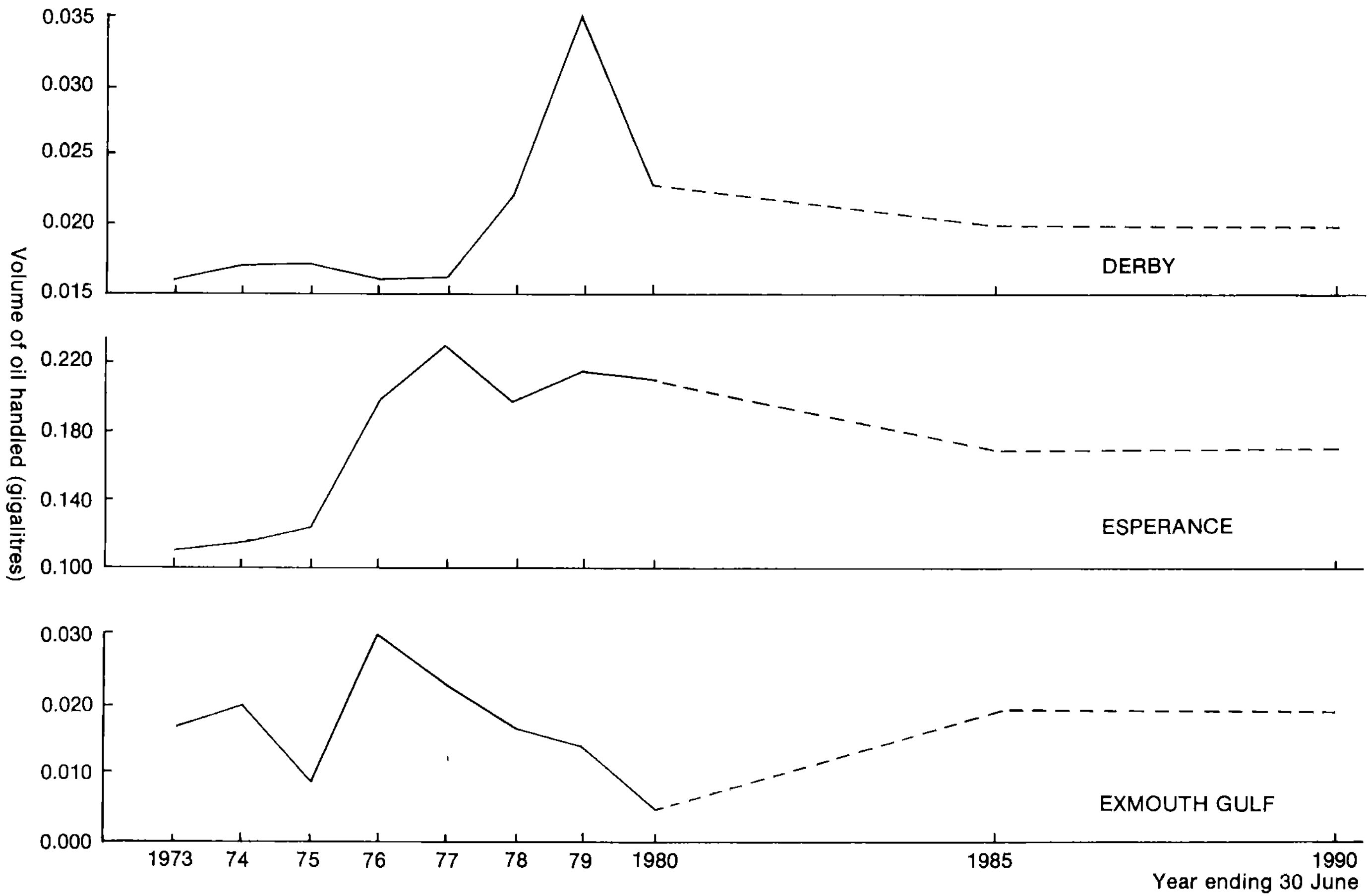

Figure I.16 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Derby, Esperance and Exmouth Gulf

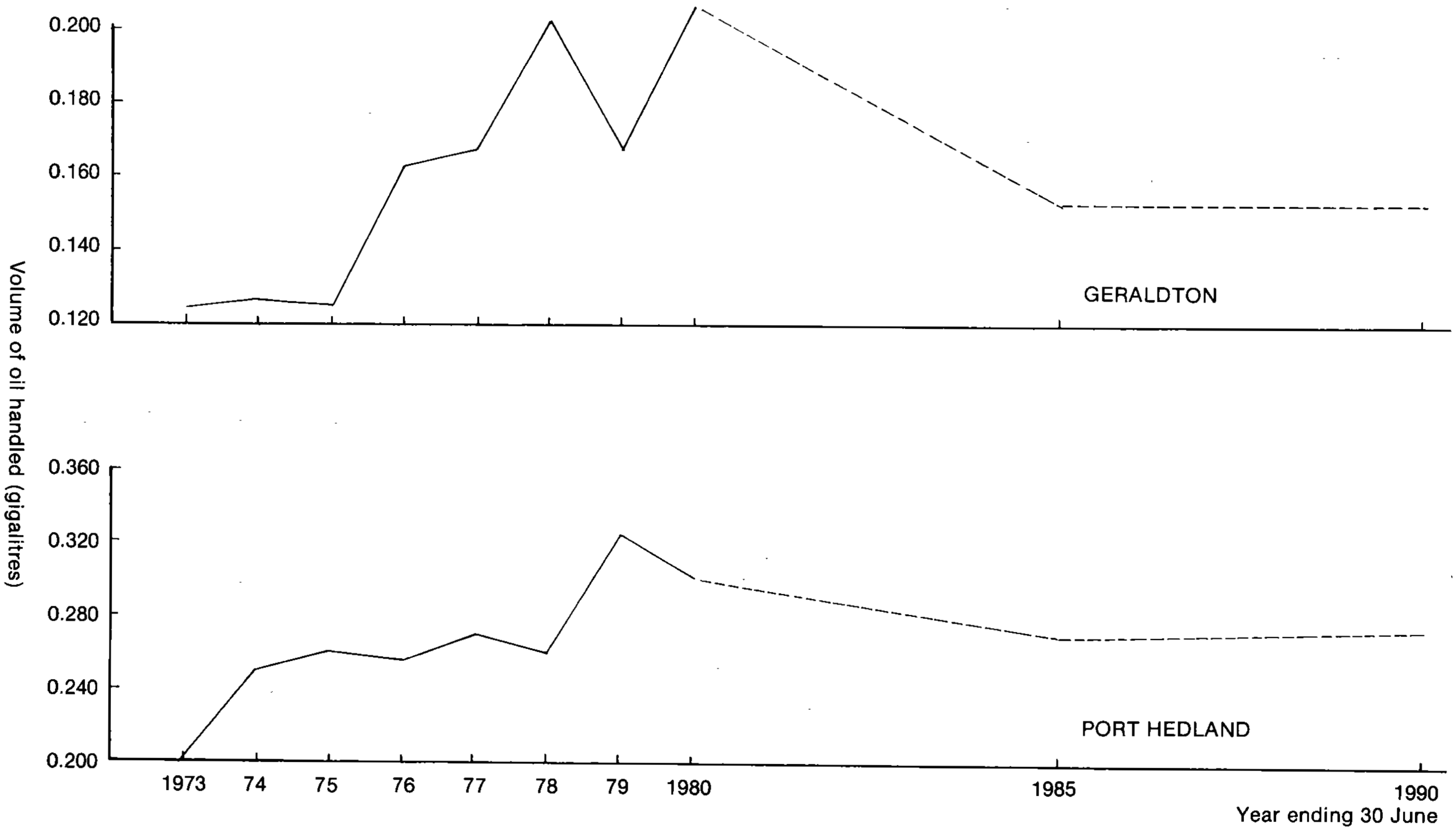

Figure I.17 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Geraldton and Port Hedland

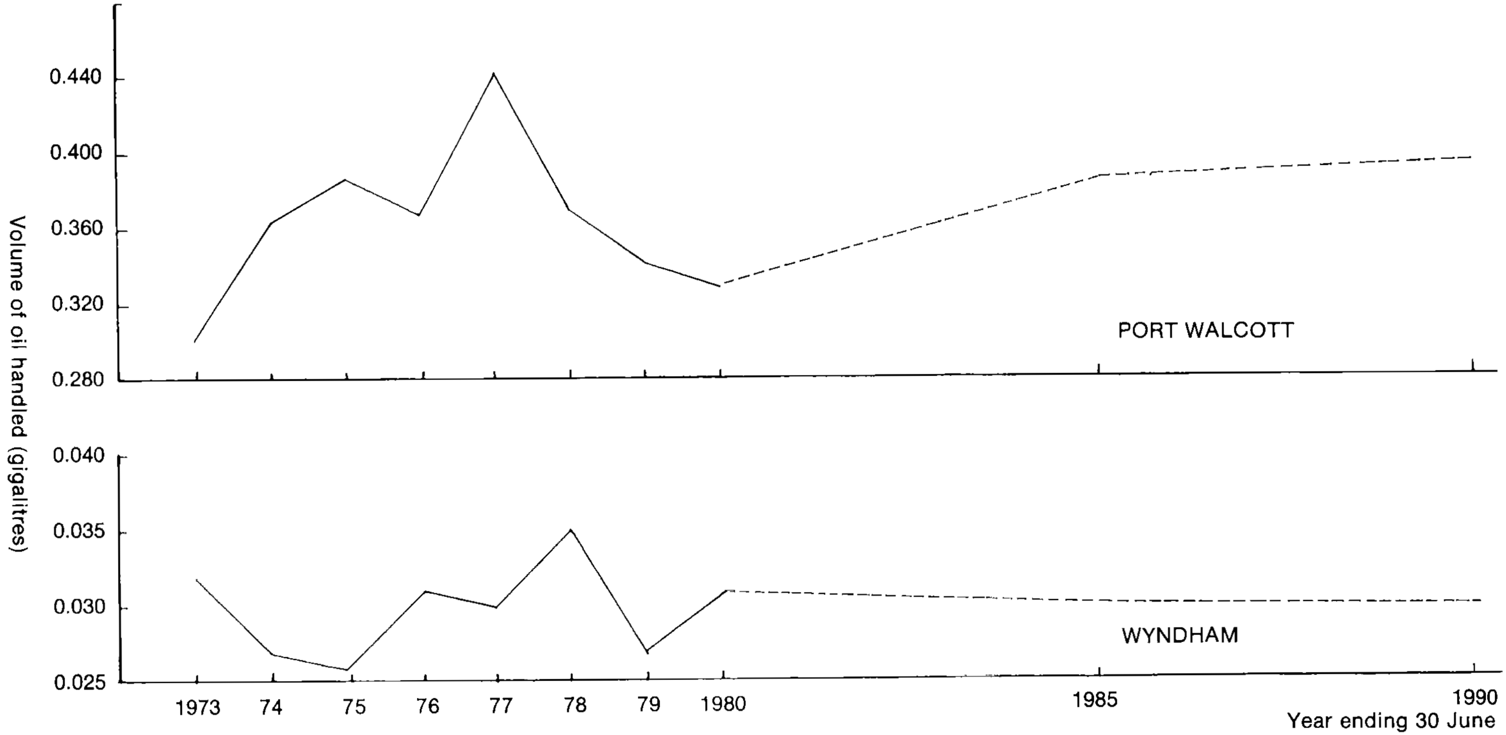

Figure I.18 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Port Walcott and Wyndham

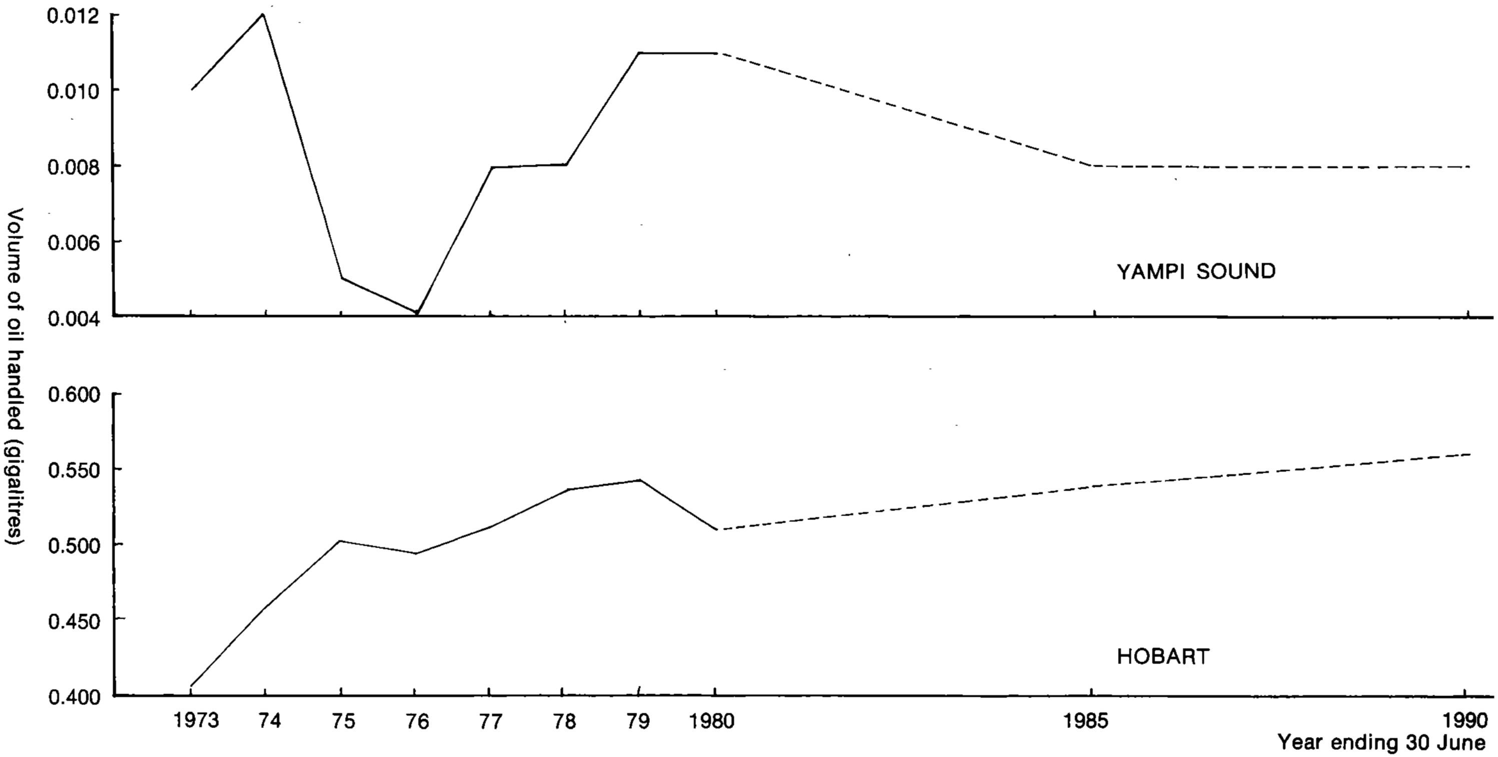

Figure I.19 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Yampi Sound and Hobart

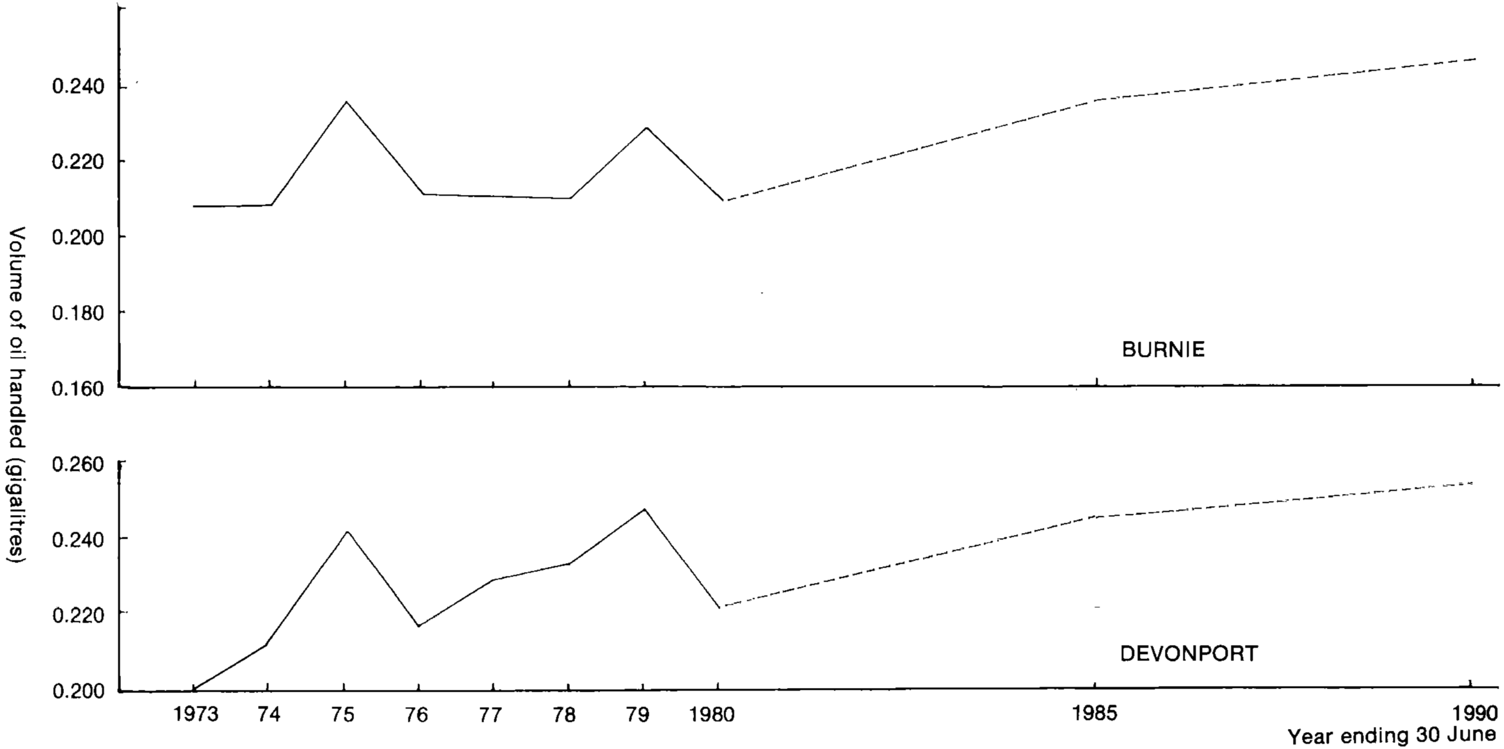

Figure I.20 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Burnie and Devonport

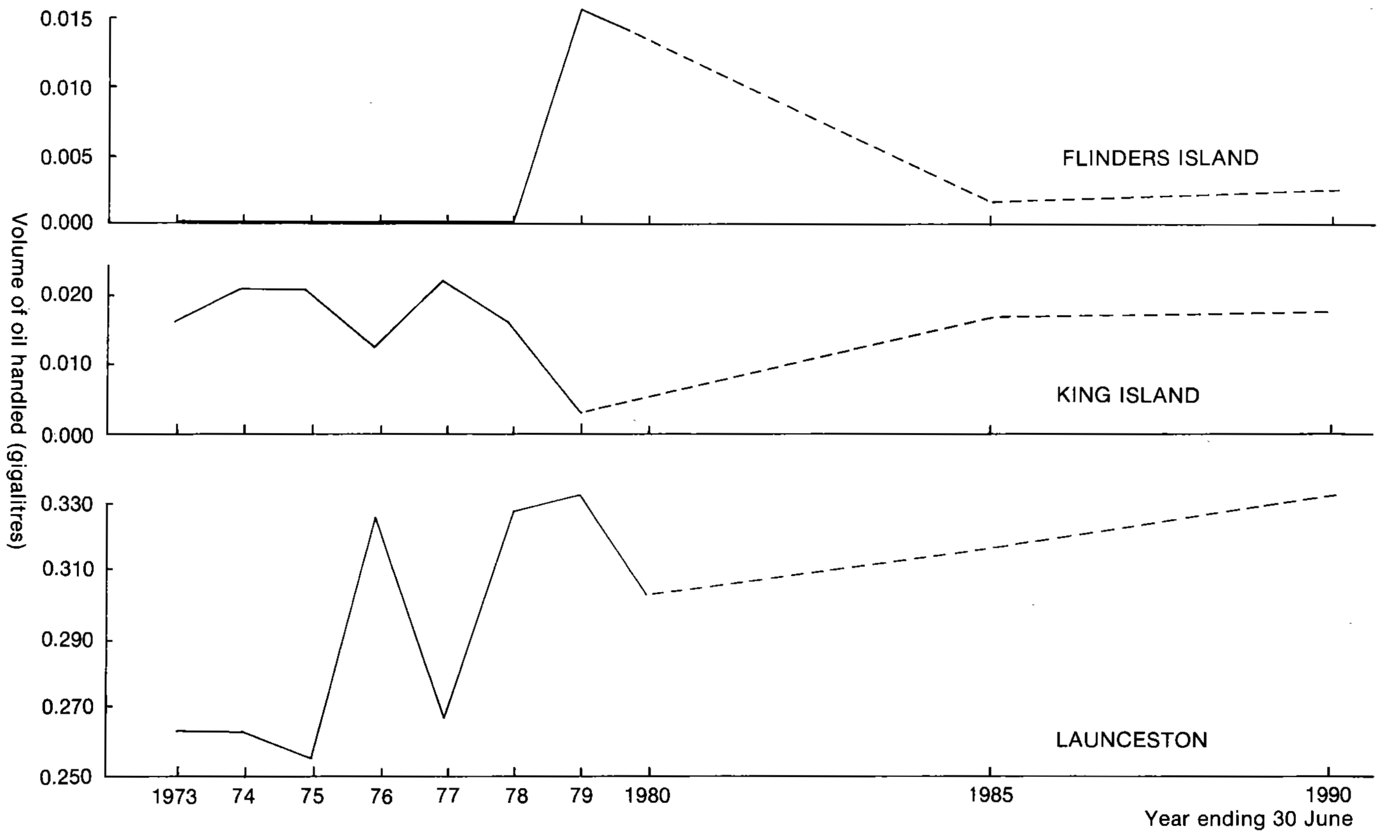

Figure I.21 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Flinders Island, King Island and Launceston

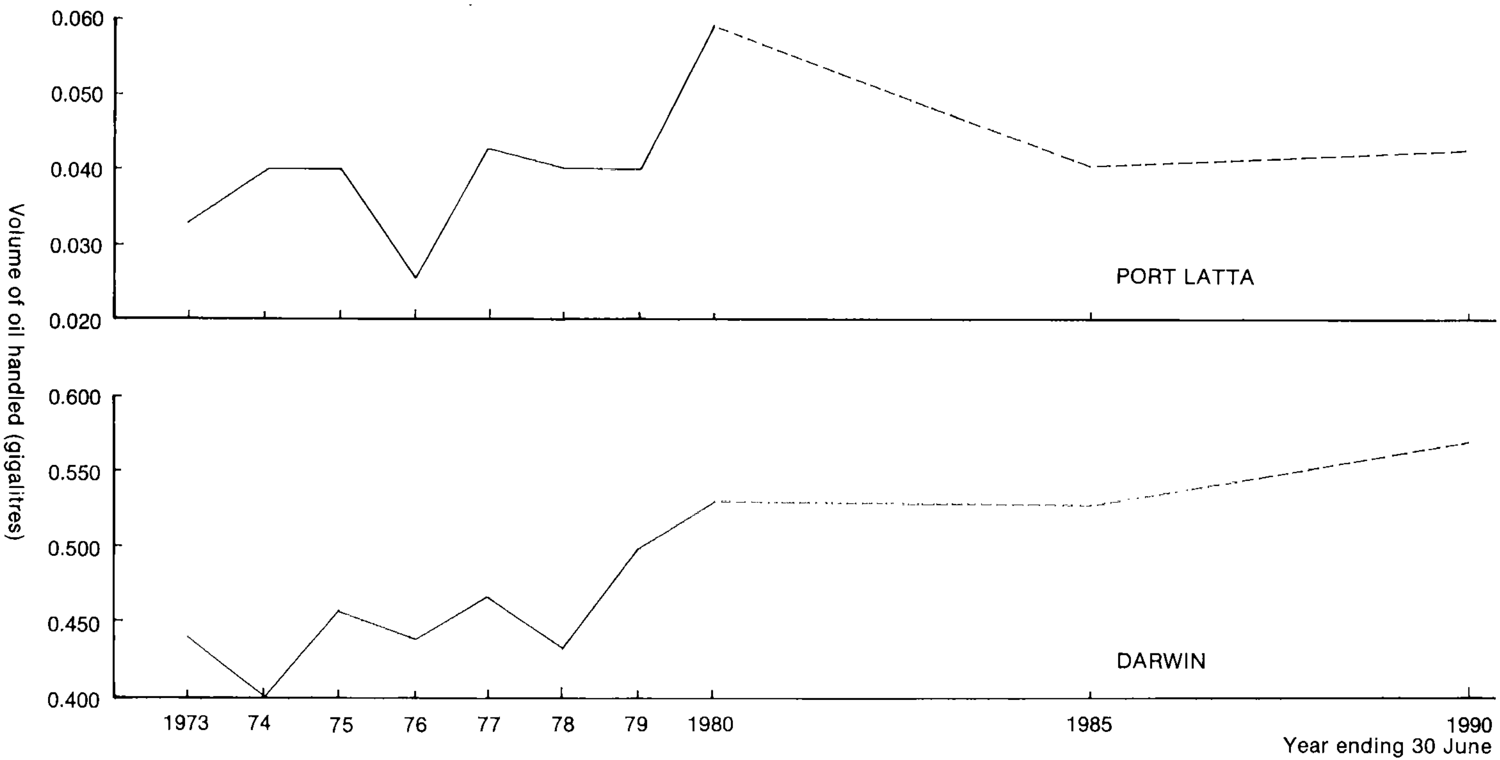

Figure I.22 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Port Latta and Darwin

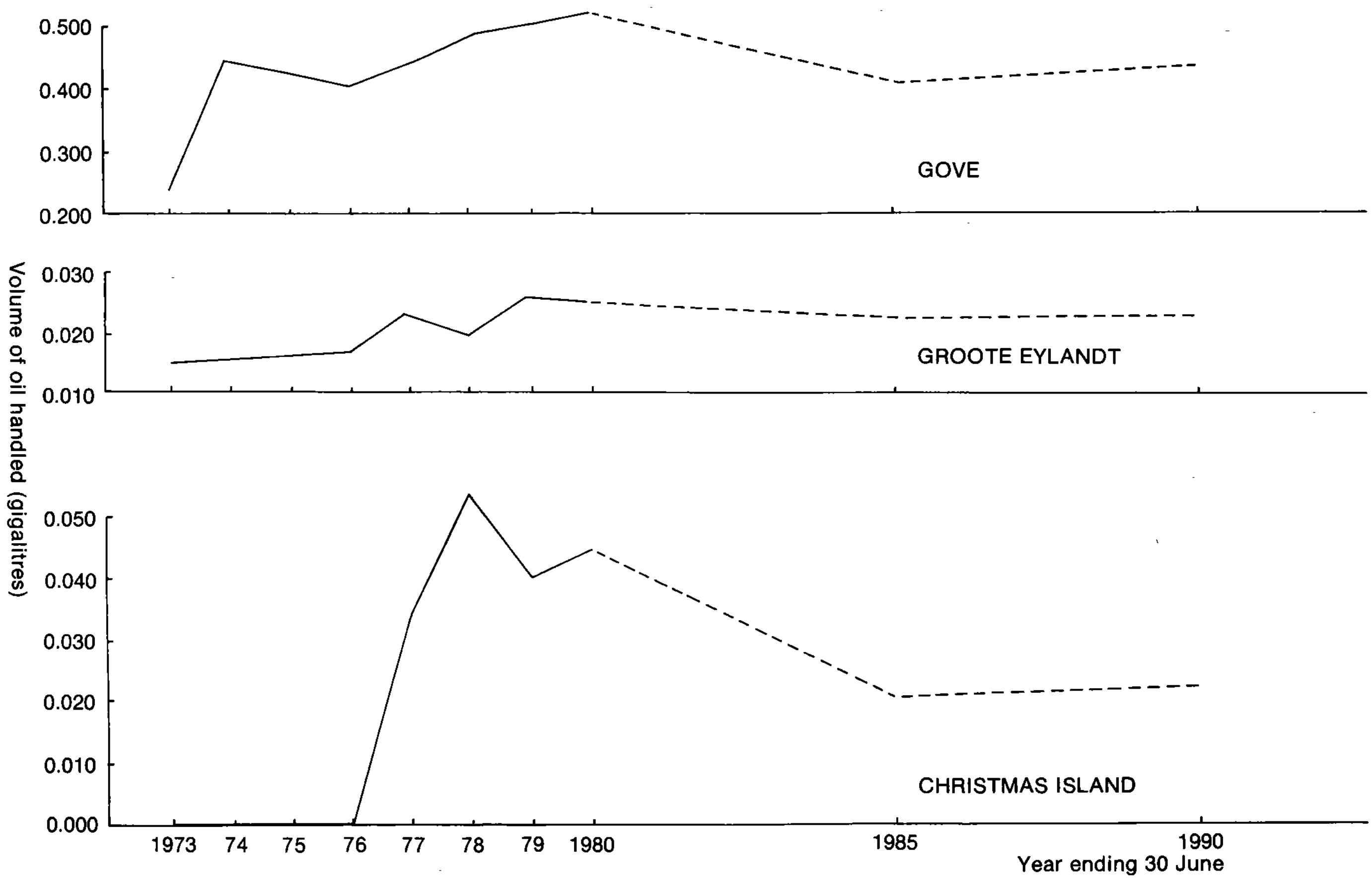

Figure I.23 Actual and projected annual volumes of oil handled: 1 July 1972 to 30 June 1990—Gove, Groote Eylandt and Christmas Island

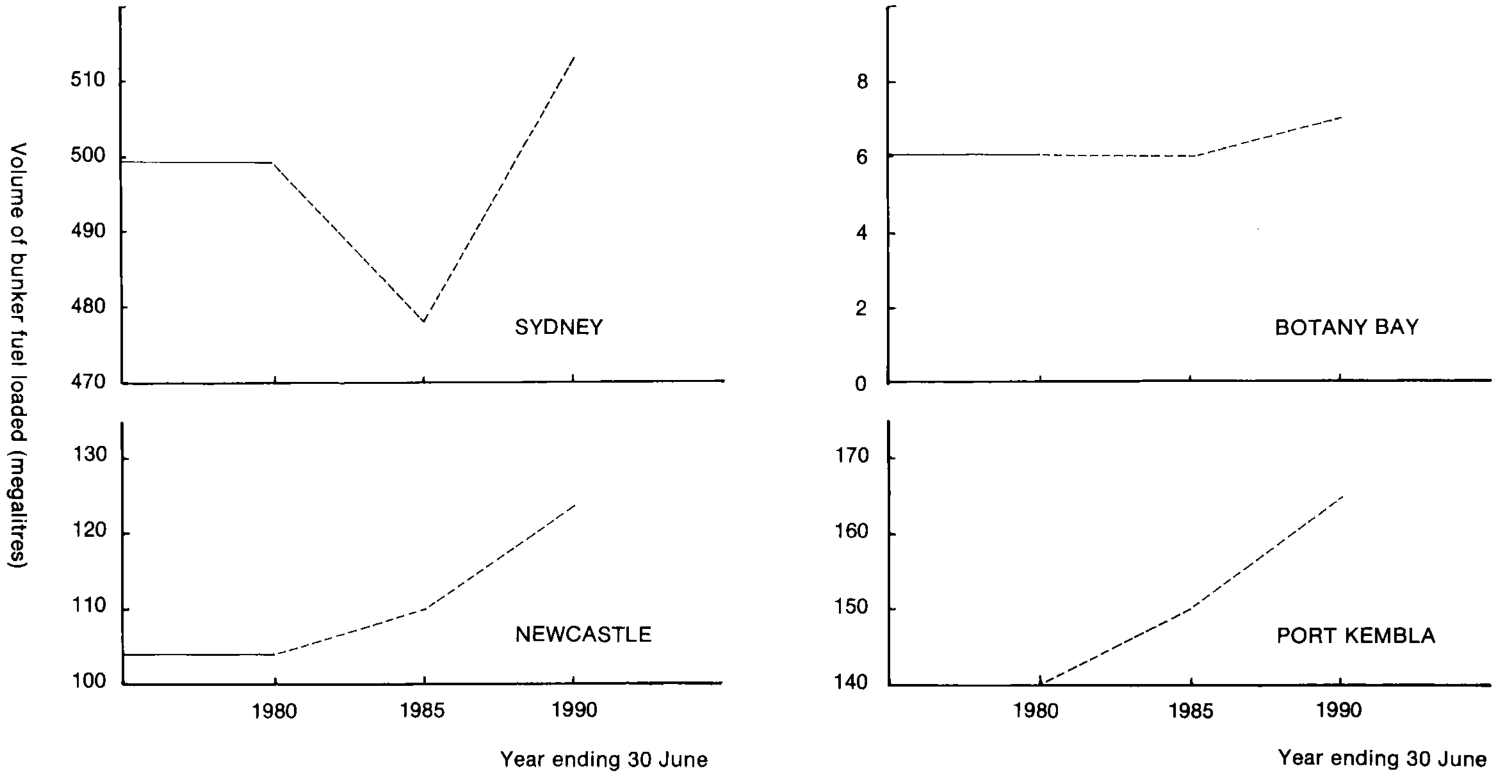

Figure I.24 Estimated and projected annual volumes of bunker fuel loaded: 1 July 1979 to 30 June 1990—Ports of New South Wales

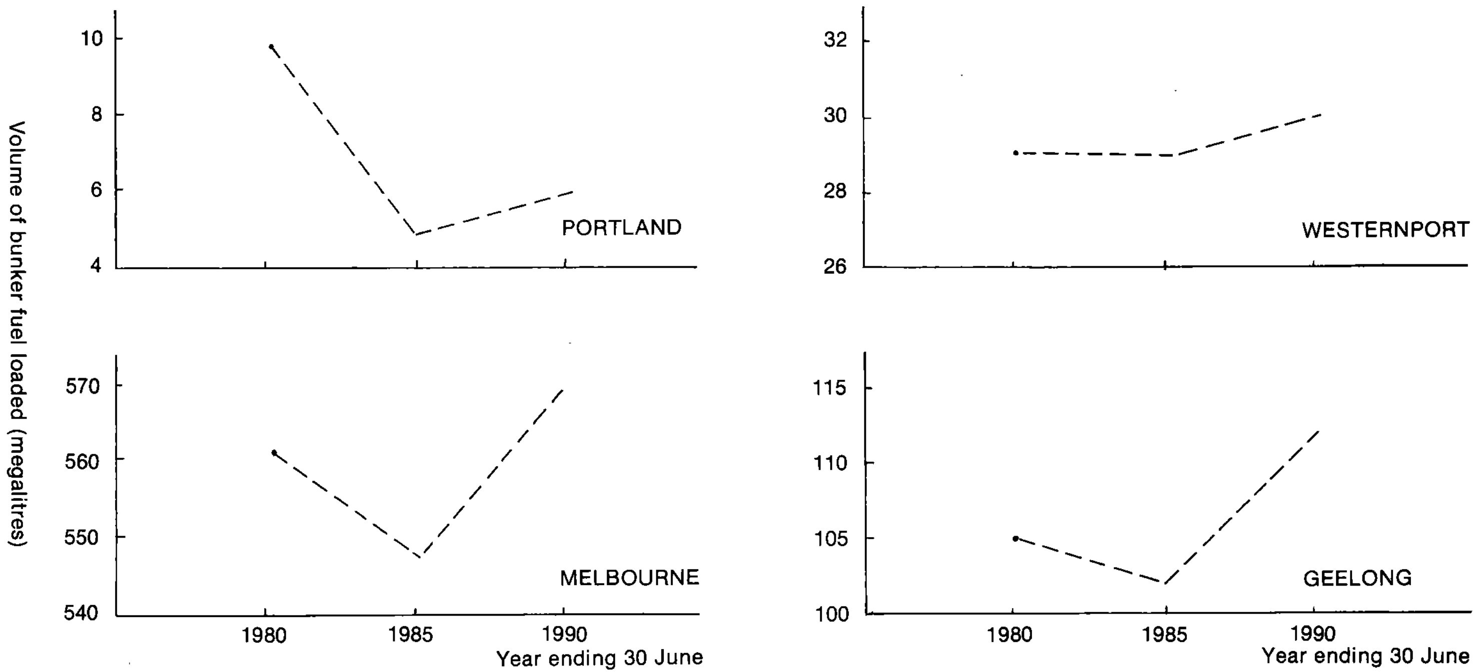

Figure I.25 Estimated and projected annual volumes of bunker fuel loaded: 1 July 1979 to 30 June 1990—Ports of Victoria

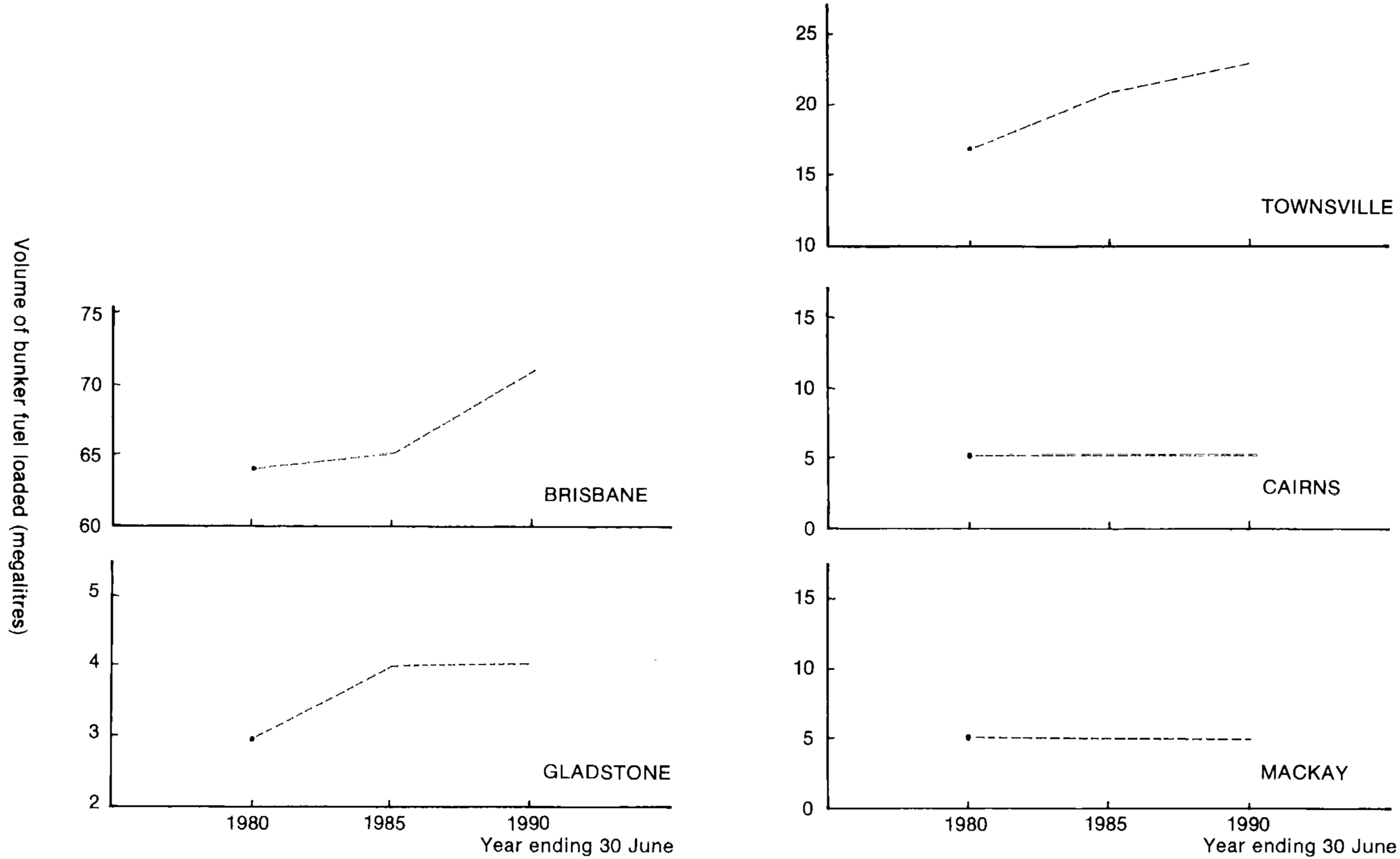

Figure I.26 Estimated and projected annual volumes of bunker fuel loaded: 1 July 1979 to 30 June 1990—Ports of Queensland

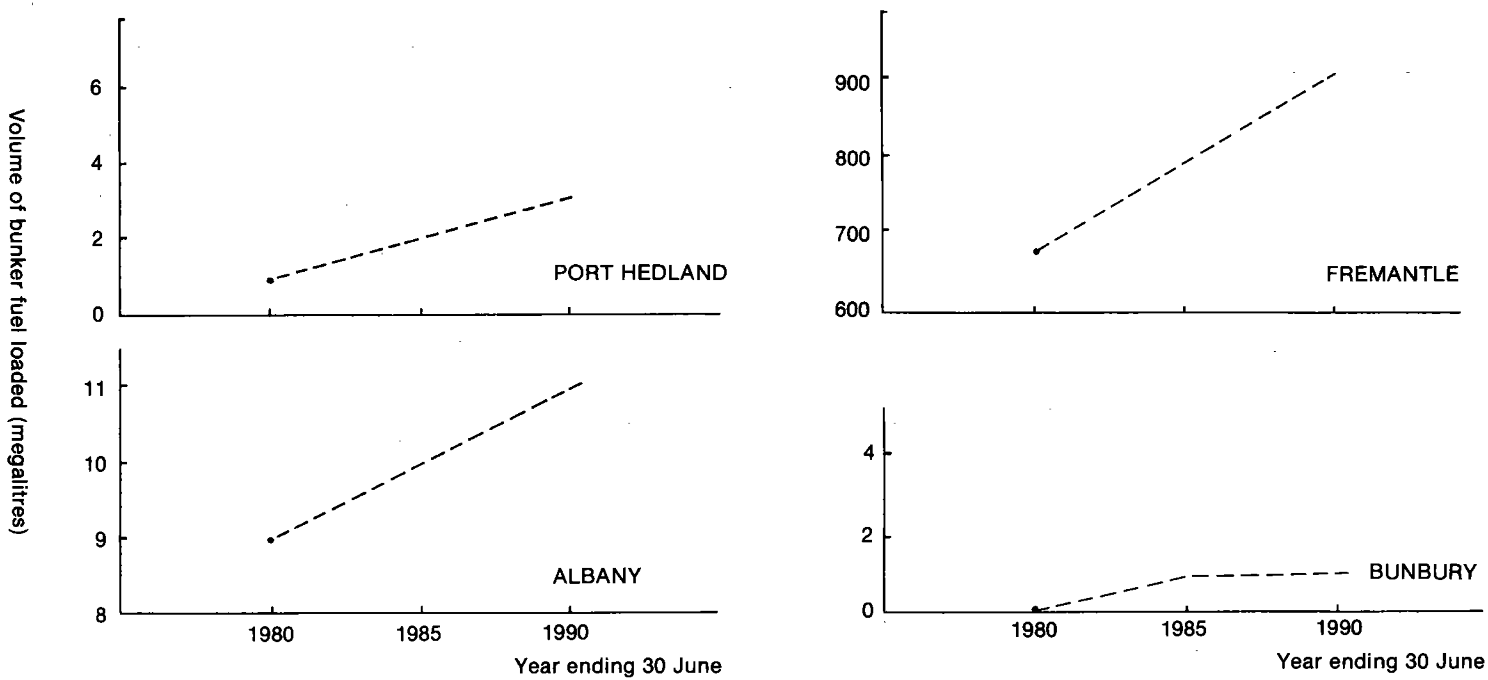

Figure I.27 Estimated and projected annual volumes of bunker fuel loaded: 1 July 1979 to 30 June 1990—Ports of Western Australia

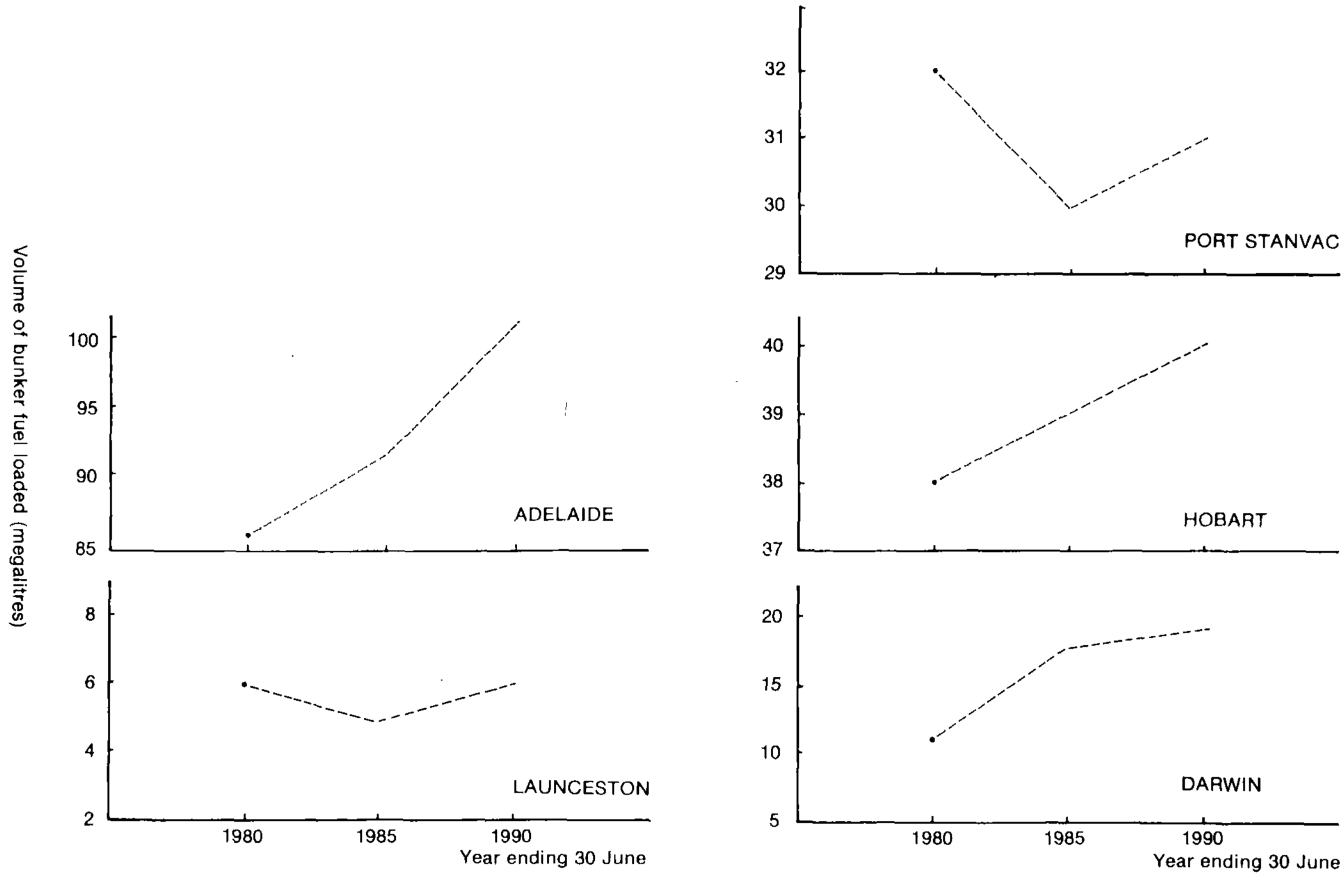

Figure I.28 Estimated and projected annual volumes of bunker fuel loaded: 1 July 1979 to 30 June 1990—Ports of South Australia, Tasmania and the Northern Territory

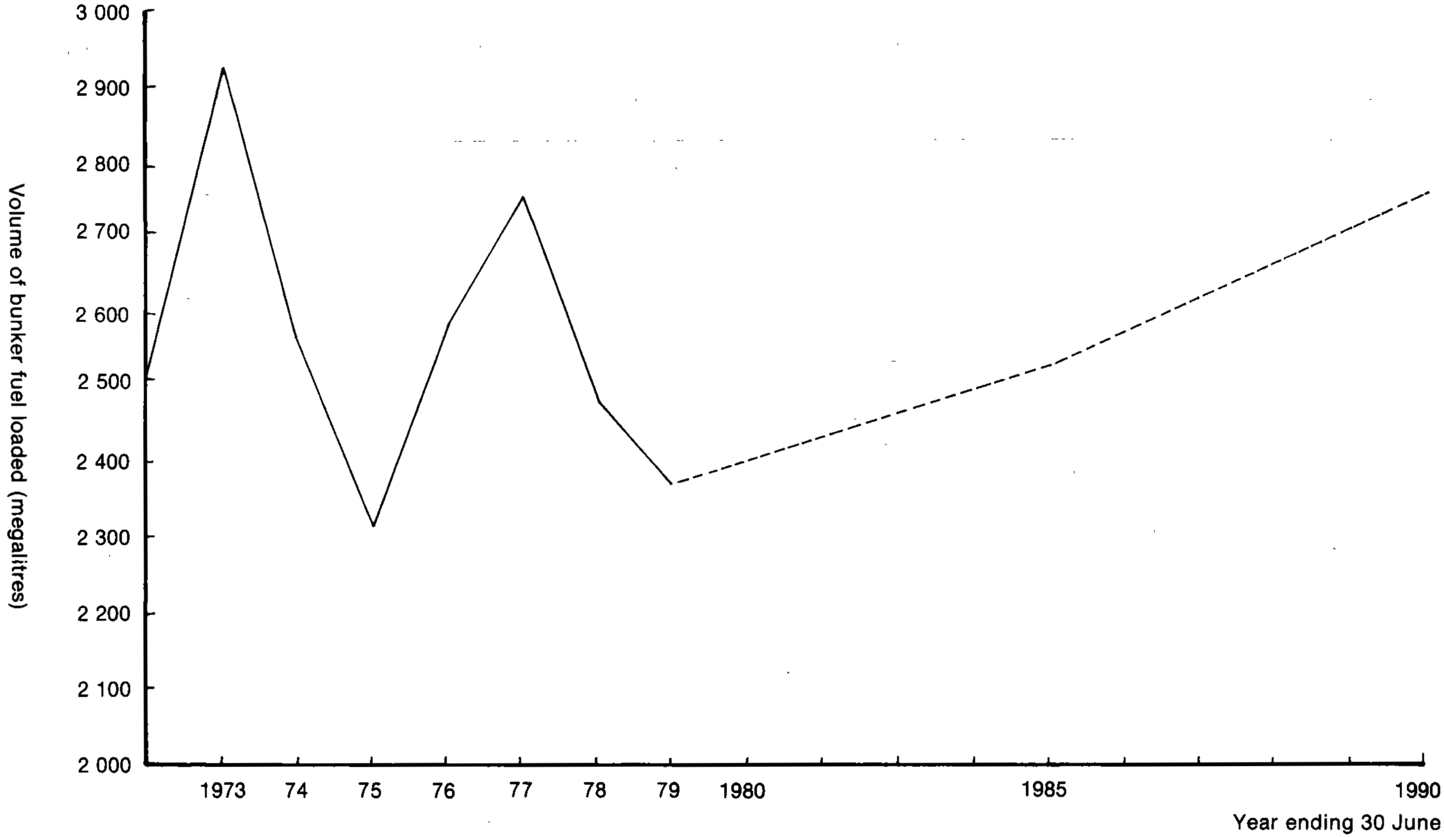

Figure I.29 Actual and projected volumes of bunker fuel loaded in Australia: 1 July 1972 to 30 June 1990

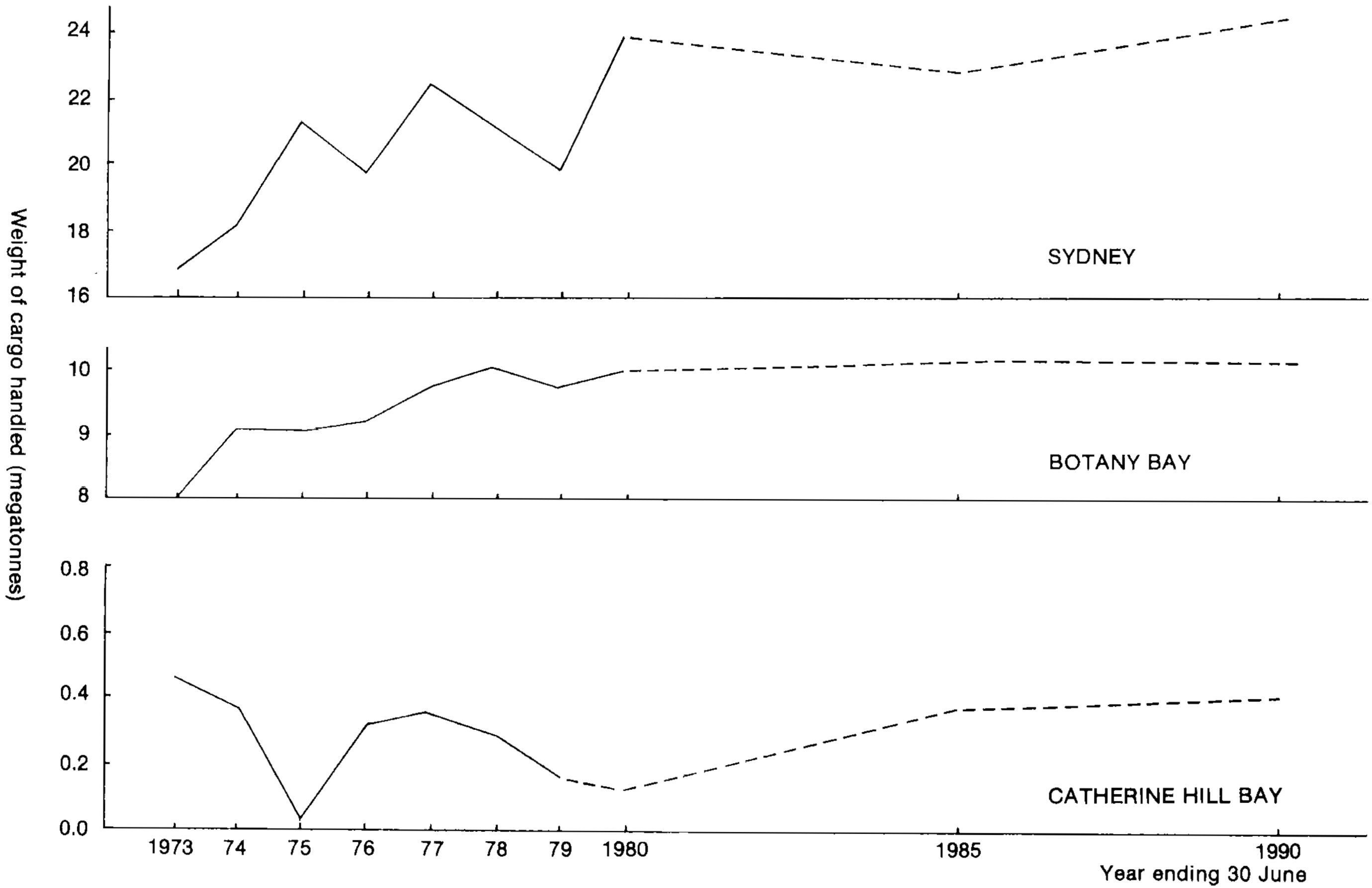

Figure I.30 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Sydney, Botany Bay and Catherine Hill Bay

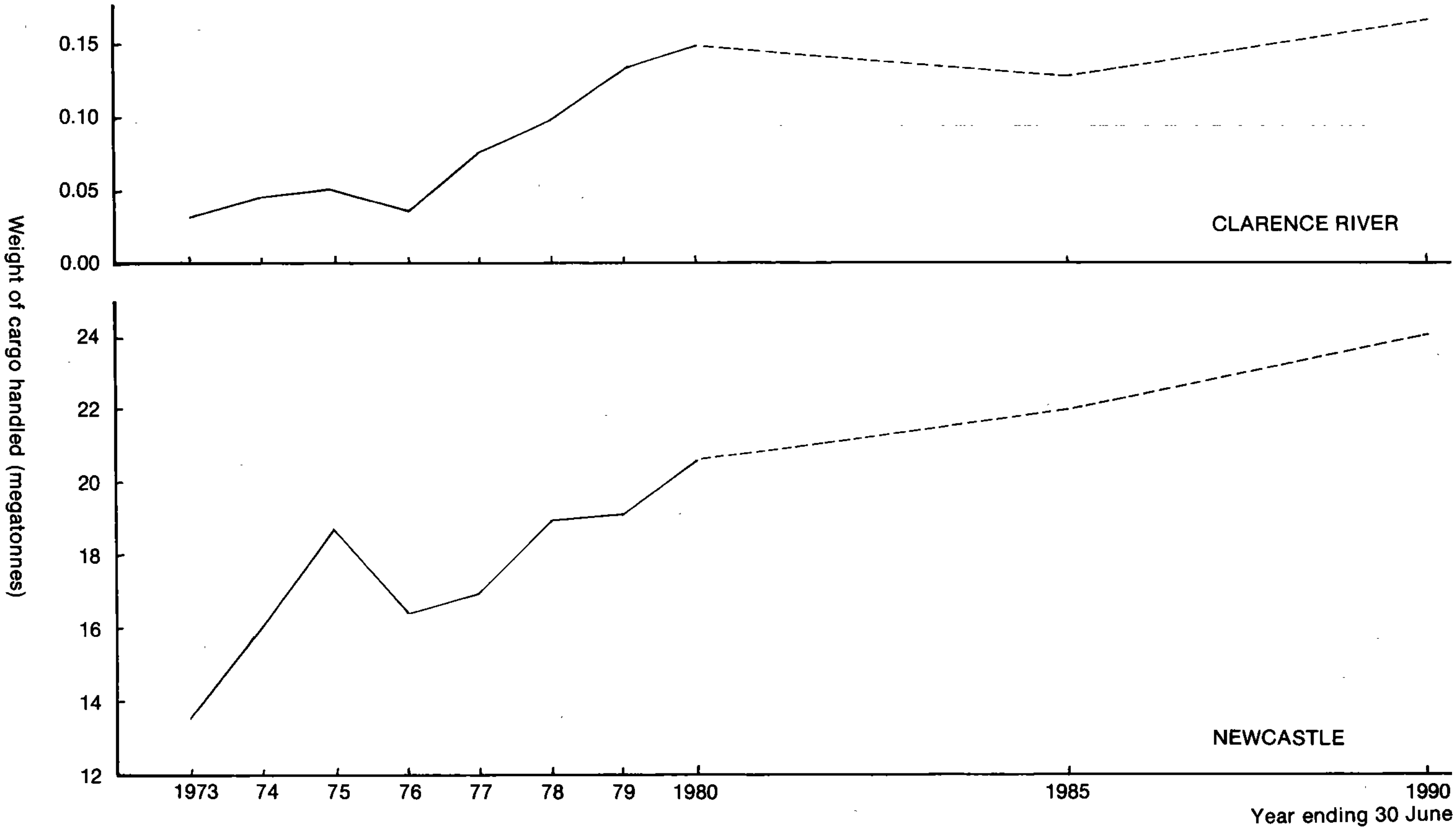

Figure I.31 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Clarence River and Newcastle

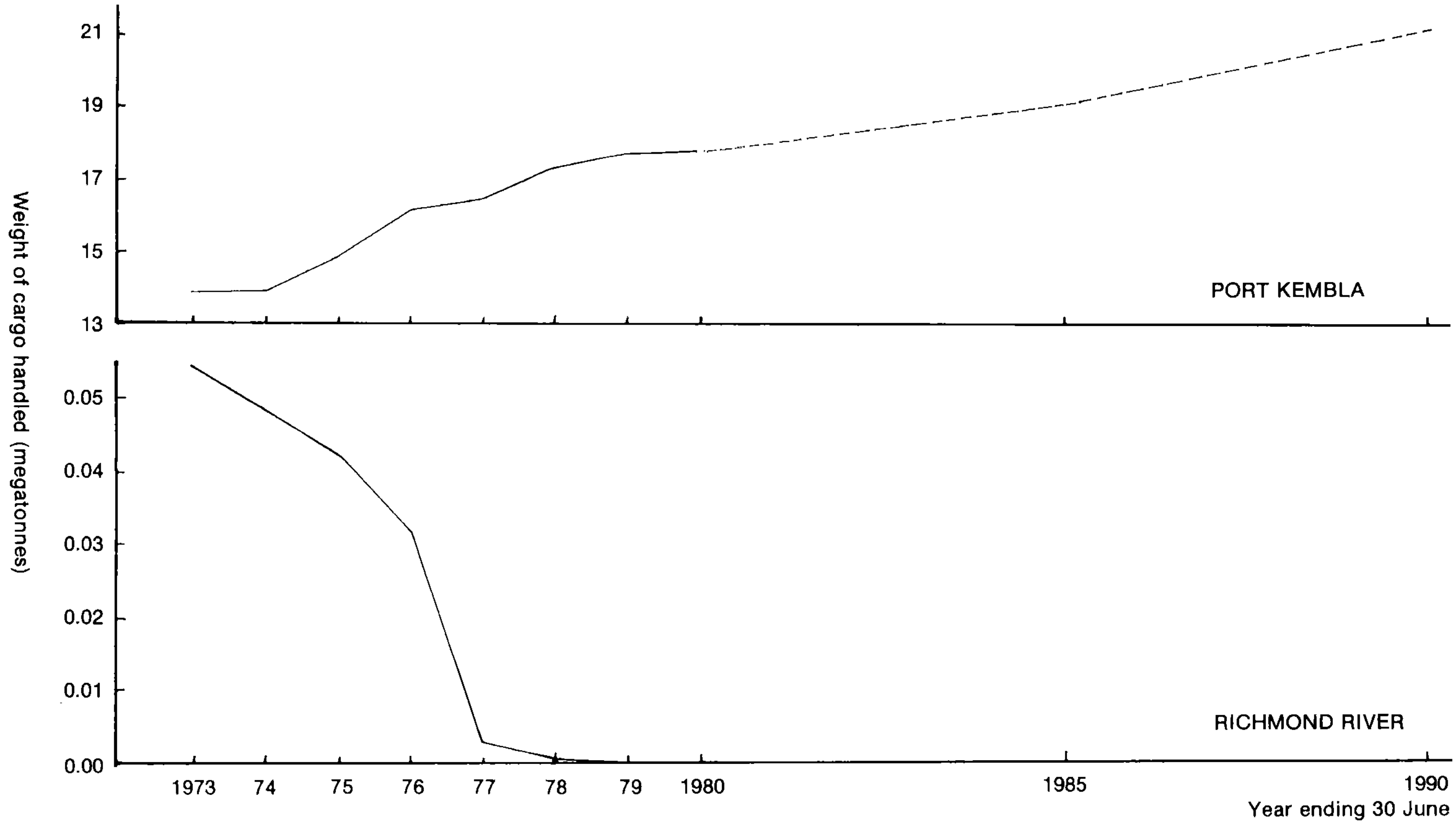

Figure I.32 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Port Kembla and Richmond River

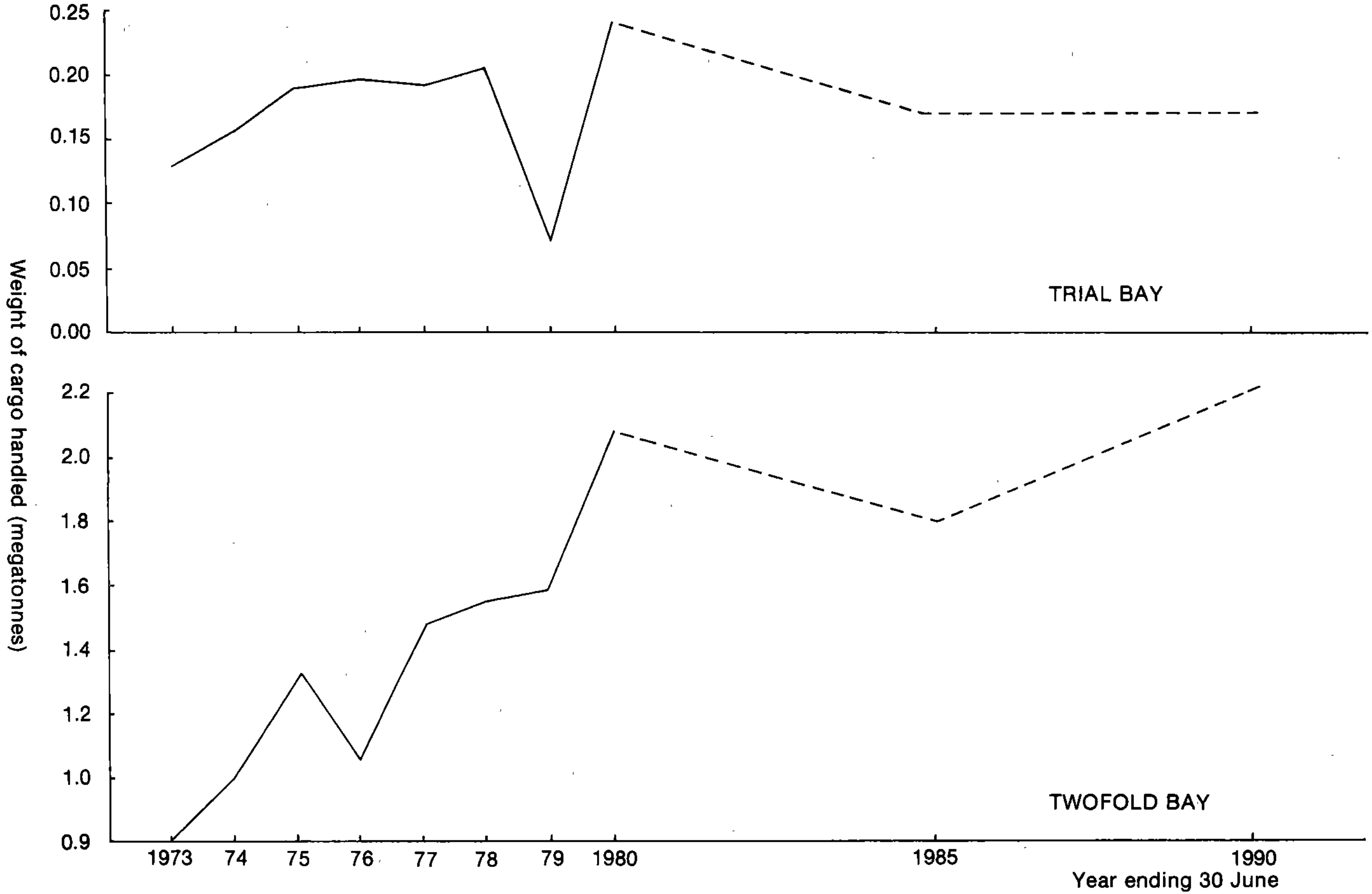

Figure I.33 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Trial Bay and Twofold Bay

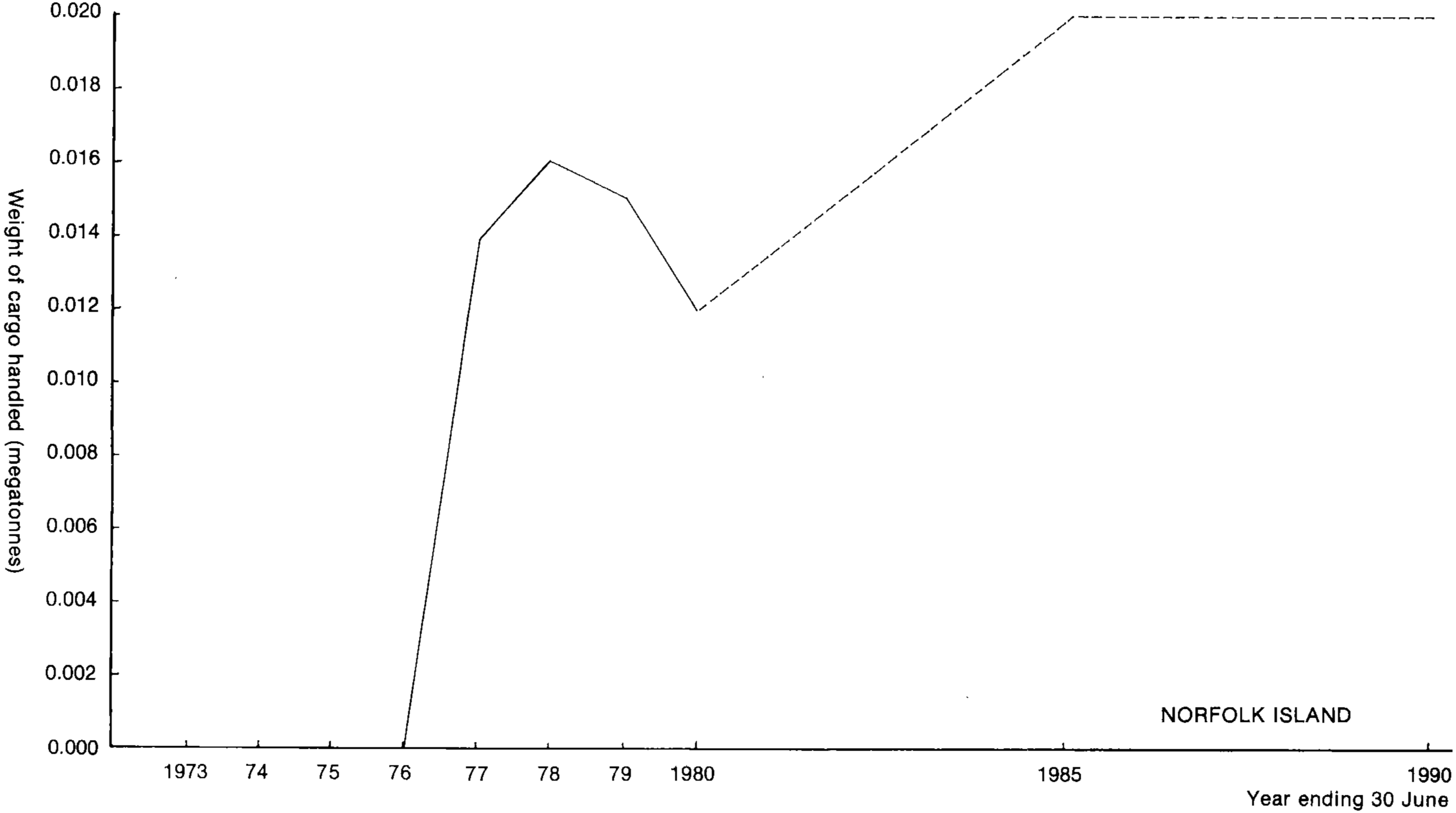

Figure I.34 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Norfolk Island

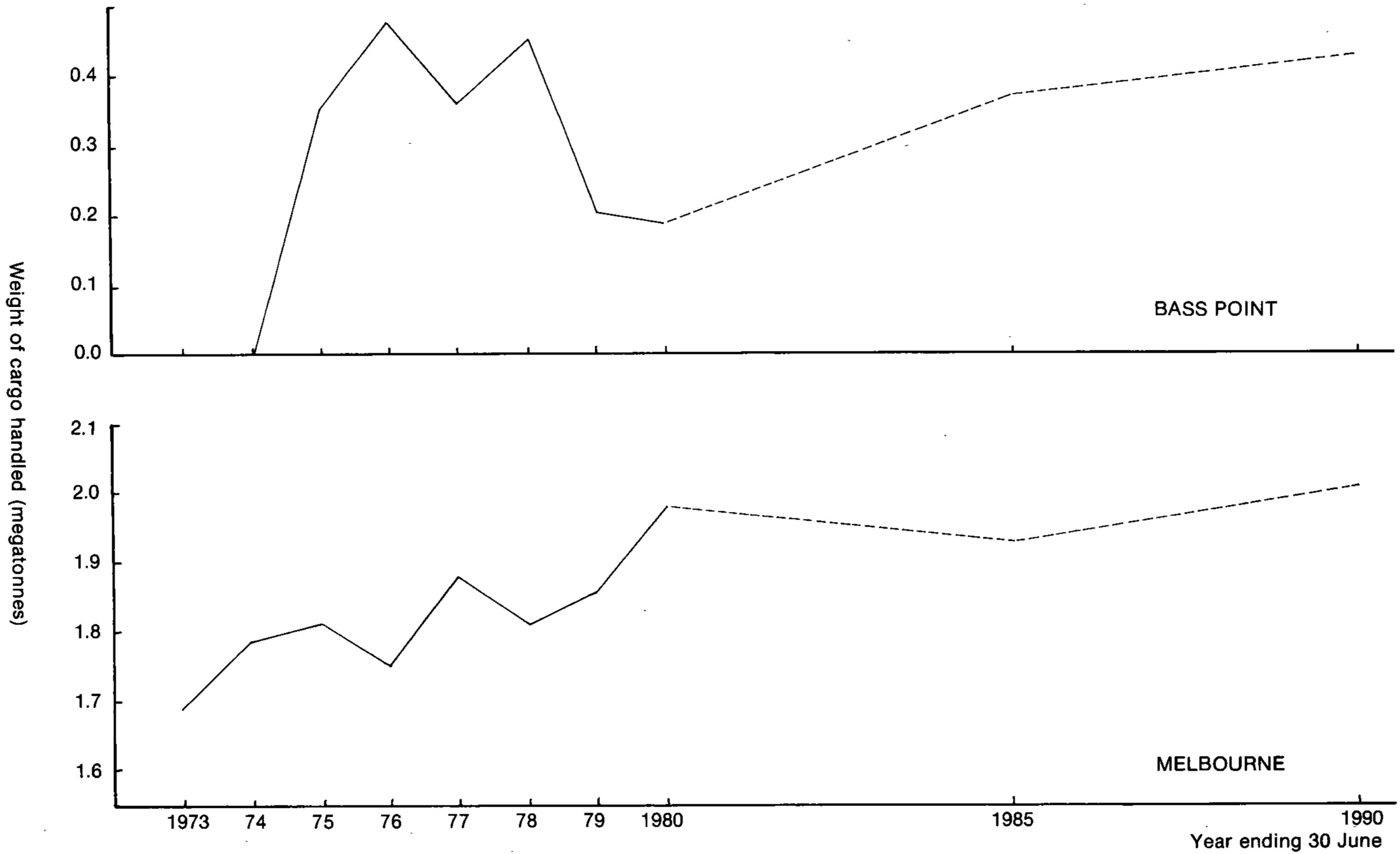

Figure I.35 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Bass Point and Melbourne

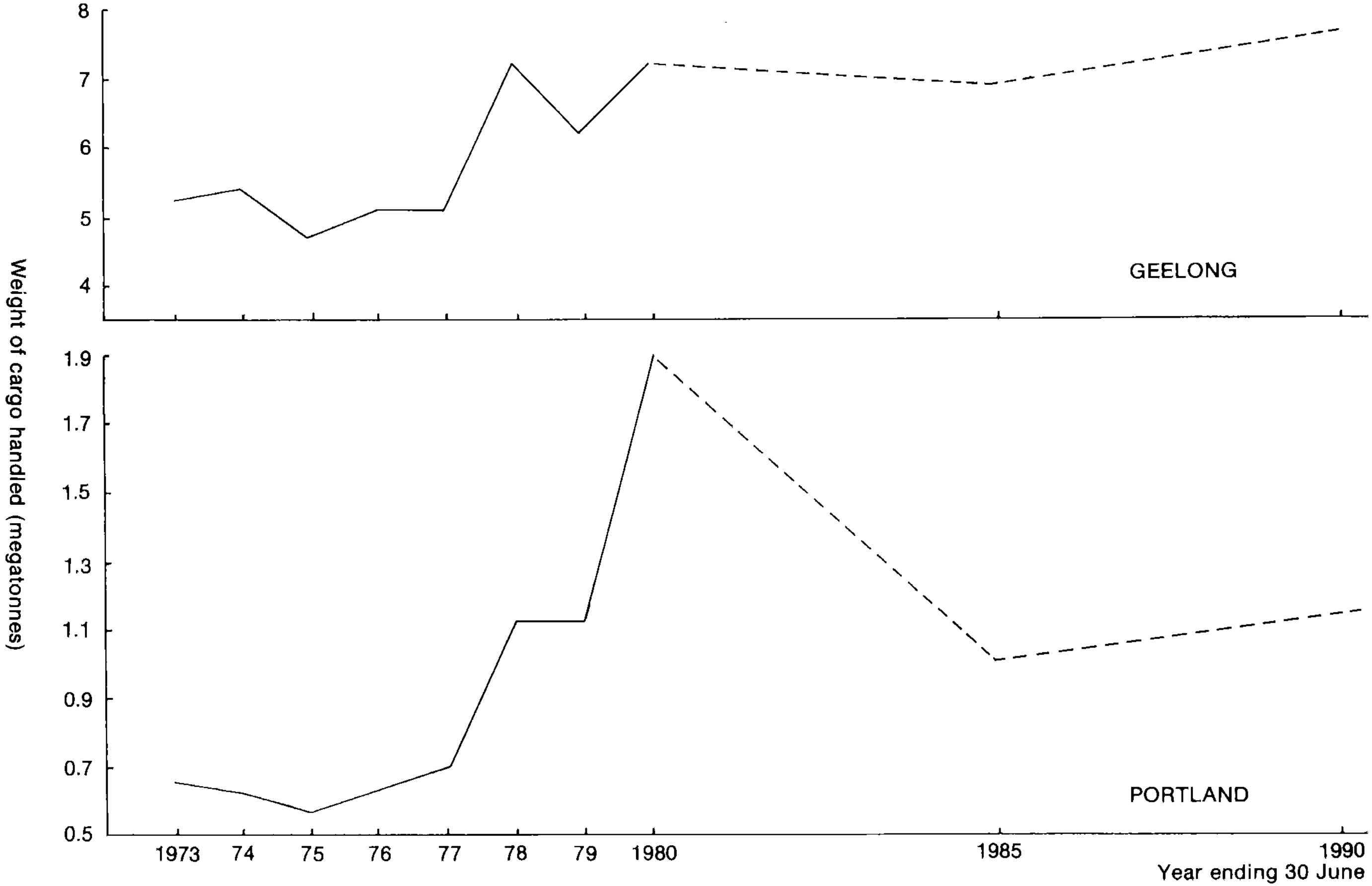

Figure I.36 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Geelong and Portland

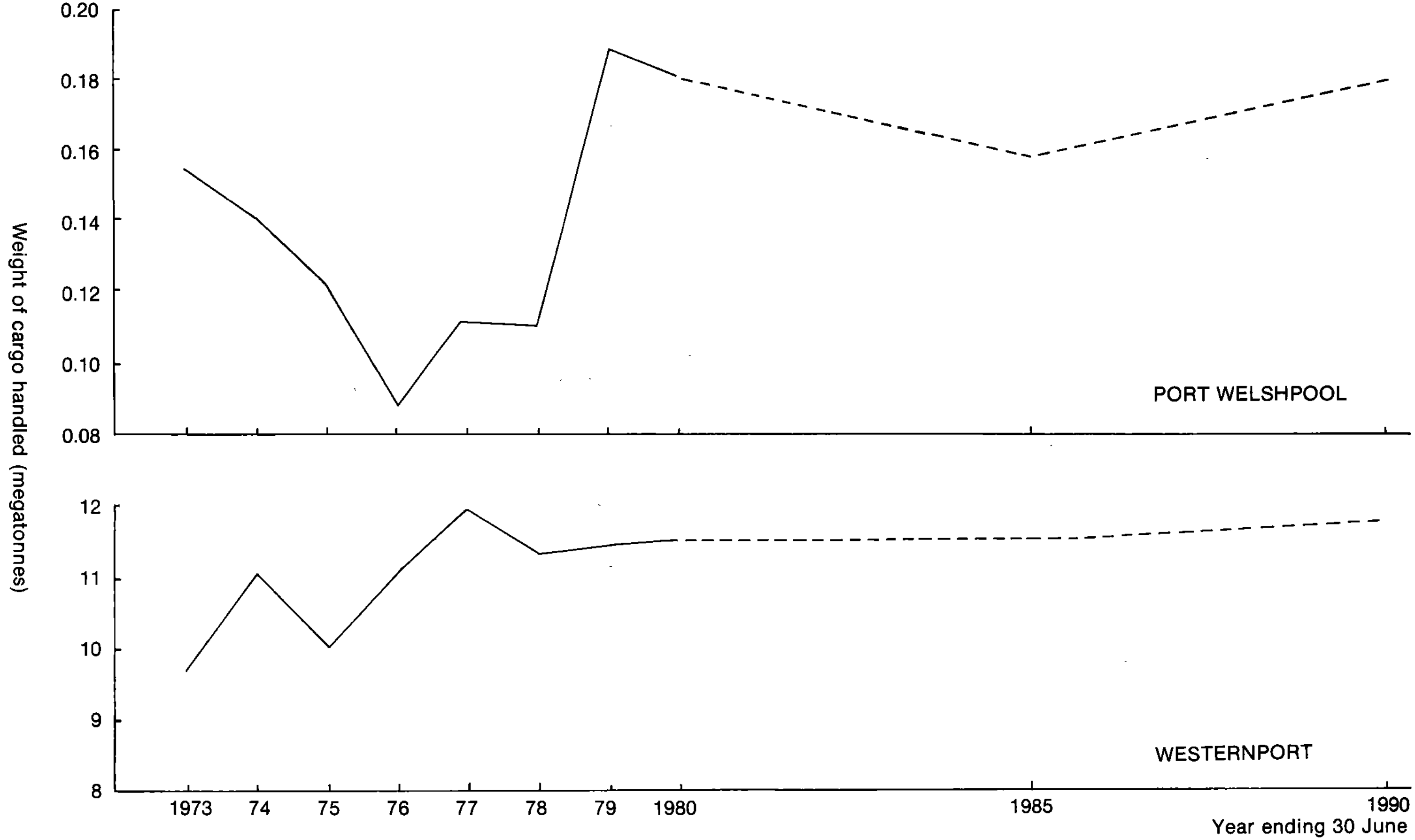

Figure I.37 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Port Welshpool and Westernport

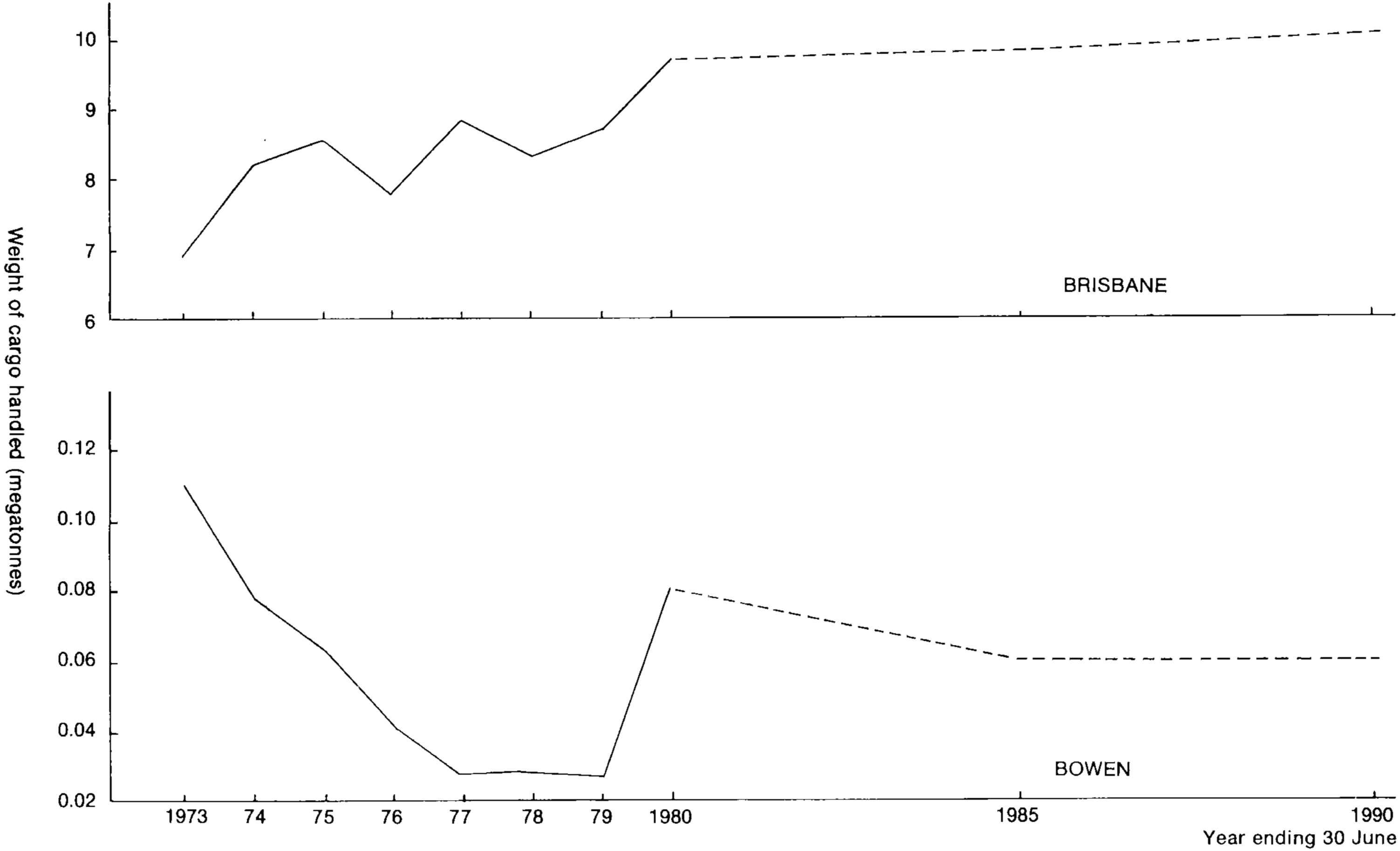

Figure I.38 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Brisbane and Bowen

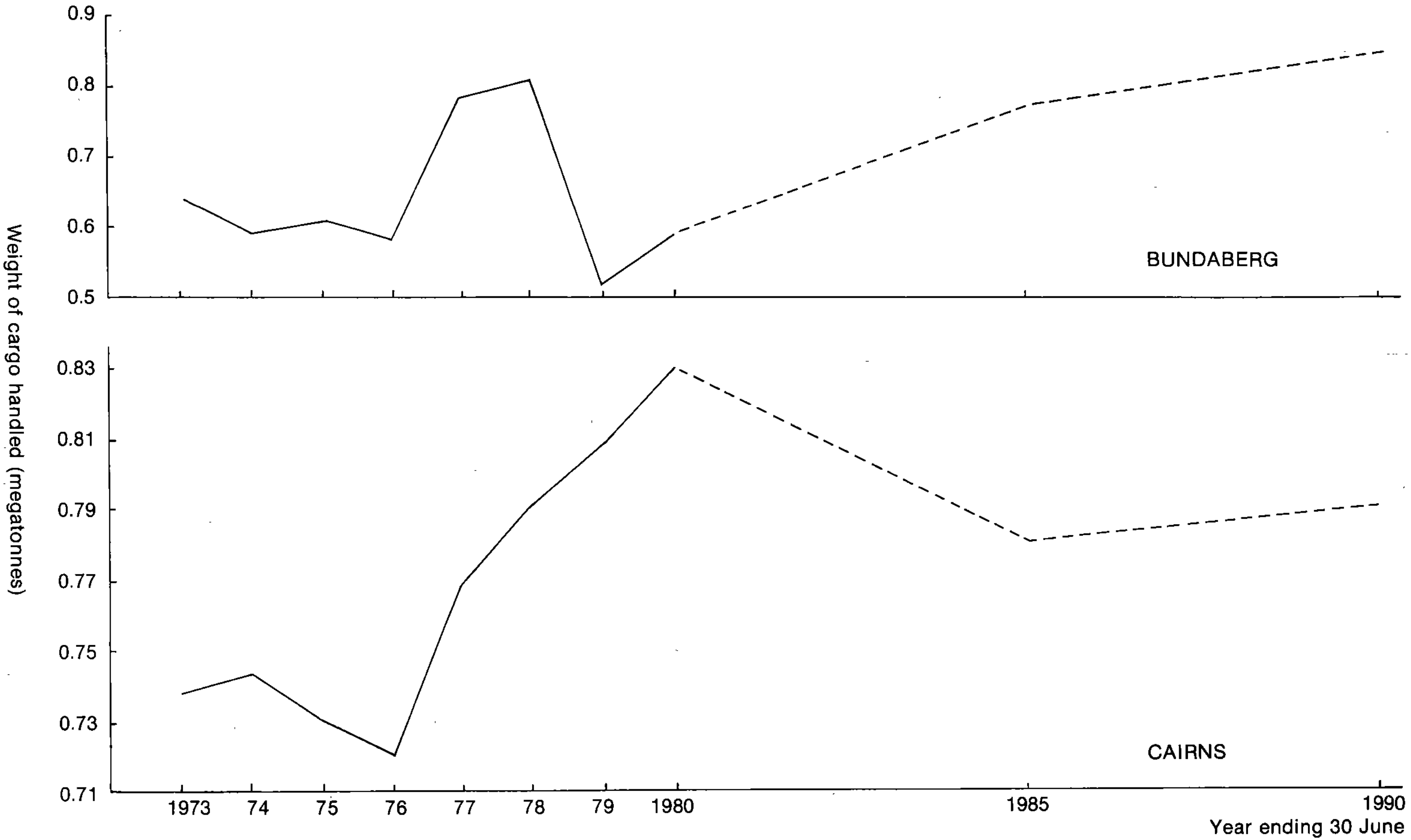

Figure I.39 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Bundaberg and Cairns

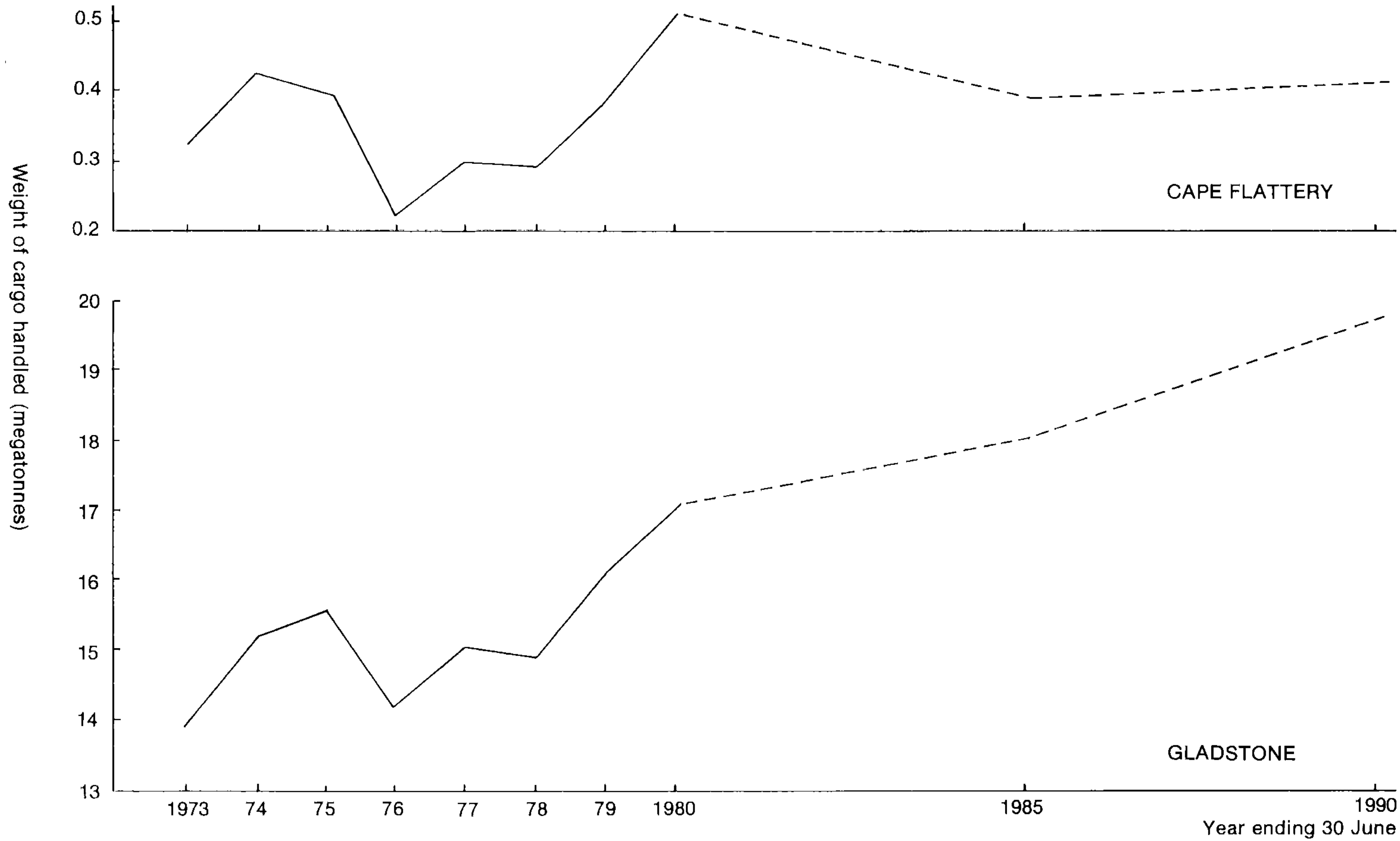

Figure I.40 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Cape Flattery and Gladstone

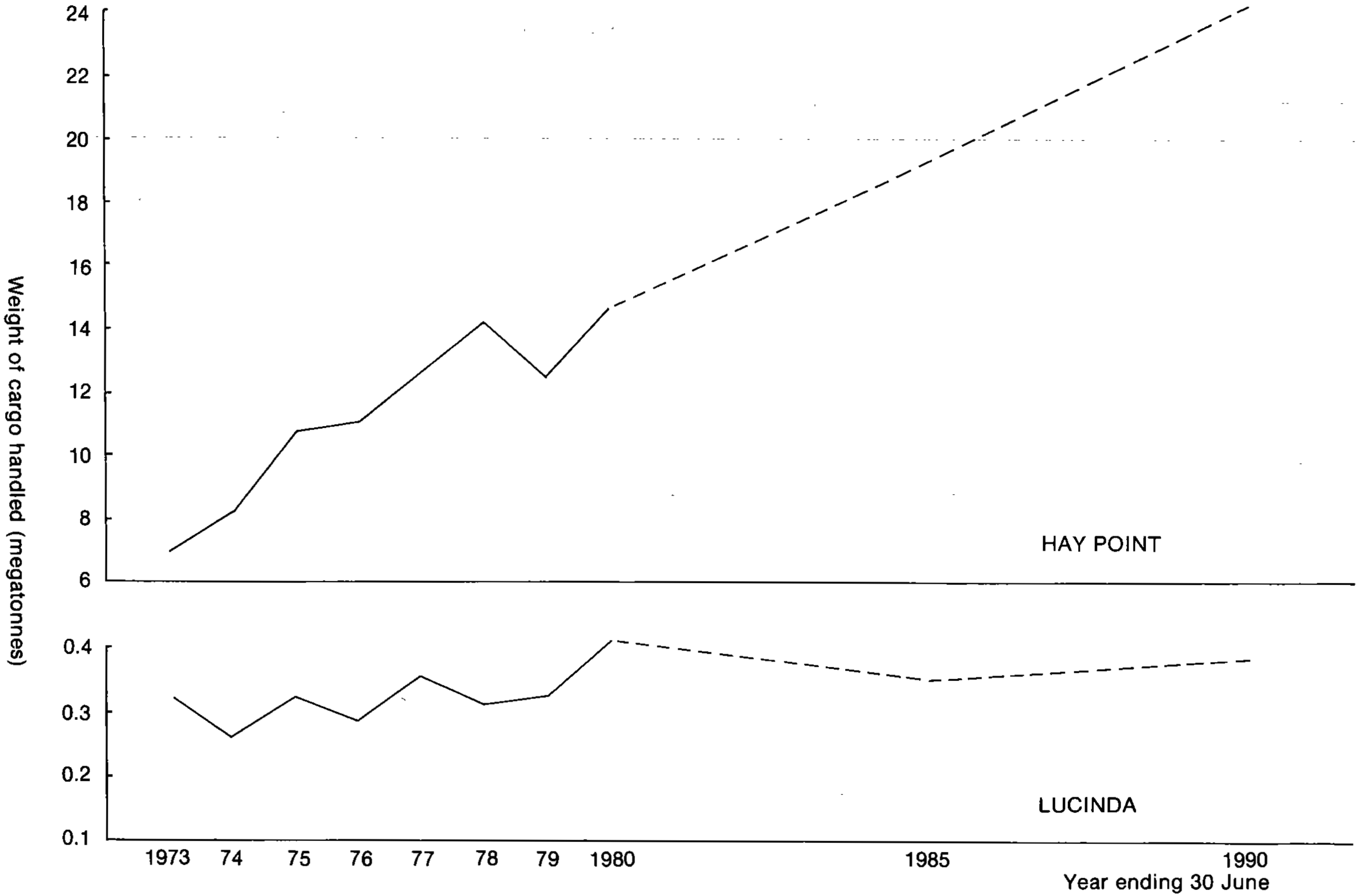

Figure I.41 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Hay Point and Lucinda

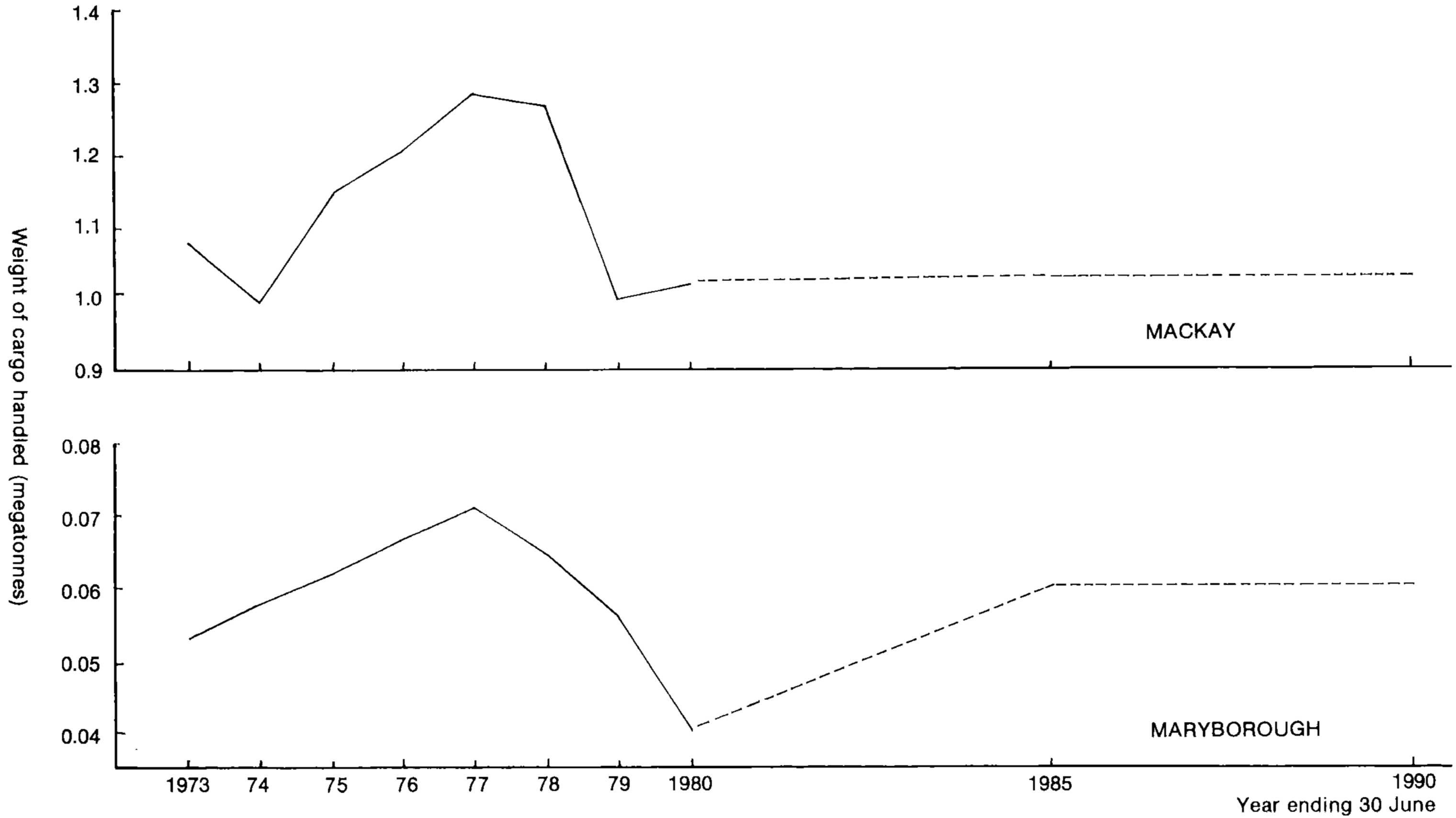

Figure I.42 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Mackay and Maryborough

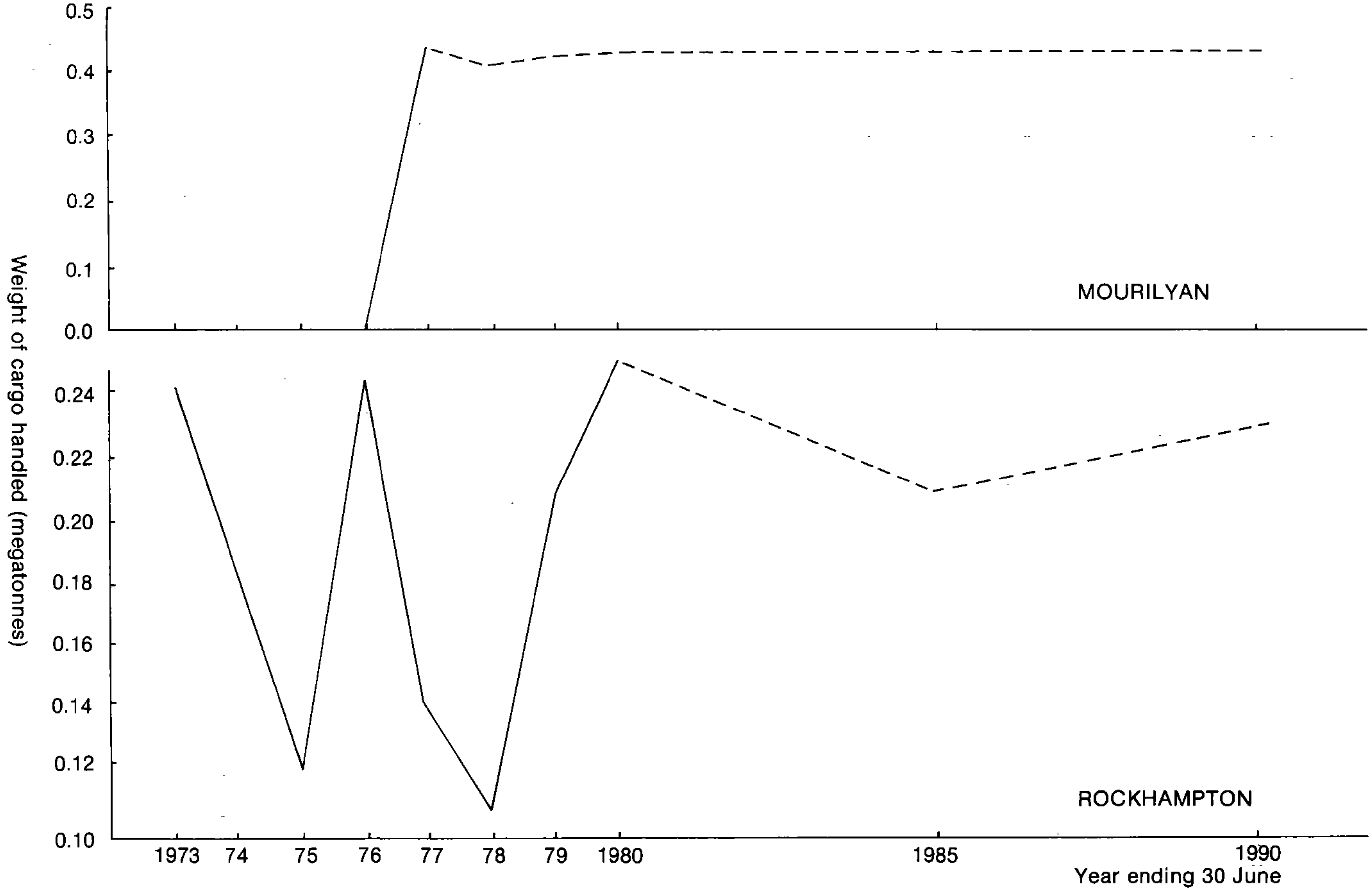

Figure I.43 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Mourilyan and Rockhampton

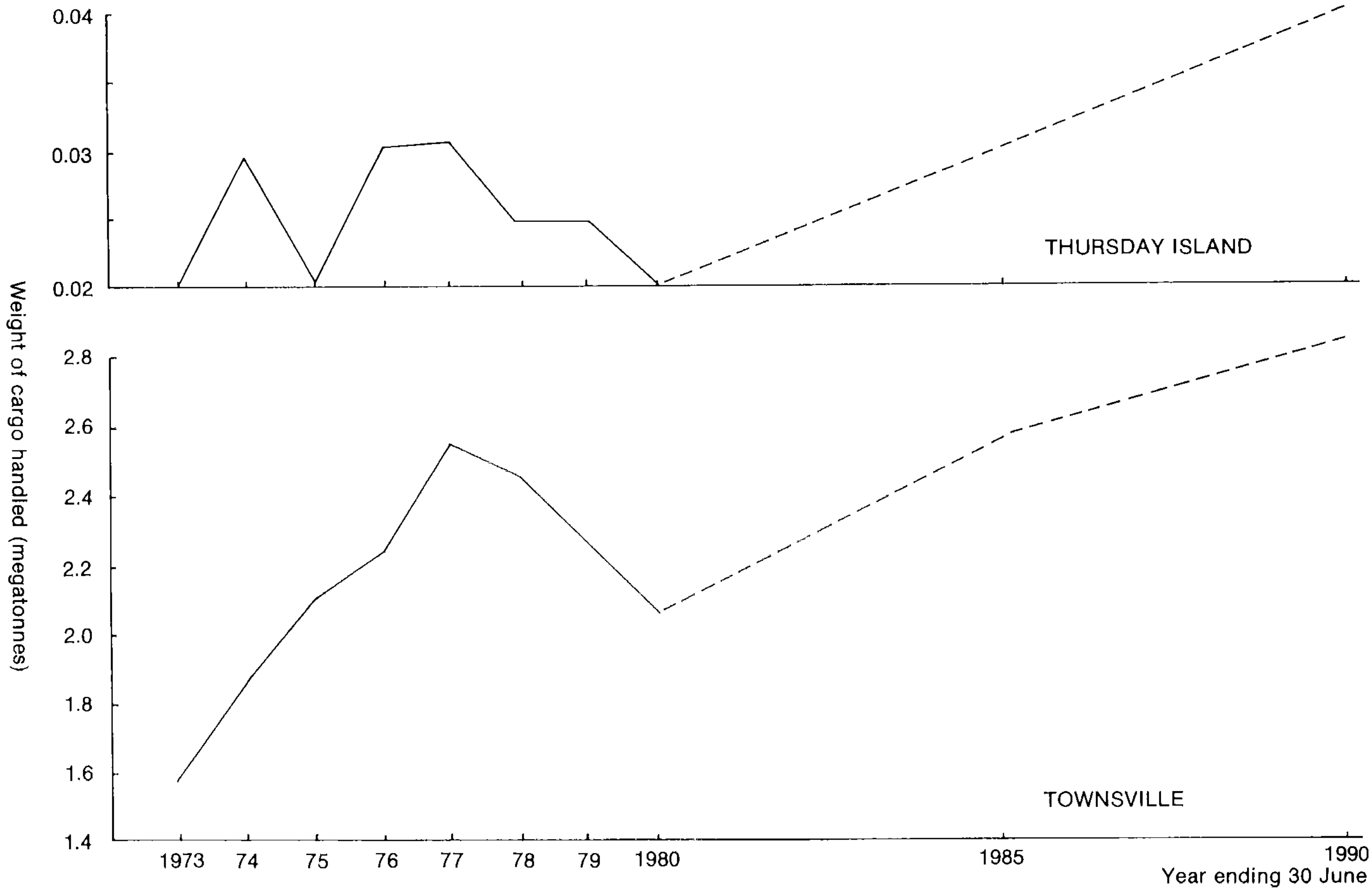

Figure I.44 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Thursday Island and Townsville

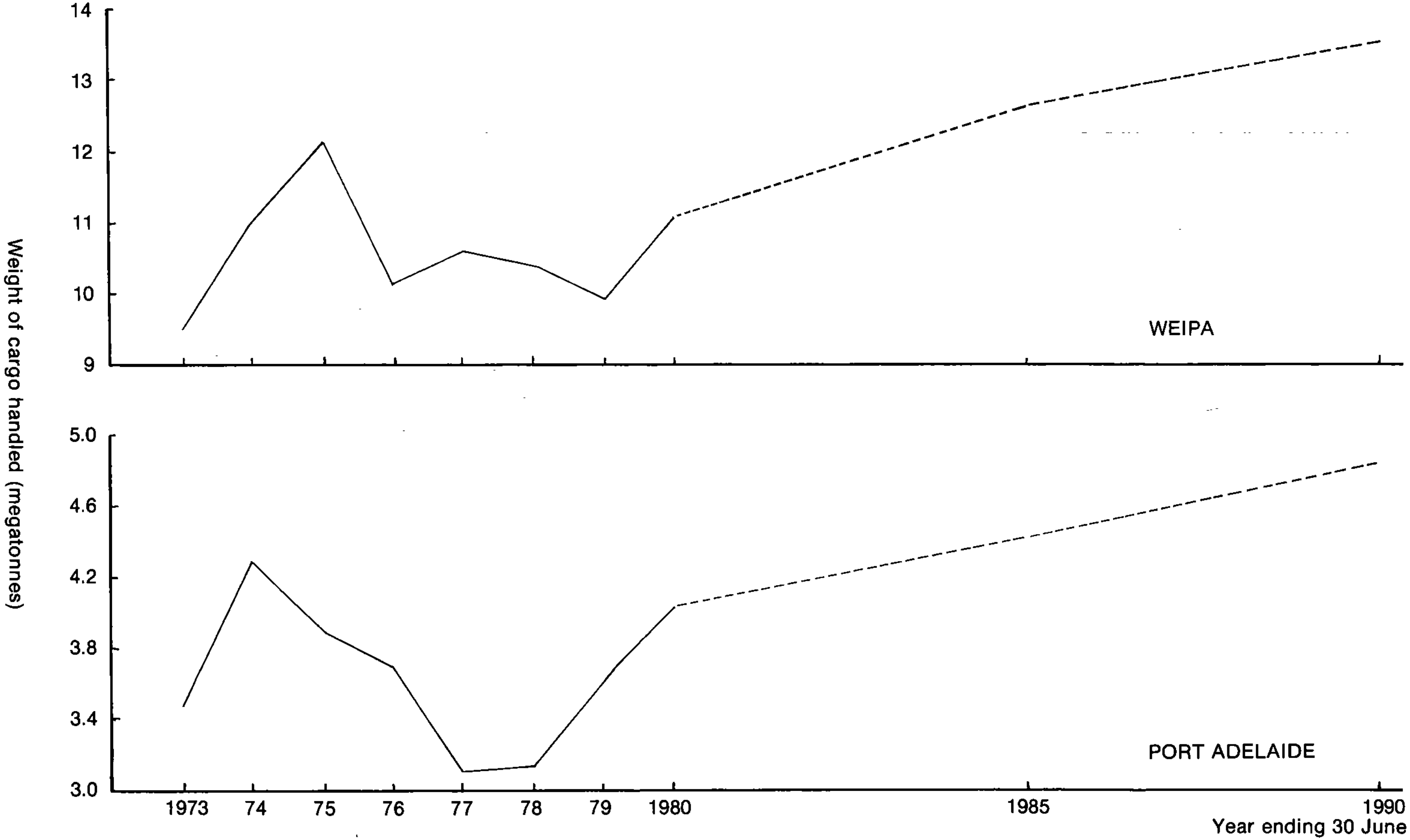

Figure I.45 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Weipa and Port Adelaide

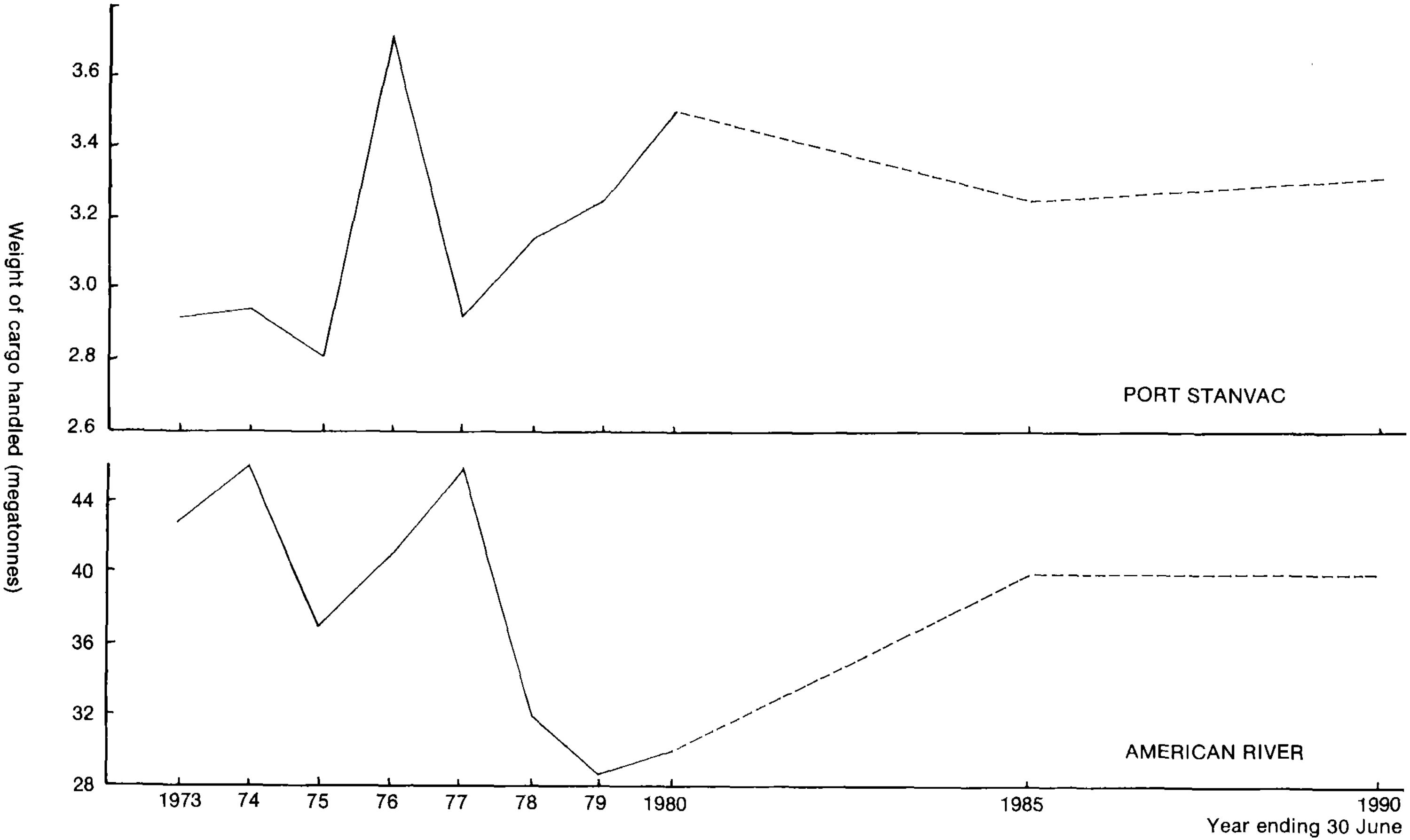

Figure I.46 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Port Stanvac and American River

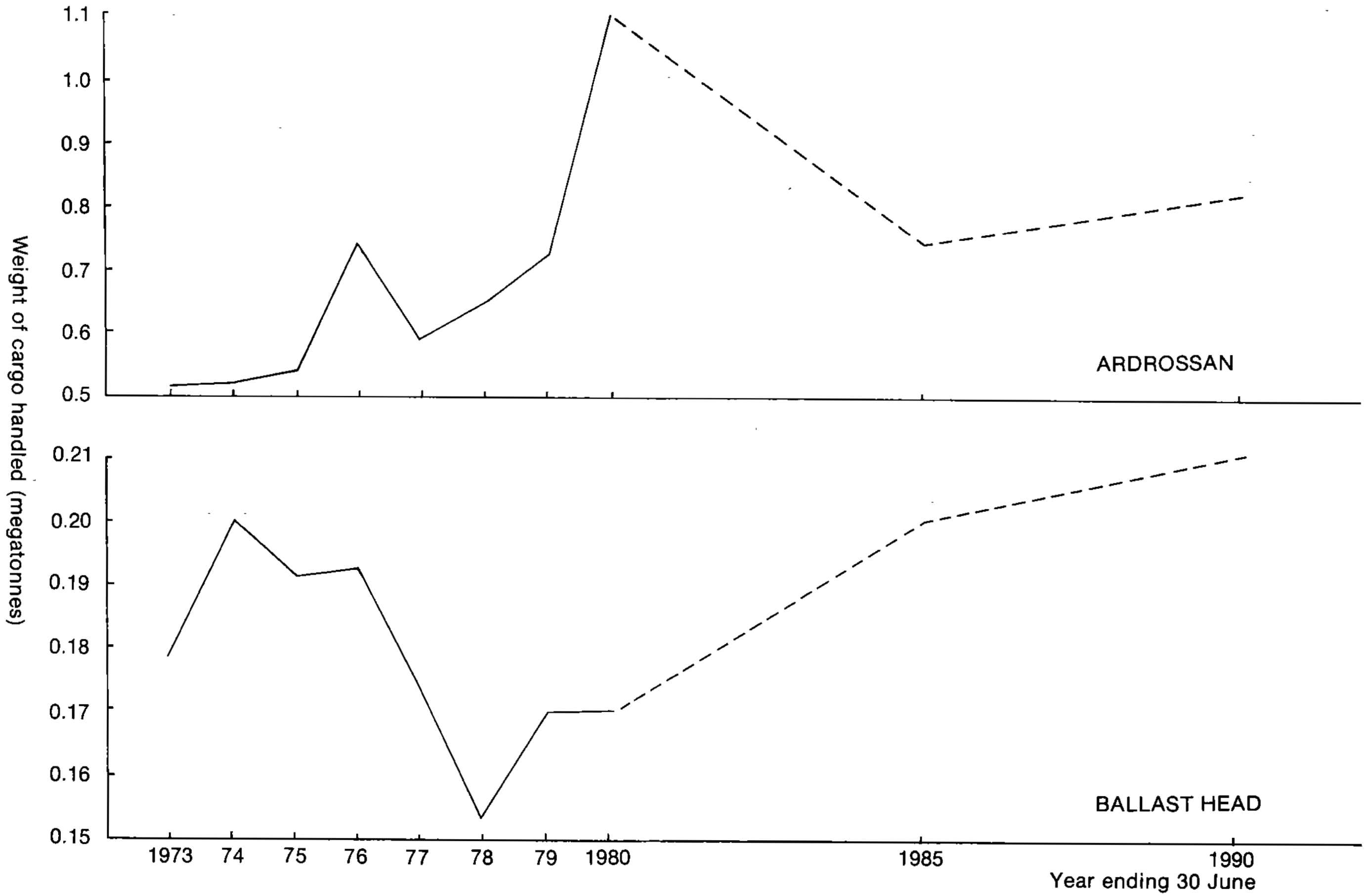

Figure I.47 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Ardrossan and Ballast Head

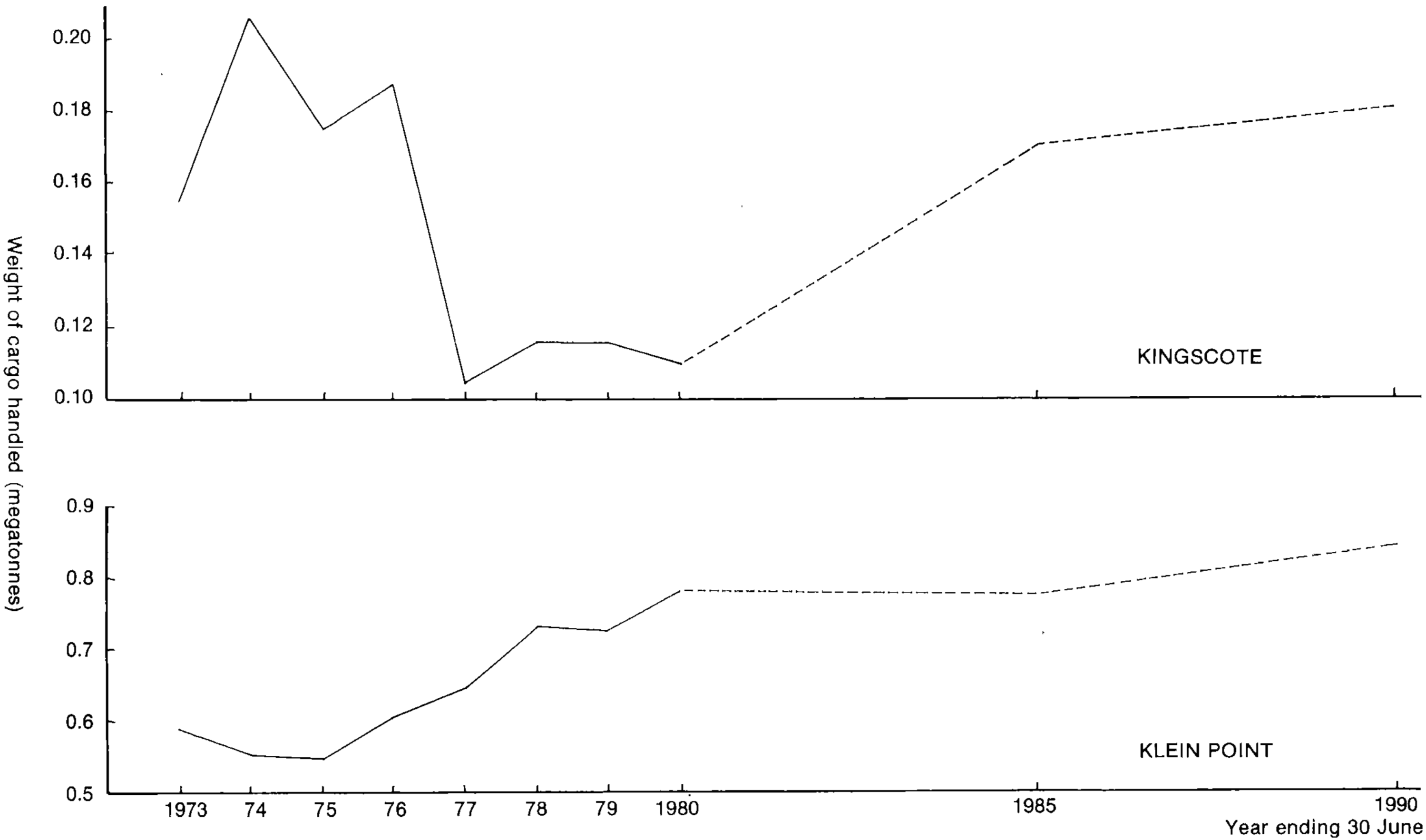

Figure I.48 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Kingscote and Klein Point

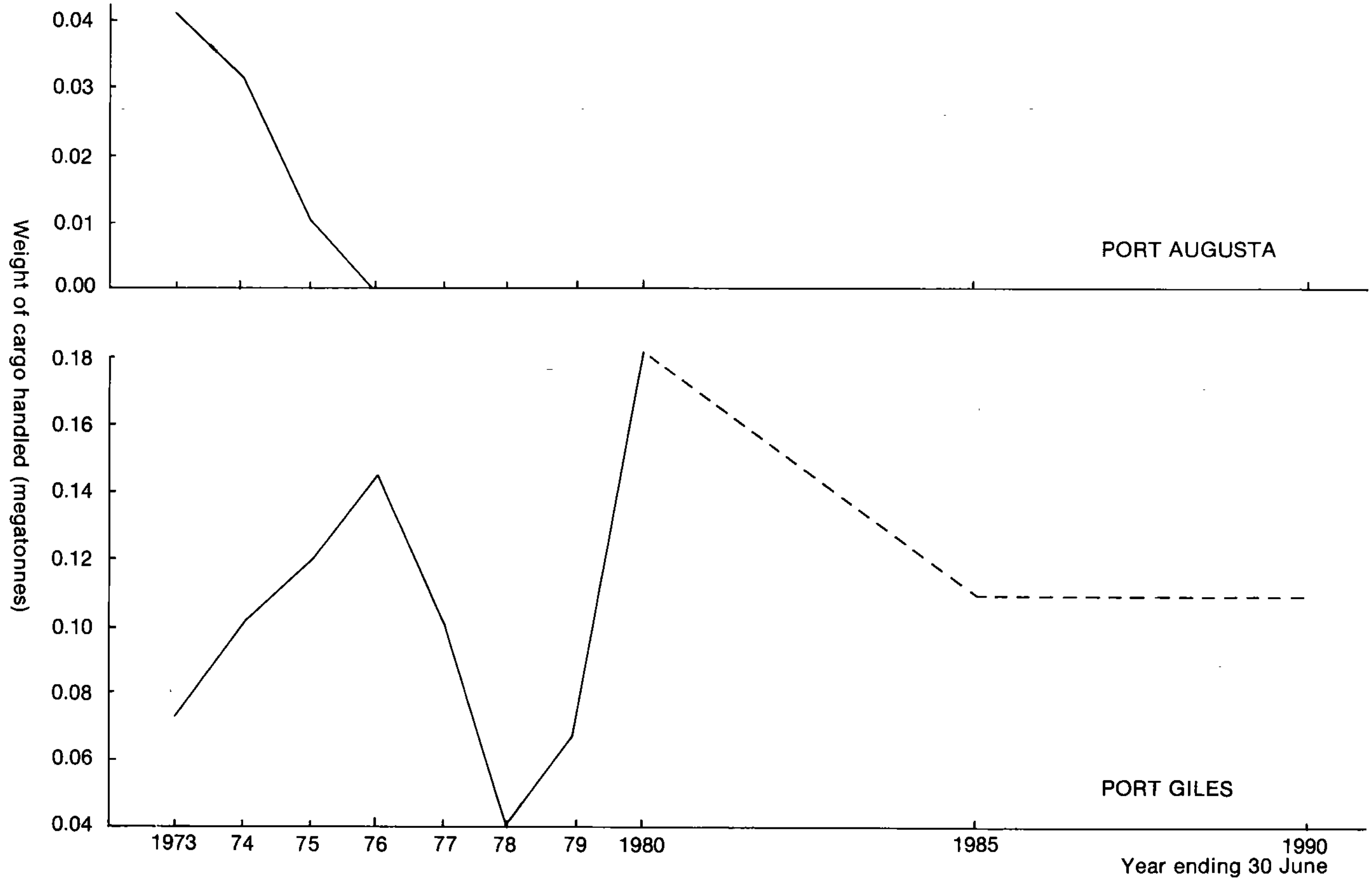

Figure I.49 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Port Augusta and Port Giles

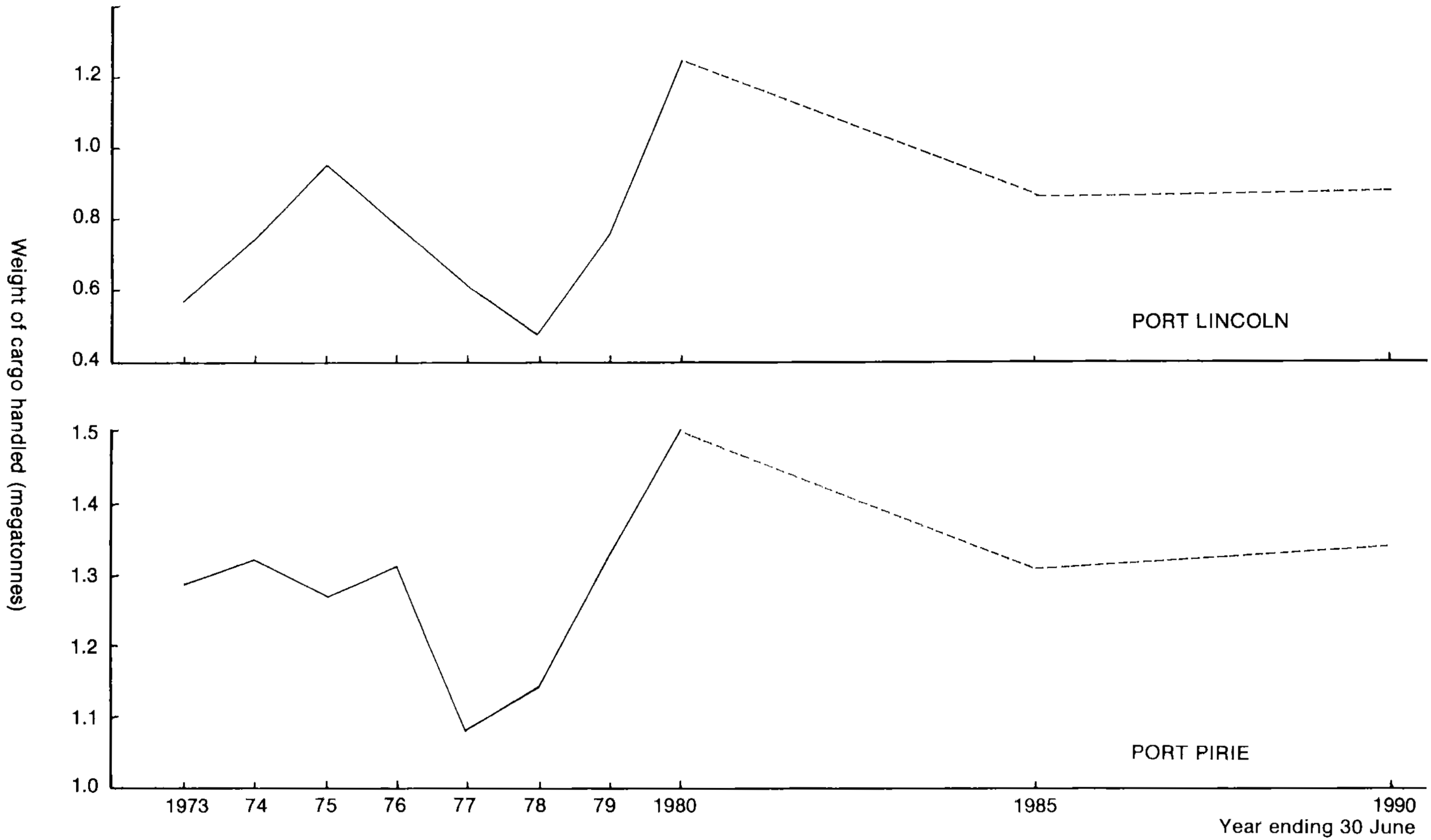

Figure I.50 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Port Lincoln and Port Pirie

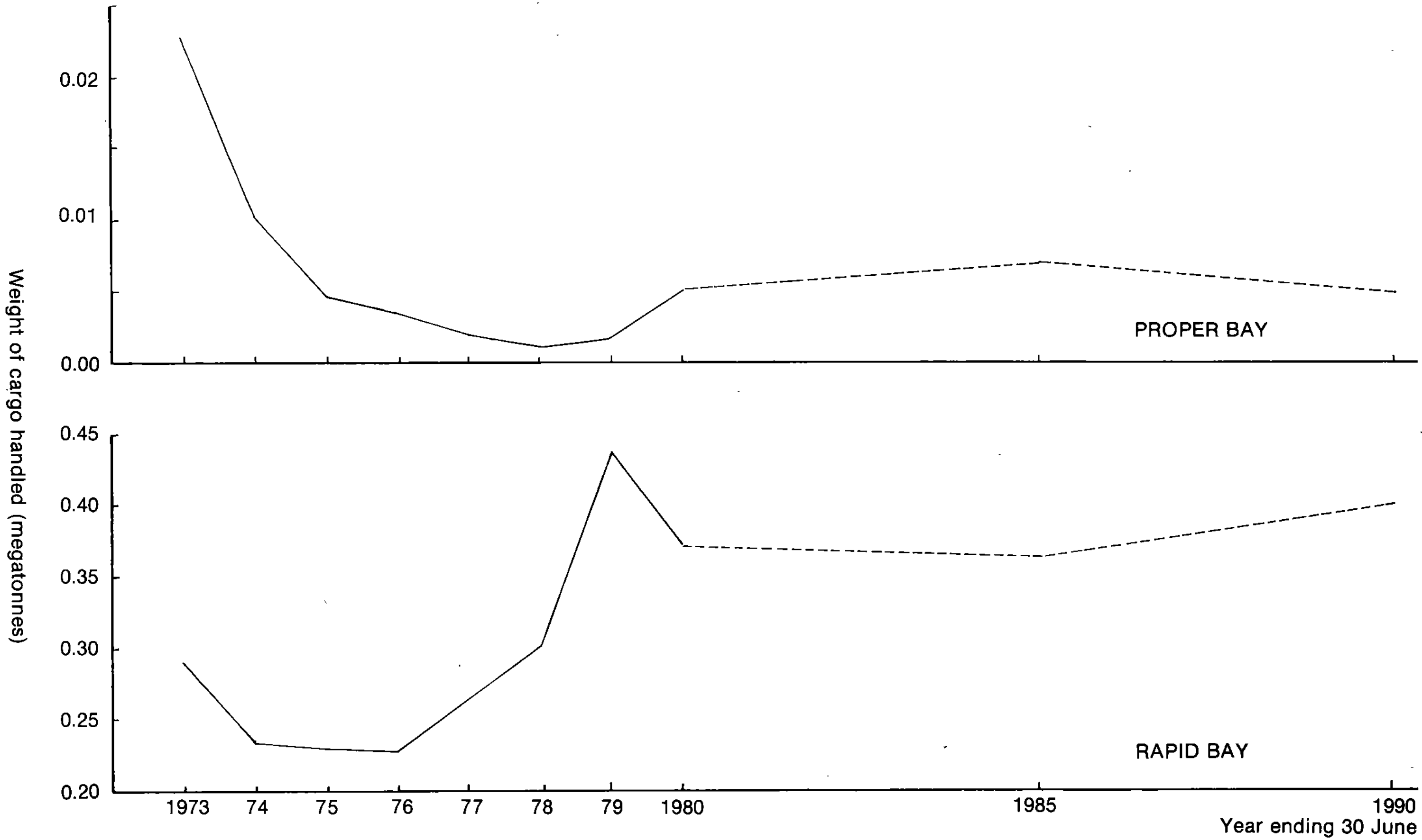

Figure I.51 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Proper Bay and Rapid Bay

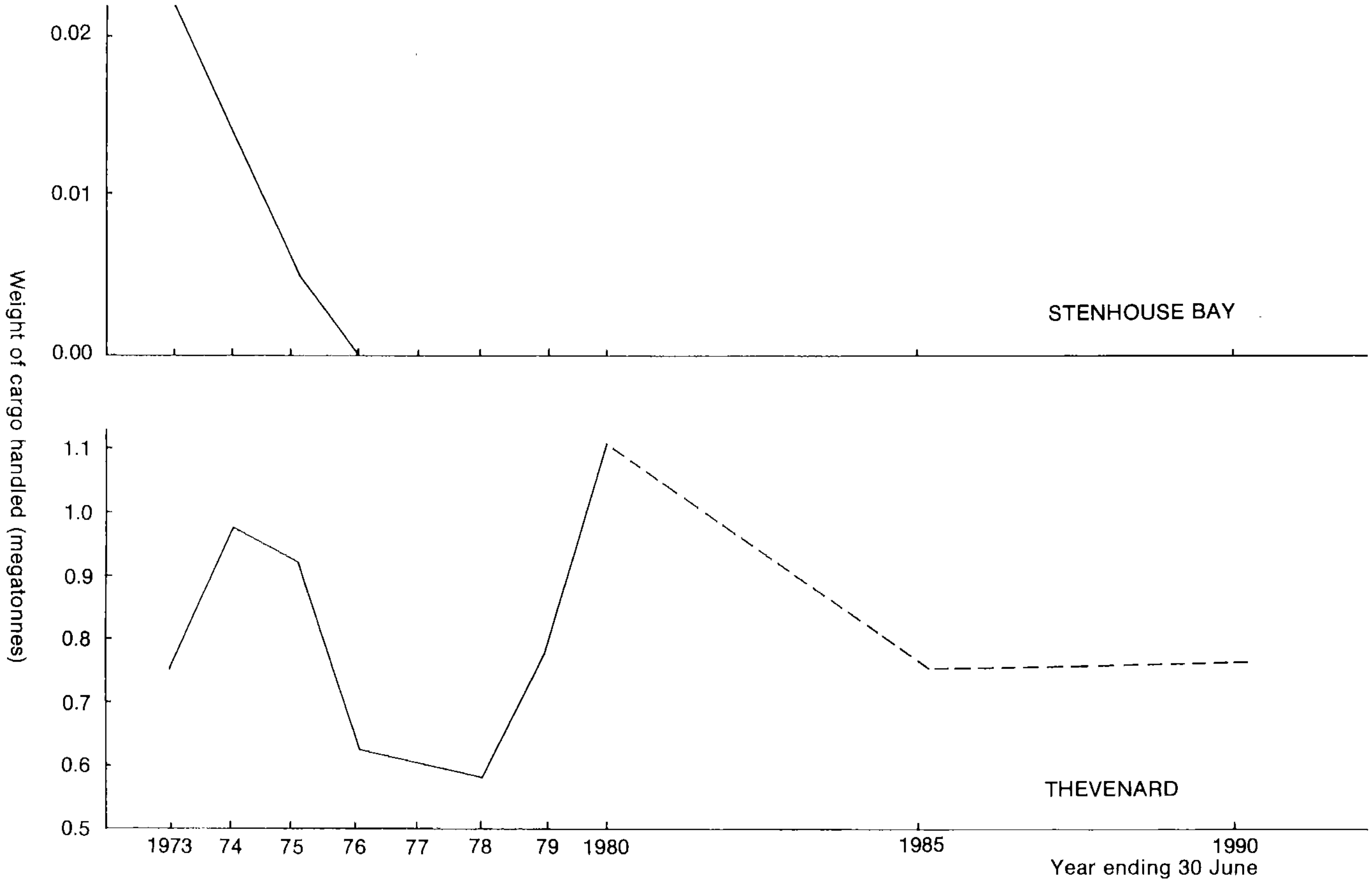

Figure I.52 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Stenhouse Bay and Thevenard

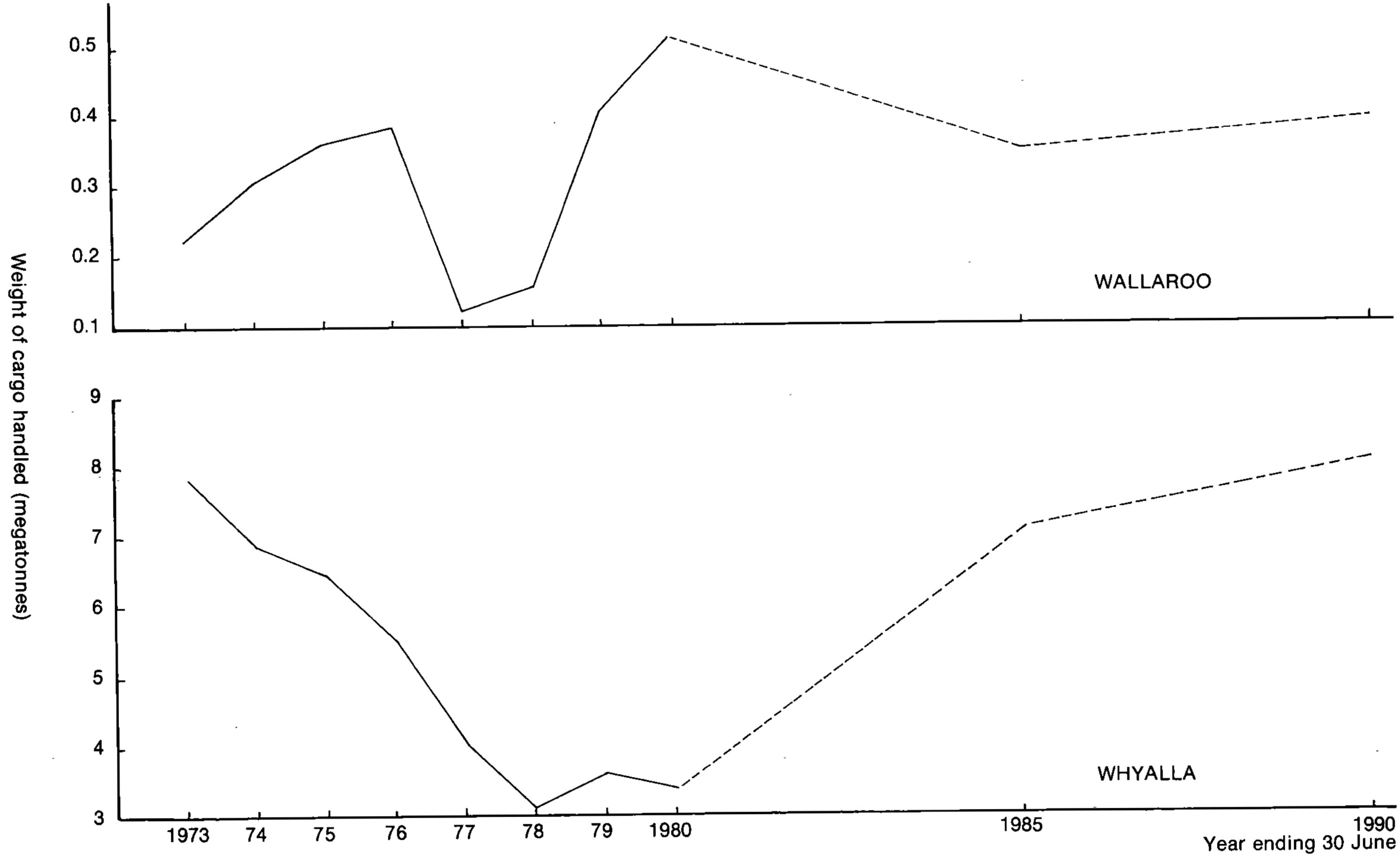

Figure I.53 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Wallaroo and Whyalla

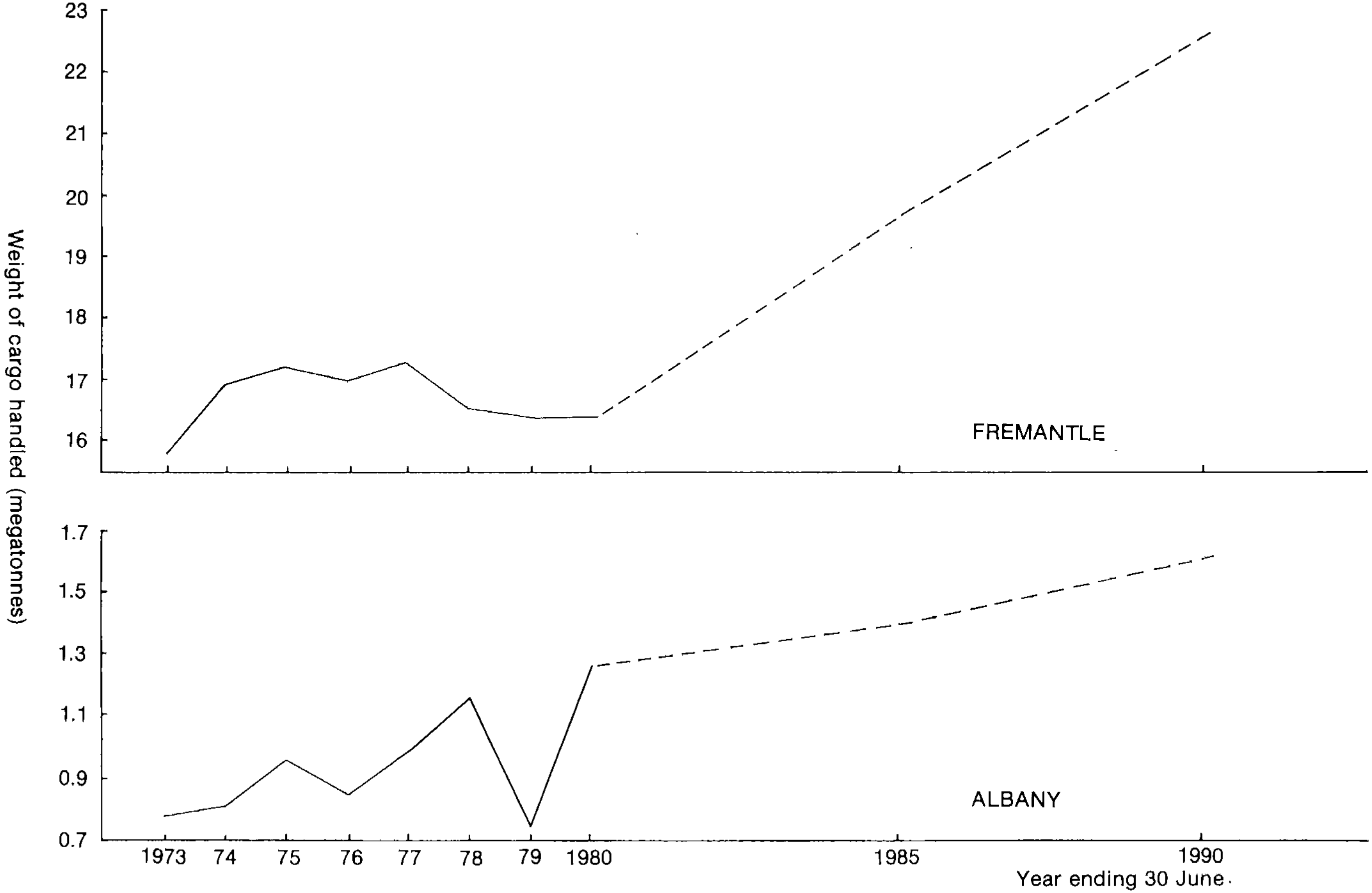

Figure I.54 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Fremantle and Albany

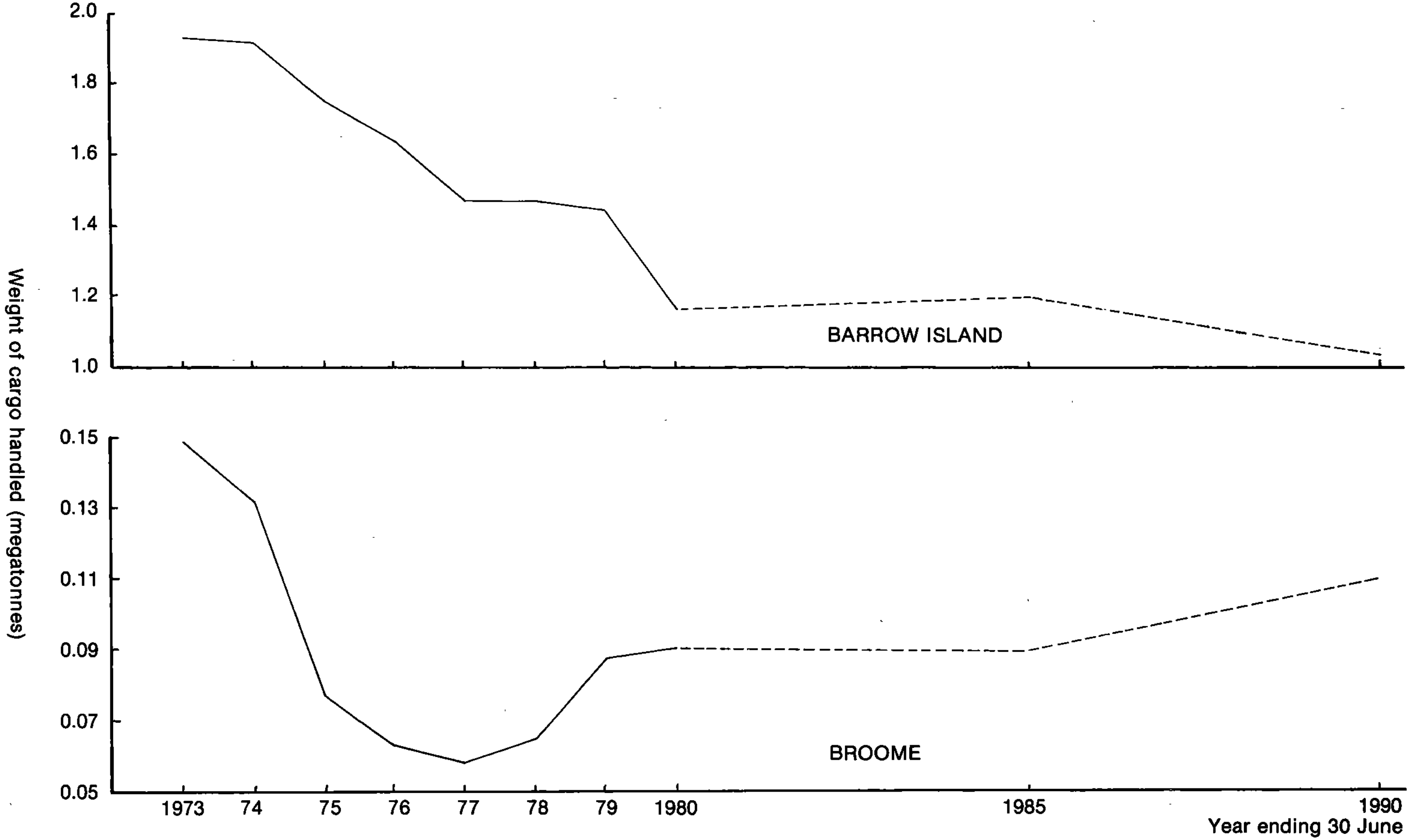

Figure I.55 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Barrow Island and Broome

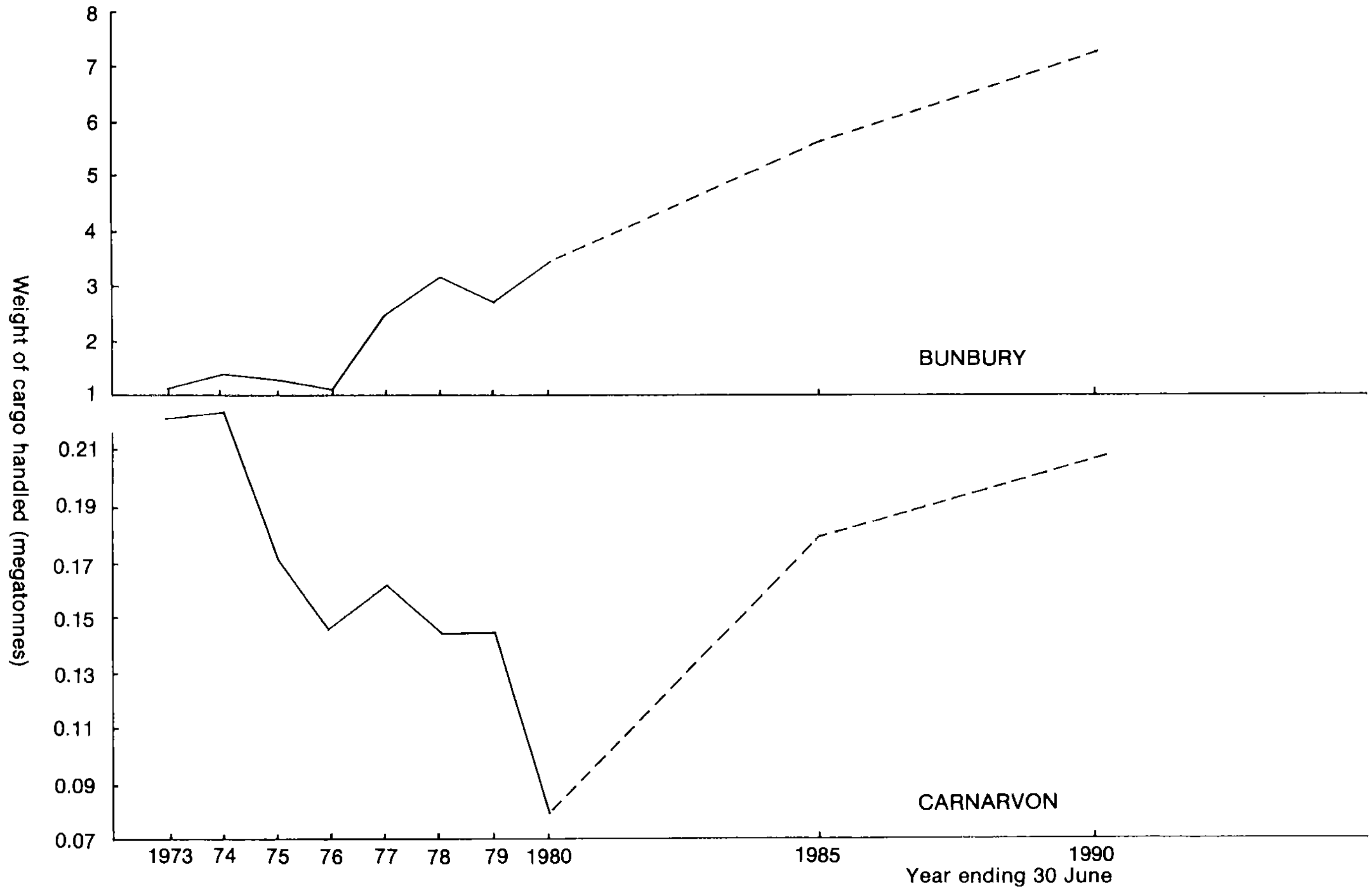

Figure I.56 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Bunbury and Carnarvon

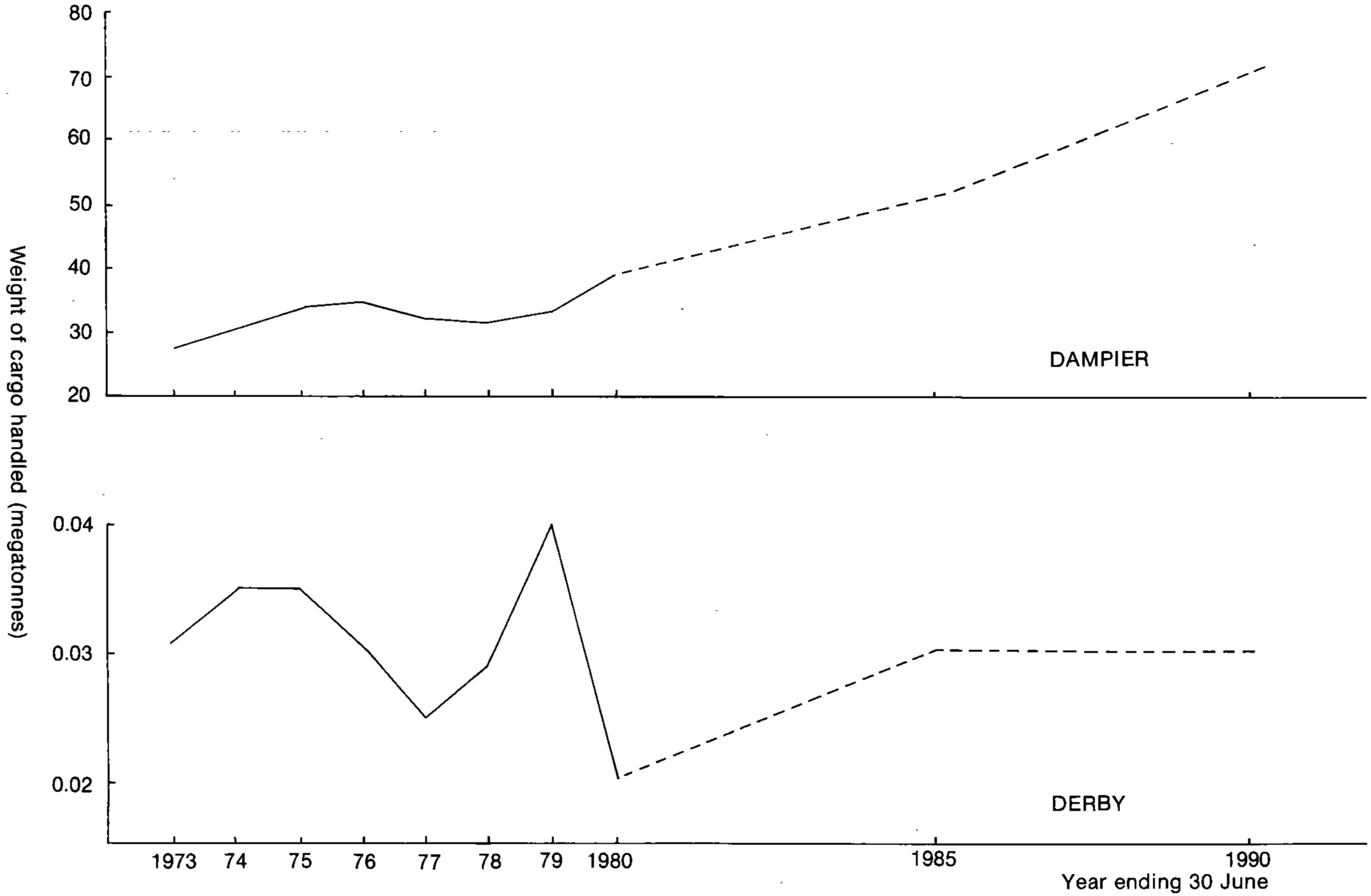

Figure I.57 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Dampier and Derby

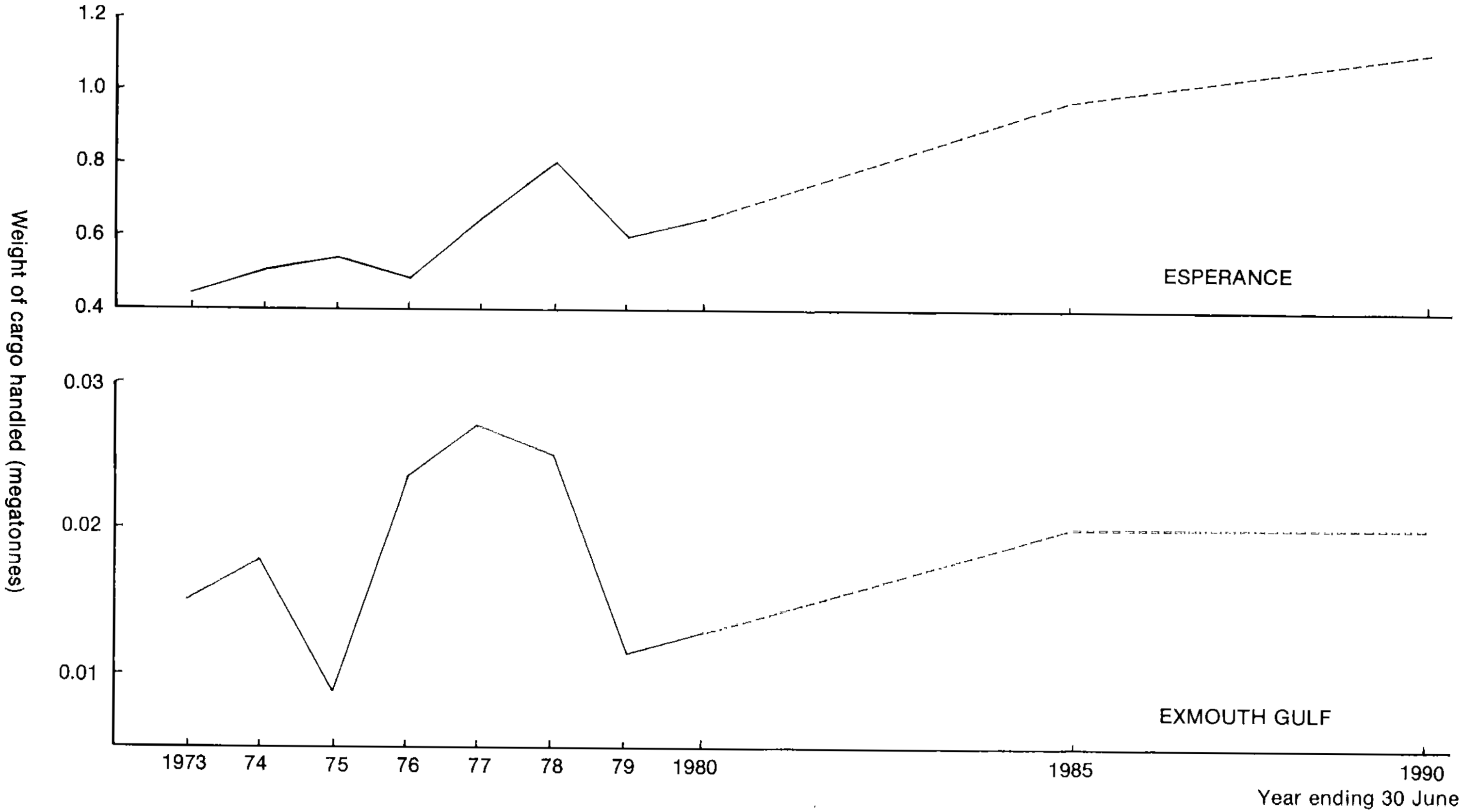

Figure I.58 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Esperance and Exmouth Gulf

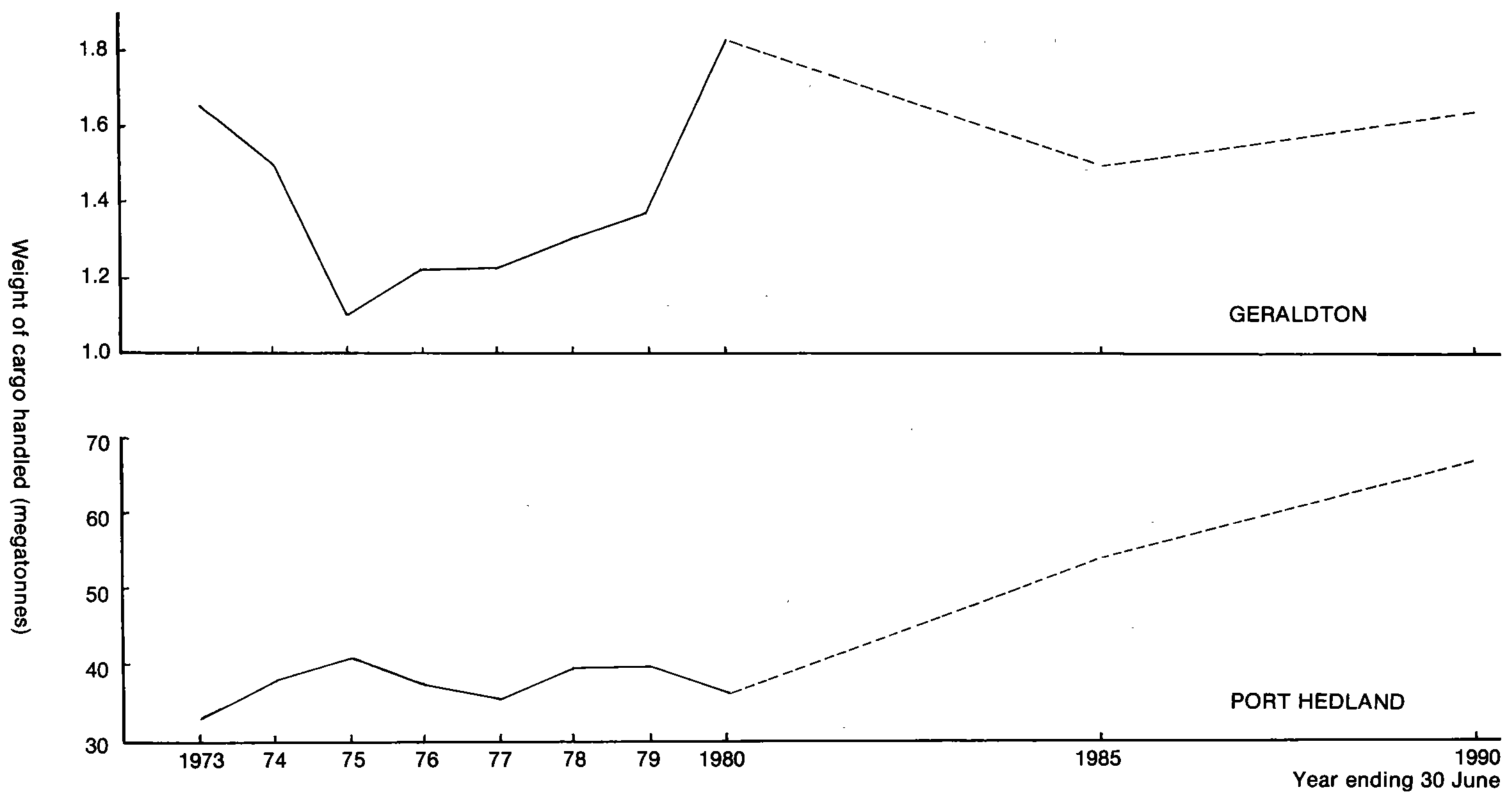

Figure I.59 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Geraldton and Port Hedland

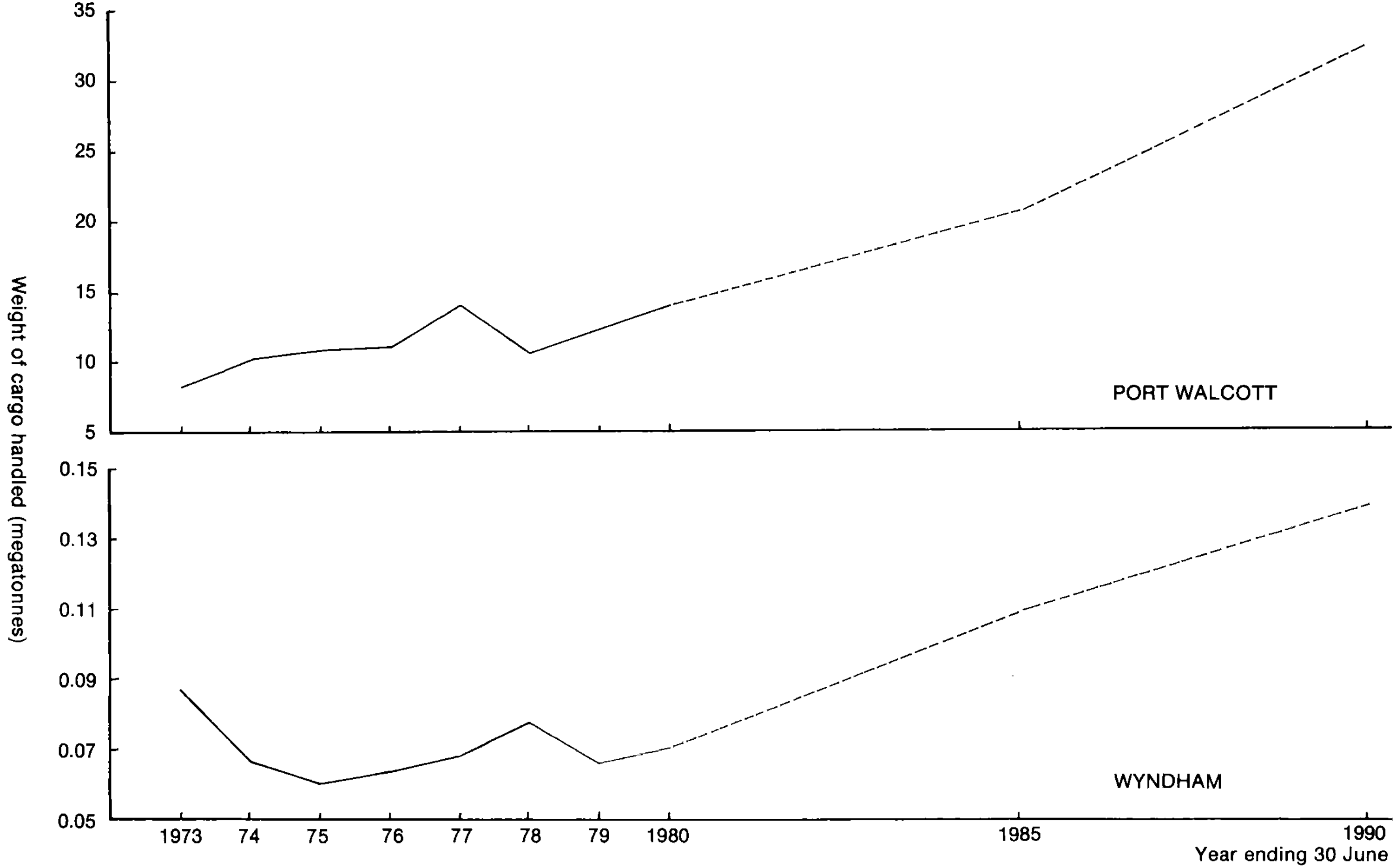

Figure I.60 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Port Walcott and Wyndham

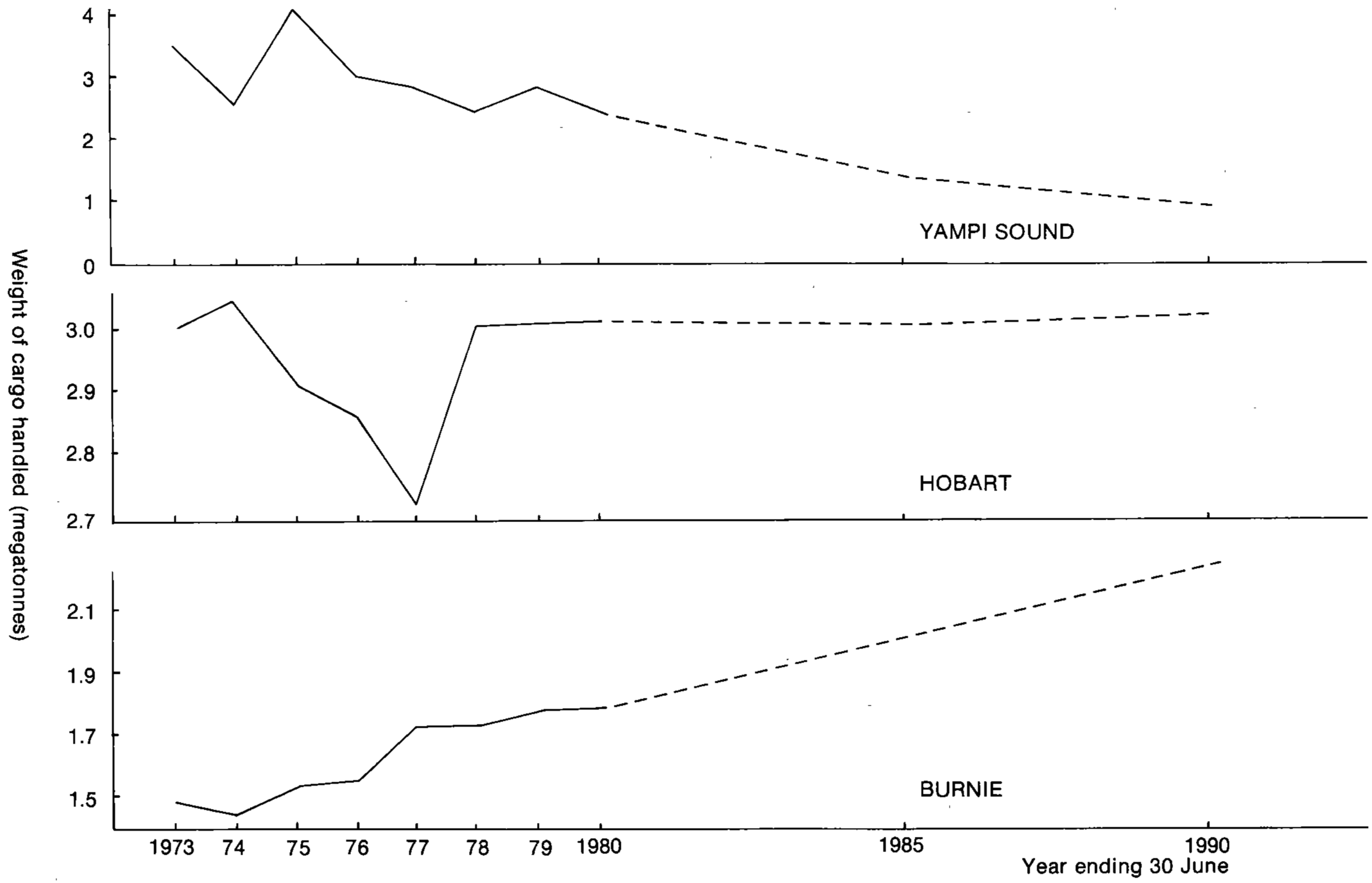

Figure I.61 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Yampi Sound, Hobart and Burnie

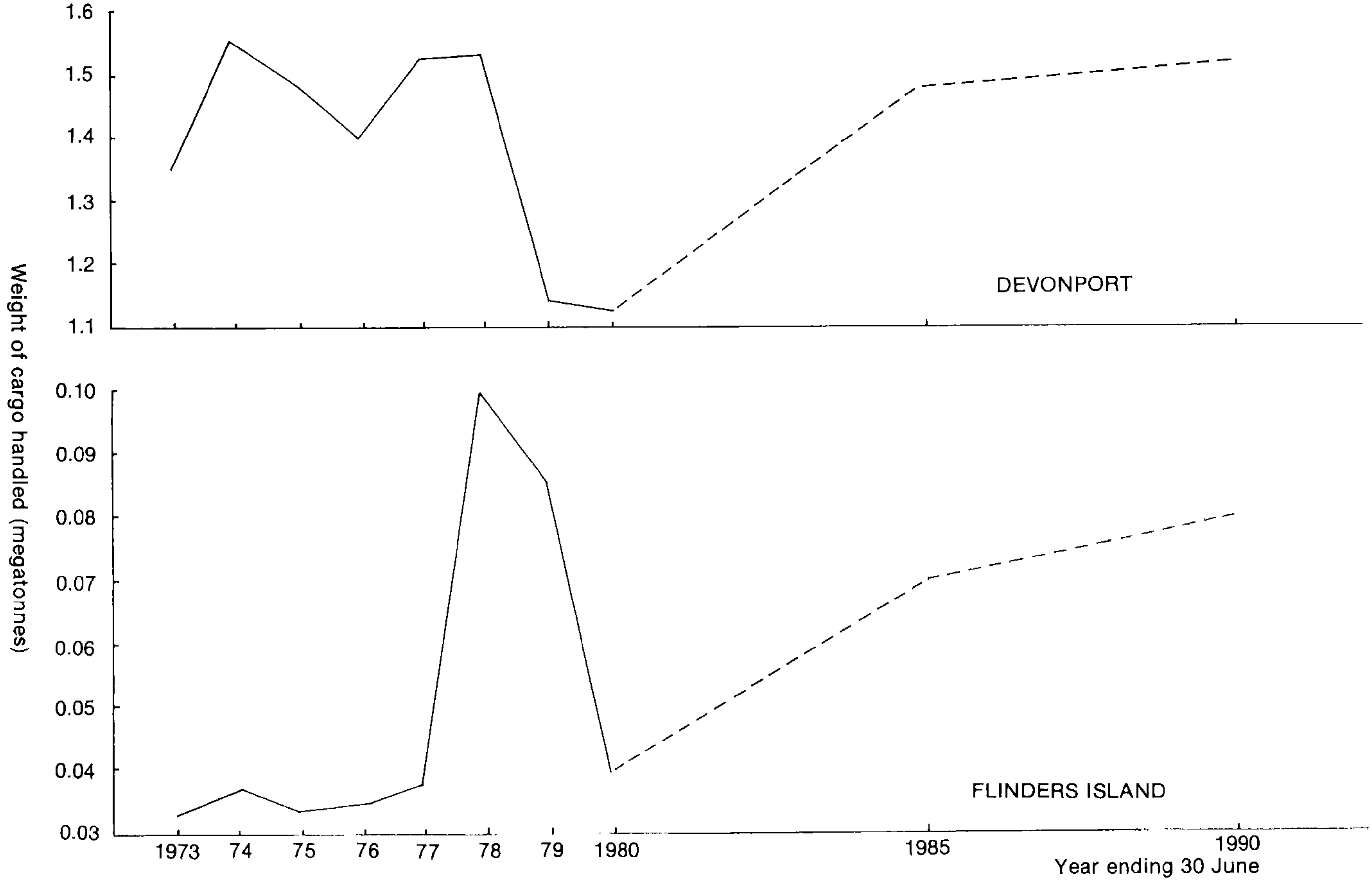

Figure I.62 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Devonport and Flinders Island

Figure I.63 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—King Island and Launceston

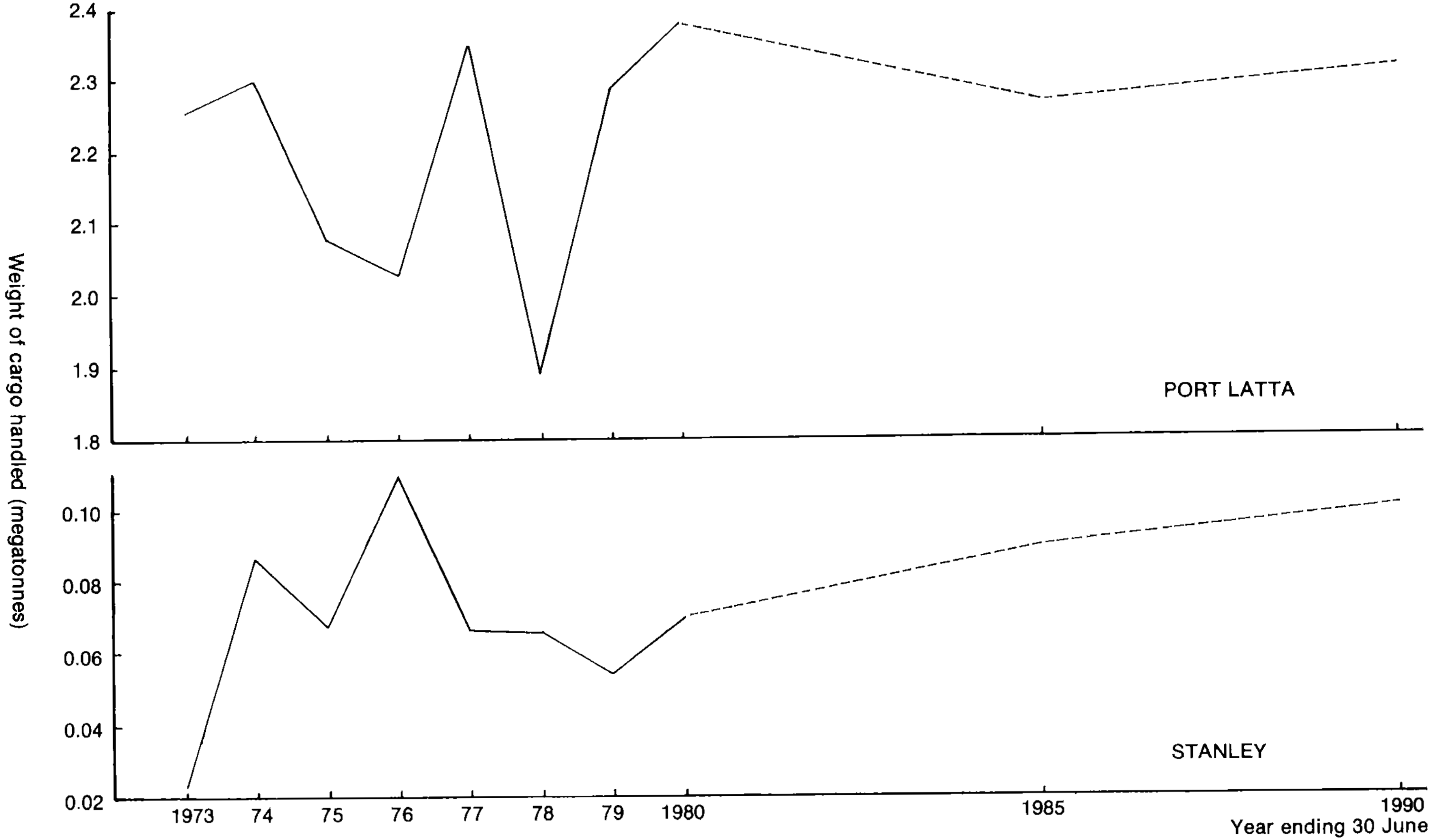

Figure I.64 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Port Latta and Stanley

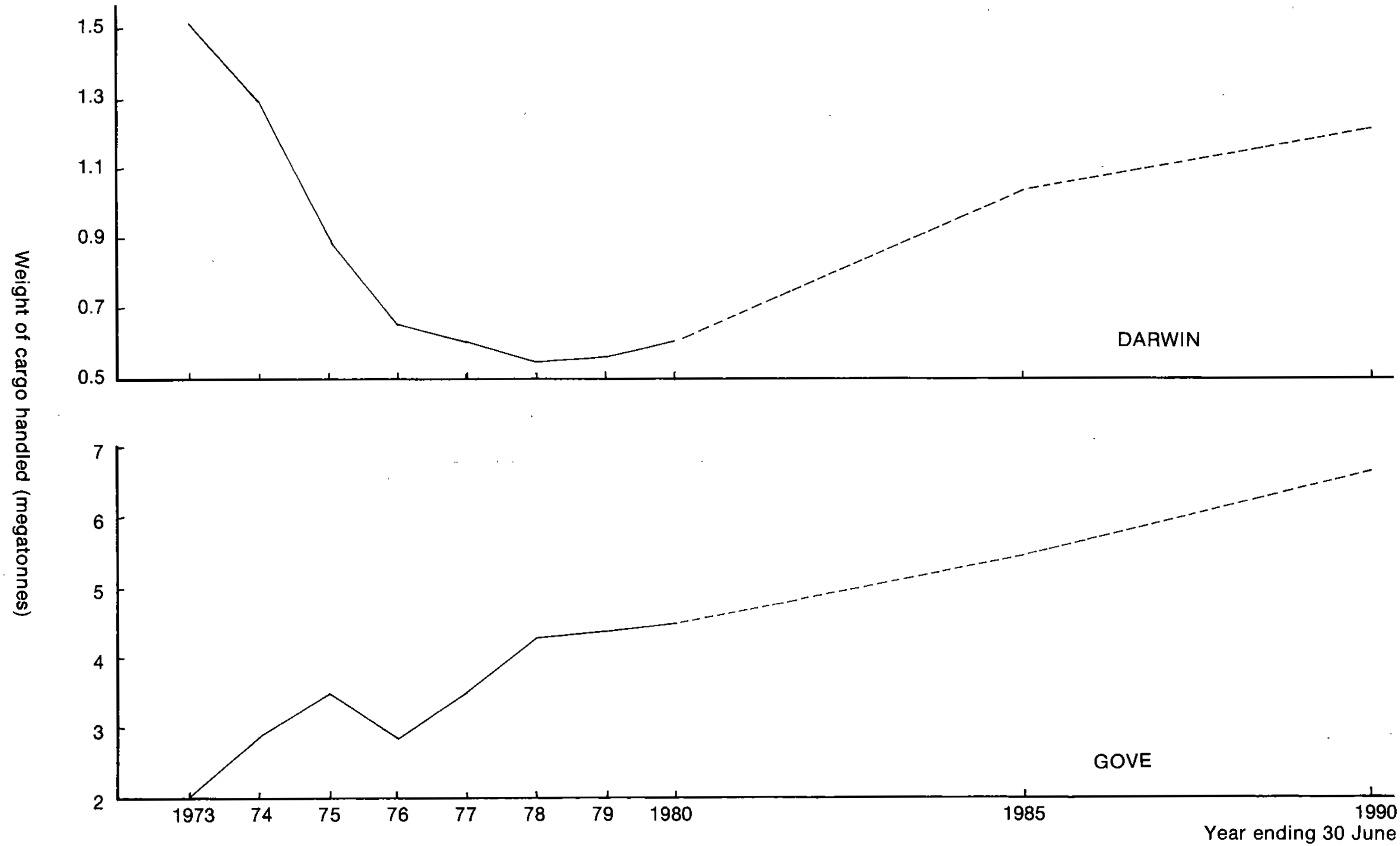

Figure I.65 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Darwin and Gove

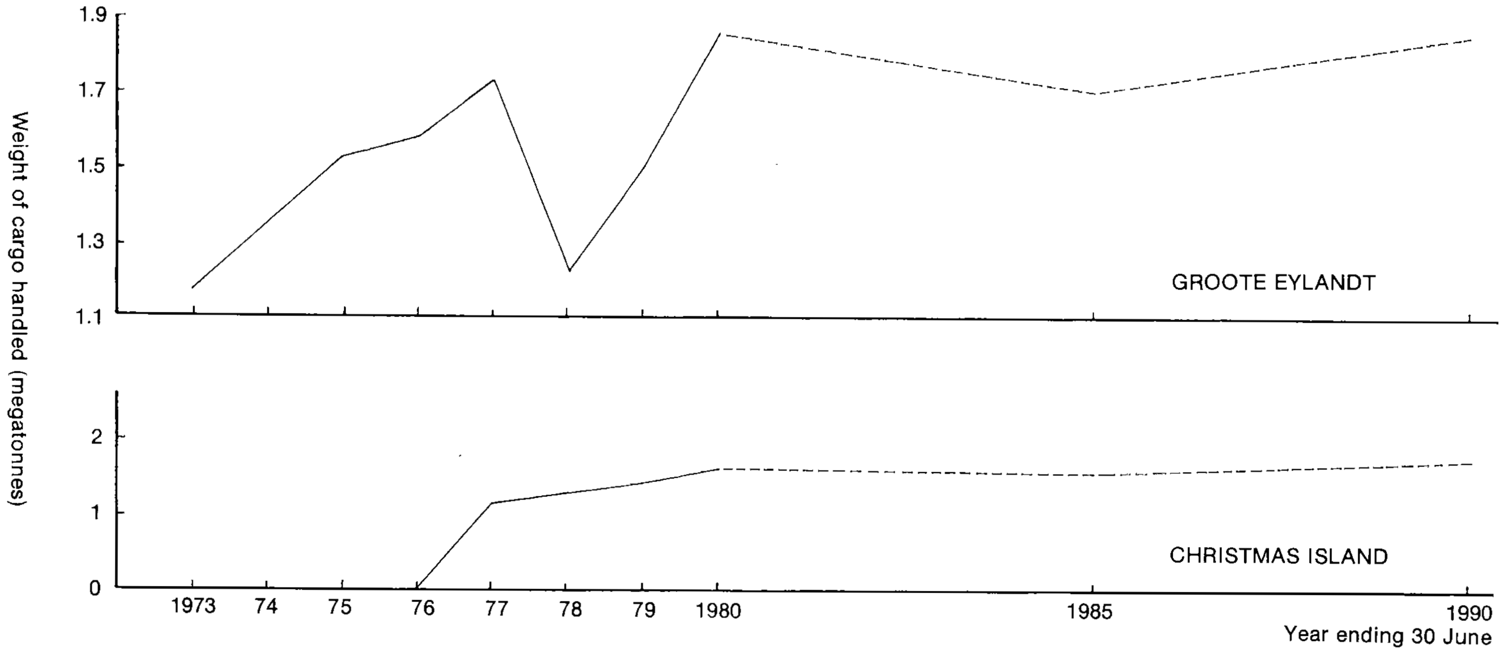

Figure I.66 Actual and projected annual weights of cargo handled: 1 July 1972 to 30 June 1990—Groote Eylandt and Christmas Island

APPENDIX II—SPILL DATA

The data on marine oil spills analysed in this study were supplied by DoTA. The data covered all spills of persistent oils which were reported to DoTA in the eight-year period from 1 July 1972 to 30 June 1980[1].

Tables II.1, II.2 and II.3 summarise some of the recorded characteristics of the oil-handling, bunkering and miscellaneous spills, respectively, which were reported for that period. The spills are listed in chronological order by port, and the information shown is the date and location of occurrence and the estimated volume spilled, where recorded.

TABLE II.1—CHARACTERISTICS OF REPORTED OIL-HANDLING SPILLS, 1 JULY 1972 TO 30 JUNE 1980

Port	*Date of spill*	*Volume spilled[a] (litres)*
	New South Wales	
Sydney	22 May 1973	na
	06 Aug 1974	455
	08 Nov 1974	68
	Jul 1975	2 046
	Aug 1975	23
Botany Bay	02 Aug 1973	1 591
	31 Oct 1974	682
	Jan 1975	318
	Apr 1975	318
	09 Dec 1976	1 140
	26 Feb 1977	70
	27 Feb 1977	70
	05 Jan 1978	600
	27 May 1978	na
	06 Aug 1978	11 400
	21 Jul 1979	na
	08 Oct 1979	na
	Victoria	
Melbourne	01 Sep 1974	na
	Jul 1975	na
	Nov 1975	na
	23 Apr 1978	na
	11 Jan 1979	na
	18 Jul 1979	na
	23 Nov 1979	na
	10 Jan 1980	na

1. Statistical models were calibrated using data for the period 1 July 1972 to 30 June 1979. The predictions based on these models were compared with the actual spill data for the fiscal year 1979-80.

TABLE II.1—CHARACTERISTICS OF REPORTED OIL-HANDLING SPILLS, 1 JULY 1972 TO 30 JUNE 1980 (Cont)

Port	*Date of spill*	*Volume spilled[a] (litres)*
Geelong	04 Aug 1972	45
	06 Nov 1972	455
	03 Aug 1977	50
	21 Jul 1979	na
Westernport	10 Jan 1973	na
	Feb 1976	na
	Feb 1976	na
	Apr 1976	na
	May 1976	na
	08 Dec 1976	1 110
	15 Dec 1976	225
	04 Jul 1977	682
	22 Jan 1979	200
	10 Dec 1979	na
	Queensland	
Brisbane	09 Nov 1972	na
	05 Jun 1973	13 638
	05 Aug 1974	1 000
	May 1975	364
	Jul 1975	32 000
	Aug 1975	400
	06 May 1978	na
Gladstone	22 Jul 1978	22 800
	South Australia	
Port Stanvac	10 Jan 1973	1 137
	30 Nov 1977	1 364
	10 Mar 1979	455
	20 Aug 1979	955
	26 Oct 1979	1 818
Port Pirie	28 Jun 1979	1 364
	Western Australia	
Fremantle	11 Jul 1972	909
(includes Kwinana	19 Feb 1973	455
	17 Apr 1973	205
	21 Jan 1974	227
	01 Mar 1974	57
	09 Mar 1974	182
	29 Jun 1977	450
	01 Oct 1977	200
	21 Jun 1978	3 000
	May 1979	na
	27 Aug 1979	450
	Tasmania	
Burnie	Oct 1972	34

a. Where recorded.

TABLE II.2—CHARACTERISTICS OF REPORTED BUNKERING SPILLS, 1 JULY 1972 TO 30 JUNE 1980

Port	Date of spill	Volume spilled[a] (litres)
	New South Wales	
Sydney	11 Sep 1972	227
	22 Sep 1972	68
	23 Sep 1972	682
	03 Oct 1972	57
	09 Oct 1972	227
	10 Nov 1972	na
	13 Dec 1972	114
	27 Dec 1972	227
	30 Mar 1973	na
	15 Jun 1973	114
	03 Jul 1973	11
	25 Jul 1973	227
	03 Nov 1973	16
	12 Dec 1973	na
	18 Feb 1974	na
	22 Mar 1974	na
	26 Mar 1974	na
	13 Jul 1974	216
	03 Aug 1974	23
	12 Sep 1974	na
	24 Oct 1974	na
	07 Nov 1974	na
	14 Dec 1974	227
	Jan 1975	9
	Jan 1975	na
	Jan 1975	182
	Jan 1975	909
	Feb 1975	2 273
	Mar 1975	na
	Apr 1975	14
	Jun 1975	57
	Aug 1975	45
	Dec 1975	40
	08 Jan 1976	1 140
	Mar 1976	1
	04 Mar 1976	5
	Jul 1976	100
	05 Oct 1976	200
	14 Dec 1976	na
	26 Dec 1976	4 560
	13 Jan 1977	50
	24 Jan 1977	180
	30 Mar 1977	22 800
	01 Apr 1977	na
	07 Jun 1977	140
	25 Jul 1977	60
	17 Dec 1977	40
	03 Feb 1978	na

TABLE II.2—CHARACTERISTICS OF REPORTED BUNKERING SPILLS, 1 JULY 1972 TO 30 JUNE 1980 (Cont)

Port	*Date of spill*	*Volume spilled[a] (litres)*
Sydney (Cont)	17 Apr 1978	90
	18 May 1978	na
	29 Jun 1978	1 710
	31 Jul 1978	45
	11 Jan 1979	25
	16 Feb 1979	450
	19 Mar 1979	20
	03 May 1979	40
	17 Jul 1979	8
	17 Aug 1979	10
	29 Aug 1979	400
	18 Sep 1979	5
	22 Feb 1980	25
Botany Bay	11 Dec 1972	23
	16 Nov 1978	10
	07 Jan 1979	90
Newcastle	16 Dec 1973	23
	25 Feb 1974	45
	15 Oct 1974	227
	12 Nov 1974	na
	Apr 1975	na
	27 Sep 1976	20
	22 Sep 1978	90
	24 Sep 1978	225
	30 Jan 1979	40
Port Kembla	01 Feb 1973	na
	Victoria	
Melbourne	18 Aug 1972	na
	22 Sep 1972	na
	10 Oct 1972	na
	13 Jan 1973	na
	18 Apr 1973	na
	24 Apr 1973	na
	15 May 1973	na
	26 Jun 1973	na
	05 Jul 1973	na
	16 Jul 1973	909
	09 Aug 1973	909
	01 Sep 1973	na
	31 Jan 1974	na
	25 Mar 1974	na
	05 Jul 1974	na
	19 Sep 1974	na
	19 Sep 1974	na
	Feb 1975	na
	Mar 1975	na
	22 Mar 1975	na
	29 Apr 1975	na

TABLE II.2—CHARACTERISTICS OF REPORTED BUNKERING SPILLS, 1 JULY 1972 TO 30 JUNE 1980 (Cont)

Port	*Date of spill*	*Volume spilled*[a] *(litres)*
Melbourne (Cont)	May 1975	na
	Jun 1975	na
	Jul 1975	na
	Sep 1975	na
	Sep 1975	na
	Oct 1975	na
	Nov 1975	na
	Jan 1976	na
	Feb 1976	na
	Mar 1976	na
	Apr 1976	na
	May 1976	na
	May 1976	na
	08 Jun 1976	na
	18 Aug 1976	na
	12 Sep 1976	na
	26 Sep 1976	na
	30 Sep 1976	na
	19 Oct 1976	na
	27 Dec 1976	na
	04 Apr 1977	na
	04 May 1977	na
	25 Aug 1977	na
	30 Sep 1977	na
	03 Nov 1977	na
	29 Jan 1978	na
	21 Apr 1978	na
	05 May 1978	na
	26 May 1978	na
	04 Aug 1978	na
	18 Mar 1979	na
	17 Jul 1979	na
	22 Aug 1979	na
	09 Sep 1979	na
	02 Apr 1980	na
	21 May 1980	na
Geelong	4 Apr 1974	na
	09 Jul 1974	182
	Jan 1975	na
	29 Apr 1975	318
	Dec 1975	50
	05 Apr 1977	700
	15 Jul 1978	na
	09 May 1980	na
Portland	Jan 1975	1 137
Port Welshpool	14 Aug 1973	636
Westernport	20 Sep 1978	300
	22 Sep 1978	na
	12 Jan 1979	na

TABLE II.2—CHARACTERISTICS OF REPORTED BUNKERING SPILLS, 1 JULY 1972 TO 30 JUNE 1980 (Cont)

Port	*Date of spill*	*Volume spilled[a] (litres)*
	Queensland	
Brisbane	09 Nov 1972	na
	03 Jun 1973	1 137
	04 Oct 1973	341
	30 Oct 1973	27
	04 Mar 1974	na
	07 Jun 1974	9 092
	17 Oct 1974	na
	23 Jul 1976	2 280
	28 Jul 1976	na
	Sep 1976	100
	Dec 1976	700
	23 Jun 1978	1 364
	20 Oct 1978	1 100
	01 Dec 1978	13
Cairns	29 Mar 1973	4 060
	21 Nov 1973	1 140
Gladstone	09 Nov 1972	na
Mackay	02 Mar 1973	182
	28 May 1975	50
Townsville	04 Dec 1973	227
	02 Jan 1974	250
	07 Oct 1974	na
	Dec 1976	na
	South Australia	
Port Adelaide	07 Jul 1974	205
	Jun 1976	180
	08 Nov 1979	455
Port Stanvac	20 Jul 1978	1 500
Port Pirie	Nov 1976	450
Wallaroo	21 Jun 1973	125
Whyalla	Apr 1976	35
	Western Australia	
Fremantle (includes Kwinana)	04 Jul 1972	91
	31 Jul 1972	34
	10 Aug 1972	na
	22 Oct 1972	455
	26 Nov 1972	32
	12 Jan 1973	580
	20 Mar 1973	80
	03 Apr 1973	23
	07 Apr 1973	205
	23 Apr 1973	23
	12 Sep 1973	227
	23 Oct 1973	91
	12 Nov 1973	114

TABLE II.2—CHARACTERISTICS OF REPORTED BUNKERING SPILLS, 1 JULY 1972 TO 30 JUNE 1980 (Cont)

Port	*Date of spill*	*Volume spilled*[a] *(litres)*
Fremantle	19 Nov 1973	91
(includes Kwinana) (Cont)	17 Dec 1973	50
	07 Jan 1974	318
	02 Apr 1974	182
	06 Sep 1974	57
	14 Nov 1974	455
	08 Dec 1974	682
	Nov 1975	227
	04 Feb 1976	25
	14 Feb 1976	500
	28 Feb 1977	20
	19 Mar 1977	136
	25 Sep 1977	1 140
	02 Oct 1977	45
	05 May 1978	50
	26 Jun 1978	65
	24 Nov 1978	7 410
	15 Sep 1979	na
	11 Nov 1979	na
	23 Nov 1979	na
	17 Dec 1979	na
	04 Feb 1980	500
	08 Feb 1980	400
	12 Mar 1980	na
	30 Apr 1980	65
	03 May 1980	10
Albany	08 Feb 1979	116
	24 Nov 1979	na
Port Hedland	16 Feb 1979	na

a. Where recorded.

NOTE: No bunkering spills were reported for Tasmania in the period shown.

TABLE II.3—CHARACTERISTICS OF REPORTED MISCELLANEOUS SPILLS, 1 JULY 1972 TO 30 JUNE 1980

Port	Date of spill	Volume spilled[a] (litres)
	New South Wales	
Sydney	24 Oct 1973	455
	Apr 1975	na
	Aug 1975	91
	Oct 1975	na
	Jun 1976	90
	Aug 1976	200
	Aug 1976	3
	10 Jan 1977	na
	17 Jan 1977	na
	20 Jan 1977	45
	21 Mar 1977	na
	27 May 1977	na
	09 Jun 1977	na
	02 Oct 1977	450
	13 Jan 1978	na
	13 Jan 1978	20
	23 Feb 1978	na
	16 Jul 1978	450
	06 Mar 1979	na
	21 Apr 1979	na
	11 Jul 1979	350
	31 Jul 1979	na
	06 Oct 1979	10
	Nov 1979	na
Botany Bay	15 Mar 1979	20
	Sep 1979	131 100
	10 Nov 1979	45
	24 Nov 1979	2
	20 Mar 1980	na
Newcastle	Oct 1974	800 000
	Dec 1975	na
	07 Nov 1976	180
Port Kembla	13 Oct 1976	200
	23 Mar 1978	800
	20 Jul 1979	455
	Victoria	
Melbourne	07 May 1973	na
	29 Sep 1973	na
	Mar 1975	na
	Apr 1975	na
	Jul 1975	na
	Sep 1975	na
	Oct 1975	na
	Oct 1975	na
	25 Jun 1976	na
	15 Aug 1976	na
	23 Aug 1976	na

TABLE II.3—CHARACTERISTICS OF REPORTED MISCELLANEOUS SPILLS, 1 JULY 1972 TO 30 JUNE 1980 (Cont)

Port	*Date of spill*	*Volume spilled*[a] *(litres)*
Melbourne (Cont)	09 Jan 1977	na
	02 Jun 1977	na
	08 Jan 1978	na
	03 May 1978	na
	10 May 1978	na
	25 Nov 1978	na
	30 Apr 1979	na
	25 Jul 1979	na
	20 Nov 1979	na
	29 Apr 1980	na
Geelong	18 Sep 1978	na
	22 May 1979	na
	03 Feb 1980	na
	07 Apr 1980	na
	30 May 1980	na
Westernport	30 Jun 1977	na
	29 Mar 1979	40
	Queensland	
Brisbane	20 May 1974	23
	Feb 1975	11 400
	Feb 1975	11 400
	Mar 1975	3 600
	14 Jan 1976	9
	27 Feb 1976	95
	13 Aug 1976	17
	17 Feb 1977	900
	06 May 1977	60
	09 May 1977	36
	10 Oct 1977	14 250
	12 Jan 1978	227
	28 Jul 1978	200
	02 Apr 1979	45
	26 Jan 1980	25
	30 Mar 1980	na
Cairns	05 Nov 1973	18
Gladstone	Jul 1975	na
	04 Jan 1977	na
	04 Jul 1978	na
Mackay	03 Oct 1977	na
Rockhampton	Jan 1975	227
Townsville	Jan 1975	568

TABLE II.3—CHARACTERISTICS OF REPORTED MISCELLANEOUS SPILLS, 1 JULY 1972 TO 30 JUNE 1980 (Cont)

Port	*Date of spill*	*Volume spilled[a] (litres)*
	South Australia	
Port Adelaide	17 Jul 1973	205
	05 Nov 1978	na
	20 Oct 1979	1 818
	23 Oct 1979	1 818
Port Stanvac	17 Oct 1979	3 480
Port Pirie	Jul 1976	855
	26 Feb 1980	50
Thevenard	18 Jan 1979	na
	Western Australia	
Fremantle	Feb 1979	18
(includes Kwinana)	Nov 1975	68
	24 Feb 1977	114
	07 Mar 1977	546
	01 Oct 1977	900
	23 Jul 1978	5
	03 Apr 1979	na
	06 Apr 1979	78
	04 Oct 1979	na
Albany	13 Dec 1979	na
Barrow Island	28 Apr 1978	na
Dampier	22 May 1979	1 160
Port Walcott	21 Sep 1979	1 000
Yampi Sound	27 Dec 1979	na
	Tasmania	
Hobart	09 May 1979	na
Launceston	08 Jan 1979	450

a. Where recorded.

APPENDIX III—OIL SPILL FREQUENCY MODELS

TYPES OF SPILLS

It was hypothesised that, if X_{ij} was the number of oil spills of type i in a given period at a port j, then X_{ij} followed a Poisson distribution with mean $\lambda_i V_{ij}$, where V_{ij} was the value of the exposure variable for this period associated with spill type i at port j. The probability distribution is given in the following equation:

$$P(X_{ij}=n) = \frac{e^{-\lambda_i V_{ij}}(\lambda_i V_{ij})^n}{n!} \qquad \text{(III.1)}$$

where X_{ij} = the random number of spills of type i during a period at port j;

n = the actual number of spills represented by X_{ij};

λ_i = mean number of spills of type i per unit of the relevant exposure variable; and

V_{ij} = level of the exposure variable for the period, associated with spill type i at port j.

The spills were categorised into three general types as follows:

- spills associated with the loading and discharging of oil and oil products (oil-handling spills) (i=1);
- spills associated with bunkering operations (bunkering spills) (i=2); and
- spills associated with any other type of ship operation in port (miscellaneous spills) (i=3).

The exposure variables V_{ij} were determined to be as follows:

- V_{1j} gigalitres of oil handled;
- V_{2j} megalitres of bunker fuel loaded; and
- V_{3j} megatonnes of cargo handled.

For oil-handling spills (i=1) three types of port were defined as follows:

- capital city ports with associated oil refineries;
- non-capital city ports with associated oil refineries; and
- other ports.

For bunkering spills (i=2) four types of port were defined as follows:

- capital city ports with associated oil refineries;
- capital city ports without associated oil refineries;
- non-capital city ports primarily associated with refineries; and
- all other ports.

For miscellaneous spills (i=3) four types of port were defined as follows:

- capital city ports;
- non-capital city 'light'[1] ports;
- non-capital city 'medium'[1] ports; and
- non-capital city 'heavy'[1] ports.

The values of the spill rates for oil handling spills (λ_1) and miscellaneous spills (λ_3) were found to depend on port type, while the rate for bunkering spills (λ_2) was constant for all ports.

Goodness-of-fit tests indicated that the Poisson distribution was a good representation of the distributional characteristics of the historical data. Maximum likelihood estimates for the λ_i (spill rates) are given in Table III.1.

TABLE III.1—MAXIMUM LIKELIHOOD ESTIMATES OF THE PARAMETERS OF THE POISSON DISTRIBUTIONS CHARACTERISING SPILL FREQUENCIES

Type of spill	*Type of port*	*Number of spills*	*Exposure variable level*[a]	*Spill rate*[b] *(λ_i)*
Handling (i=1)	Capital city with refinery	27	163	0.166
	Non-capital city with refinery	25	218	0.115
	Other	3	97	0.031
Bunkering (i=2)	All ports	194	18 159	0.011
Miscellaneous (i=3)	Capital city	63	486	0.130
	Non-capital city:			
	light	7	168	0.042
	medium	10	453	0.022
	heavy	5	954	0.005

a. Exposure variable units were defined previously in the text.
b. Number of spills per unit of the exposure variable.

PROBABILITY DISTRIBUTION OF OIL SPILL FREQUENCIES

The average number of spills (μ) of any type can be calculated for all the spill frequency models outlined in this study from the summary equations in Appendix VIII.

If μ represents the average number of spills for any of the models the probability of exactly n spills (P(X=n)) is then given by the Poisson distribution with a mean value of μ. These can be obtained from a Poisson probability table (Burington and May 1958) or from the following equation:

$$P(X=n) = \frac{e^{-\mu}(\mu)^n}{n!} \qquad \text{(III.2)}$$

1. 'Light', 'medium' and 'heavy' refer to ports at which the bulk mineral cargo associated with a single industry comprises respectively less than 50 per cent, between 50 and 85 per cent and over 85 per cent of the total weight of cargo handled.

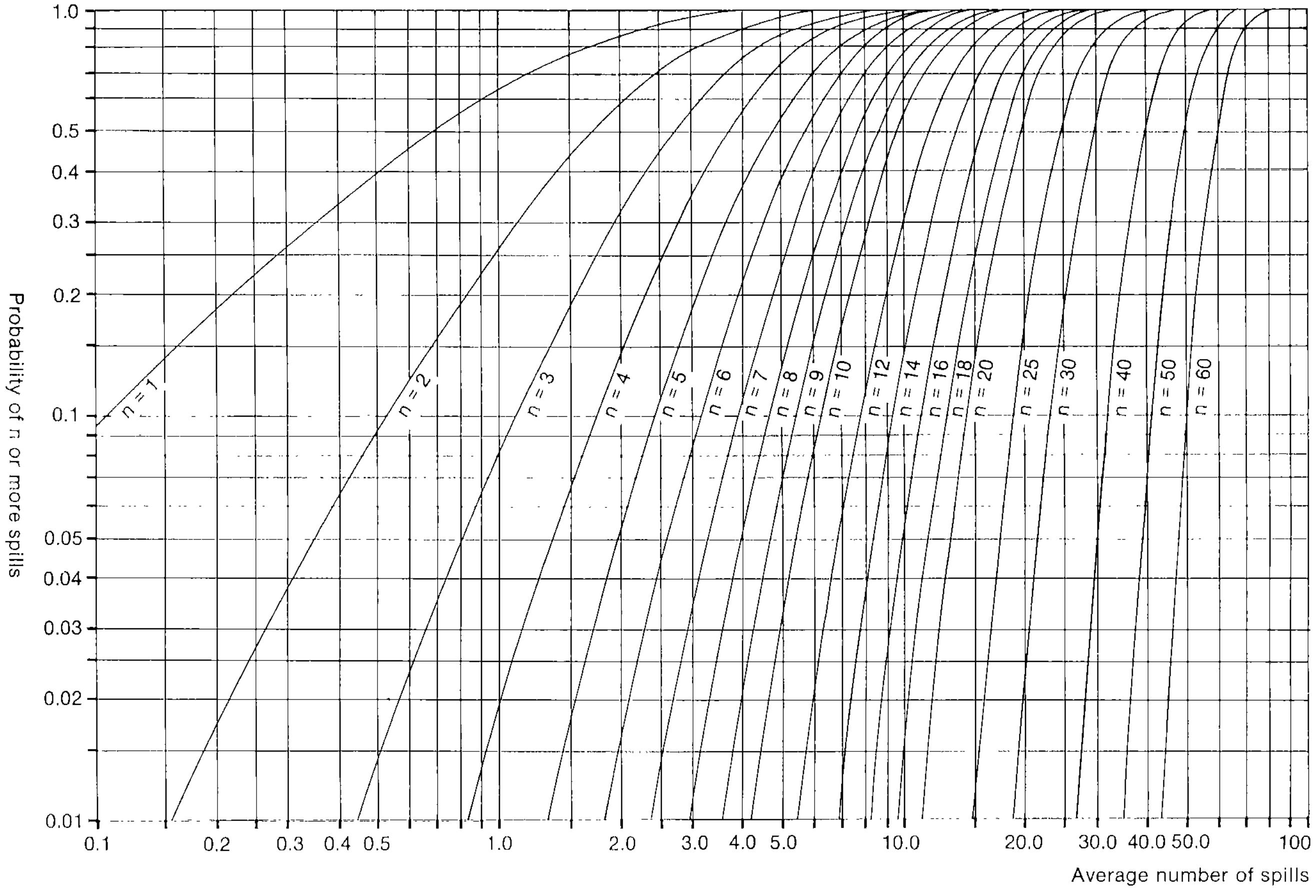

Figure III.1 Cumulative frequency distribution of numbers of oil spills as a function of the average number of spills

The probability of **n or more spills** ($P(X \geq n)$) occurring is given in the following equation:

$$P(X \geq n) = \sum_{x=n}^{\infty} \frac{e^{-\mu}(\mu)^{x}}{x!} \qquad \text{(III.3)}$$

For convenience, the probability of n or more spills has been graphed in Figure III.1 as a function of μ. The probability of less than n spills occurring is $(1-P(X \geq n))$.

The probability of **exactly n spills** can be obtained from Figure III.1 by subtracting the probability of n-1 spills or more from the probability of n spills or more.

APPENDIX IV—OIL SPILL VOLUME MODELS

It was established that the lognormal distribution, with maximum likelihood estimates of the two parameters which characterise this distribution, best describes the volume of oil spilled in the various types of spills. This appendix discusses the grouping of spill types and shows the results obtained using the maximum likelihood method for the estimates of the parameters of the distribution. The final section discusses the method for calculating resulting probabilities associated with various spill volumes.

MAXIMUM LIKELIHOOD ESTIMATORS

The volumes spilled in individual spills were examined for their possible relationship with various factors such as numbers of spills, type of spill, levels of the exposure variables and the types of ports at which the spills occurred. The only significant relationship that could be determined involved spill type. The spill volumes for the three types of spill (oil-handling, bunkering and miscellaneous) were therefore analysed separately.

The oil-handling spills, for which spill volumes were recorded, were assumed to belong to the same population of spills; that is, their volumes were essentially determined by the same (possibly latent) factors. The same assumption was made for the volumes spilled in bunkering and in miscellaneous spills.

The distribution which was used as a statistical model for spill volumes (Y litres) was the lognormal distribution. The density function for the lognormal distribution with parameters α and β is given in Equation IV.1. This distribution characterises random variables which cannot be zero or negative, have a high probability of having a low value while at the same time a significant probability of being very large.

$$f_Y(y) = \frac{\beta e^{-\frac{1}{2}(\alpha+\beta \log y)^2}}{y\sqrt{2\pi}} \qquad \text{(IV.1)}$$

where Y is the number of litres spilled.

The maximum likelihood estimators are as shown in the following equations (Kendall and Stuart 1973):

$$\hat{\beta} = \sqrt{\frac{n}{\sum_{j=1}^{n}(\log y_j)^2 - (\sum_{j=1}^{n}\log y_j)^2/n}} \qquad \text{(IV.2)}$$

$$\hat{\alpha} = -\hat{\beta}\sum_{j=1}^{n}\log y_j/n \qquad \text{(IV.3)}$$

The results for $\hat{\alpha}$ and $\hat{\beta}$, for the three spill types, are listed in Table IV.1.

TABLE IV.1—MAXIMUM LIKELIHOOD ESTIMATES OF THE PARAMETERS OF THE LOGNORMAL DISTRIBUTIONS CHARACTERISING SPILL VOLUMES

Type of spill	*Number of spills*[a]	$\hat{\alpha}$	$\hat{\beta}$
Handling	40	–3.677	0.593
Bunkering	112	–2.970	0.594
Miscellaneous	43	–2.264	0.429

a. Number of spills for which volume was recorded.

PROBABILITY DISTRIBUTIONS OF OIL SPILL VOLUMES

The spill volume distribution was best described by the lognormal distribution, with different parameters values (α, β) for the different spill types.

The lognormal distribution has a cumulative distribution given by:

$$P(Y<y) = \Phi\ (\alpha + \beta\ log\ y)$$

where Y = the number of litres spilled;
P(Y<y) = the probability that the spill volume is less than y litres; and
Φ = the standard normal distribution function.

For any value y (of Y), given the appropriate α and β, the value $\alpha + \beta\ log\, y$ is calculated and the corresponding values of Φ are given in normal distribution tables, which are published in most books of statistical tables (for example, Burington and May 1958). Alternatively, appropriate values are presented in Figures IV.1, IV.2 and IV.3 of this appendix. Figure IV.1 shows the probability that an oil handling spill will be of volume y litres or smaller. Figures IV.2 and IV.3 show the corresponding distributions for bunkering and miscellaneous spill volumes, respectively.

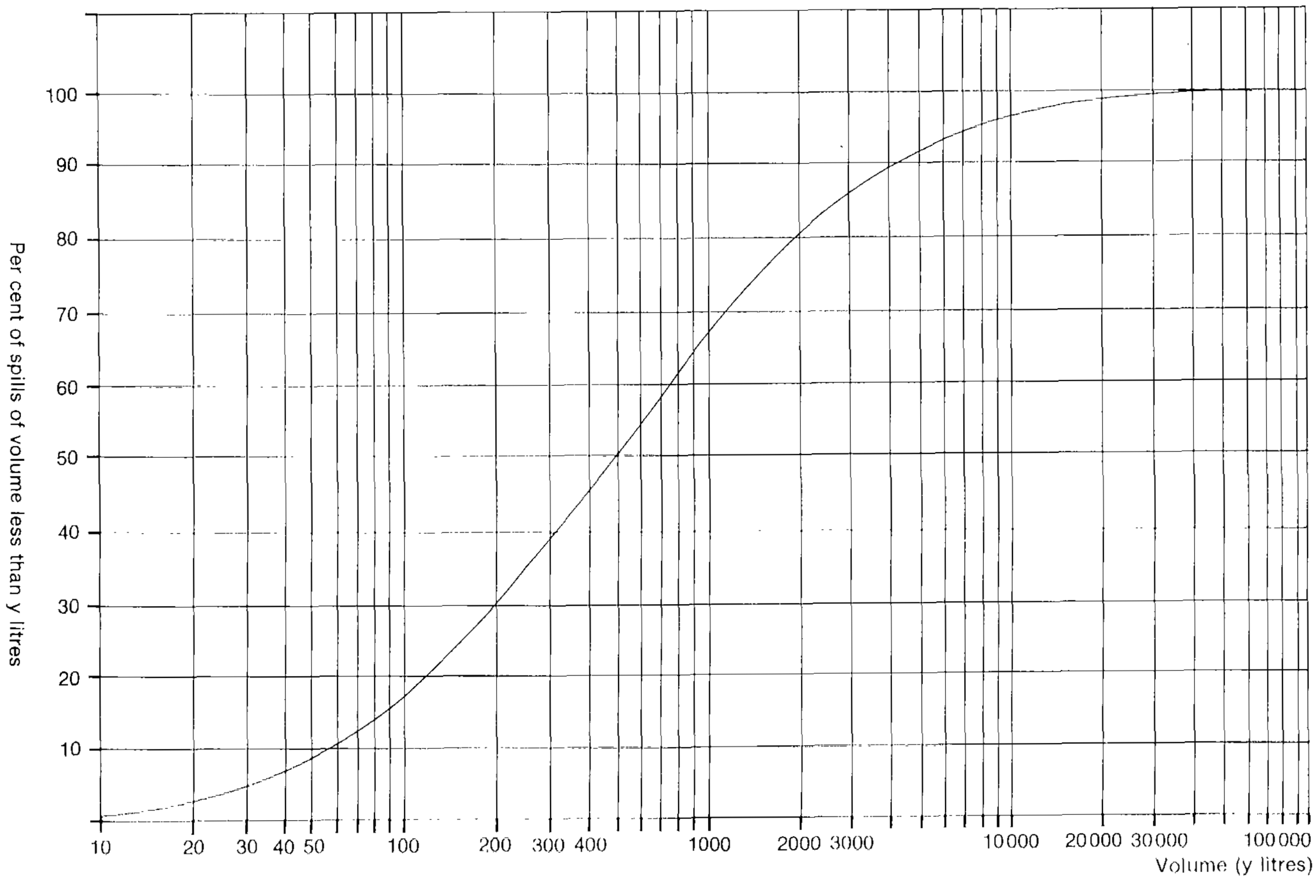

Figure IV.1 Cumulative frequency distribution of oil-handling spill volumes

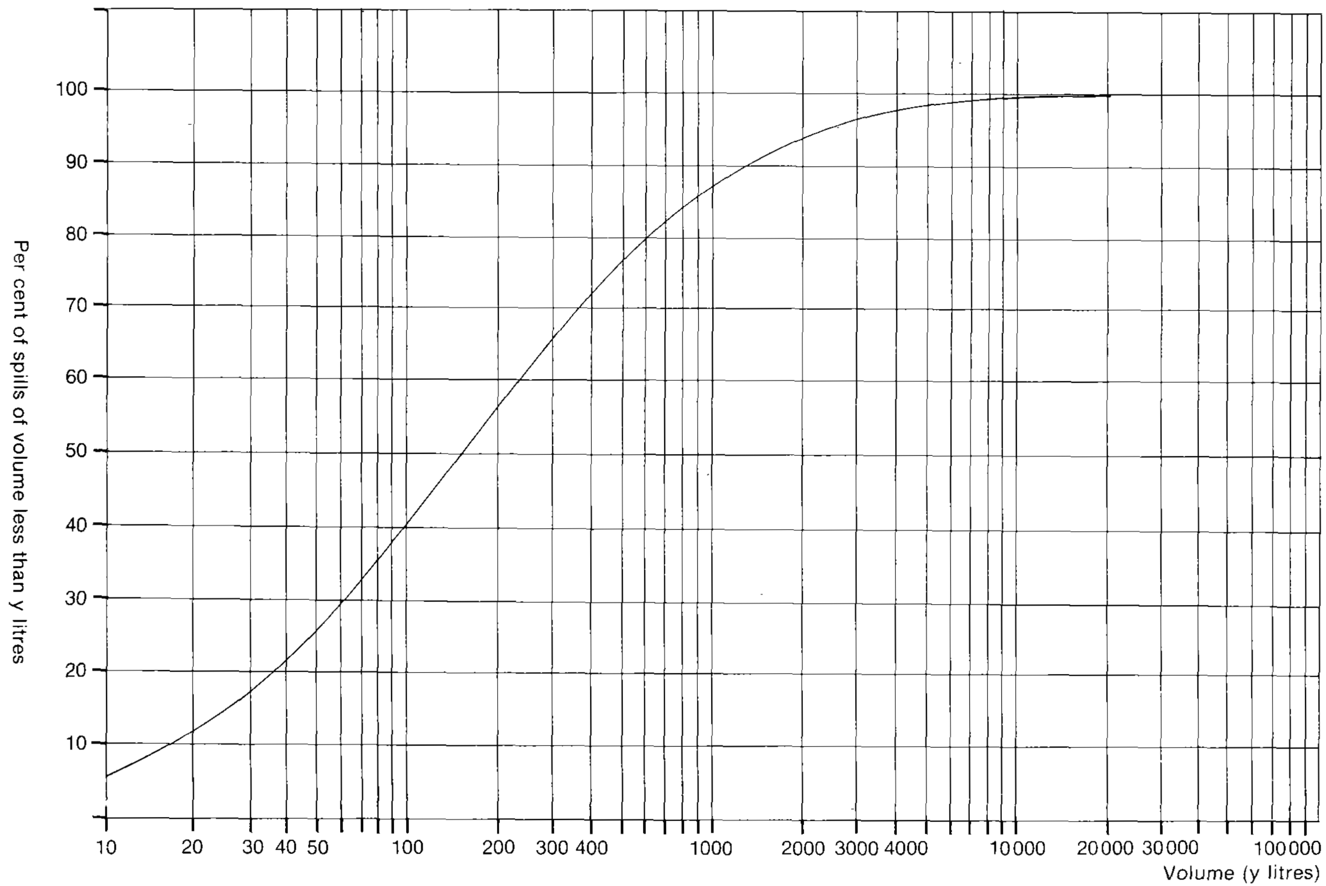

Figure IV.2 Cumulative frequency distribution of bunkering spill volumes

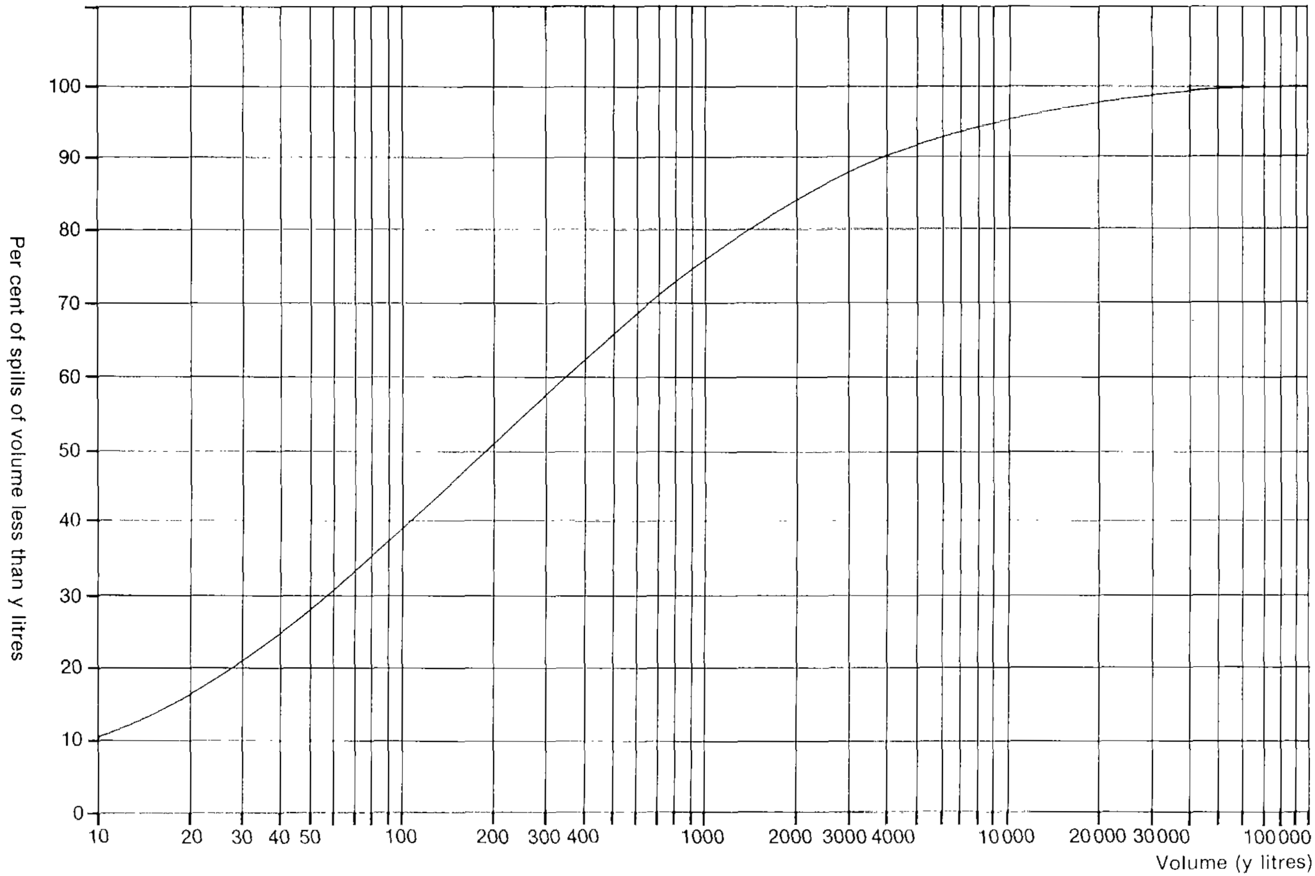

Figure IV.3 Culu lative frequency distribution of miscellaneous spill volumes

APPENDIX V—DIRECTORY OF PORT CODES

The port codes and corresponding port names used in certain parts of this Report are listed below in Table V.1. Two conventions have been used for allocating port codes to port names:

- the first digit specifies the State[1]; and
- capital city ports have 01 as the last two digits.

Apart from these conventions, the codes have been assigned arbitrarily.

1. The first digit corresponds to the first digit in the post code for that State.

TABLE V.1—DIRECTORY OF PORT CODES

State	*Port code*	*Port name*	*State*	*Port code*	*Port name*
New South Wales	201	Sydney	Queensland (Cont)	408	Lucinda
	202	Botany Bay		409	Mackay
	203	Catherine Hill Bay		410	Maryborough
	204	Clarence River		411	Mourilyan
	205	Coffs Harbour		412	Rockhampton
	206	Newcastle		413	Thursday Island
	207	Port Kembla		414	Townsville
	208	Richmond River		415	Weipa
	209	Trial Bay			
	210	Twofold Bay	South Australia	501	Port Adelaide
	211	Norfolk Island		502	Port Stanvac
	212	Bass Point		503	American River
				504	Ardrossan
Victoria	301	Melbourne		505	Ballast Head
	302	Geelong		506	Kingscote
	303	Portland		507	Klein Point
	304	Port Welshpool		508	Port Augusta
	305	Westernport		509	Port Giles
				510	Port Lincoln
Queensland	401	Brisbane		511	Port Pirie
	402	Bowen		512	Proper Bay
	403	Bundaberg		513	Rapid Bay
	404	Cairns		514	Stenhouse Bay
	405	Cape Flattery		515	Thevenard
	406	Gladstone		516	Wallaroo
	407	Hay Point		517	Whyalla

TABLE V.1—DIRECTORY OF PORT CODES (Cont)

State	*Port code*	*Port name*	*State*	*Port code*	*Port name*
Western Australia	601	Fremantle (includes Kwinana)	Tasmania	701	Hobart
	602	Albany		702	Burnie
	603	Barrow Island		703	Devonport
	604	Broome		704	Flinders Island
	605	Bunbury		705	King Island
	606	Carnarvon		706	Launceston (includes Bell Bay)
	607	Dompier		707	Port Latta
	608	Derby		708	Stanley
	609	Esperance			
	610	Exmouth Gulf			
	611	Geraldton			
	612	Port Hedland	Northern Territory	801	Darwin
	613	Port Walcott		802	Gove
	614	Wyndham		803	Groote Eylandt
	615	Yampi Sound		804	Christmas Island

APPENDIX VI—VALIDATION AND APPLICATION OF OIL SPILL MODELS

In this appendix, the statistical models (discussed in Chapter 3) which represent the characteristics of the various types of oil spills are discussed in terms of their application to a particular port.

The application of the models to the oil spill risk associated with groups of ports is also discussed. This enables statistical risk assessments to be made for all capital city ports, all ports in one State, and so on. In this context, given the average[1] number of spills of a given type at a port, the average number of spills of all types at that port is obtained by simple summation. The total volume spilled in all types of spills at a port can also be obtained through simple summation. In this appendix, methods are established to allow these results relating to aggregate spill risks to be estimated in a reasonably straightforward way.

Although the models (statistical distributions) discussed in Chapter 3 are expressed only in terms of the values of the appropriate exposure variables, the following sections examine the assessment of spill risks on an annual basis. Annual levels of the exposure variables are considered, leading to assessments of spills also on an annual basis. Data on exposure variables for the fiscal year 1979-80 are used to illustrate the application of the models to obtain forecasts of the characteristics of future spills.

As an indication of the accuracy and validity of the models, a comparison is presented between the actual and projected[2] number and volumes of spills in 1979-80.

SOURCES OF DATA

The ability to use the statistical models presented in Chapter 3 required an assessment of future levels of maritime activity of various forms, in order to permit some estimation of future levels of the relevant exposure variables. In general, these assessments were provided by the appropriate Sections of DoTA.

Exposure variables for 1979-80

The weight of oil and oil product cargo handled at each port per annum was obtained for the fiscal year 1979-80 (DoTA 1981). Using appropriate densities for the various oil products, as discussed in Chapter 1, these data were converted from tonnes to gigalitres.

The weight of total cargo handled per annum at each port for the fiscal year 1979-80 was also obtained (DoTA 1981).

Five of the major oil companies, estimated as comprising 84.4 per cent of the market, were approached to provide information concerning their volume of sales of bunker fuels for each port for the eight years ending 30 June 1980. Unfortunately, as previously noted, complete data were supplied by all five companies for only two years (1979 and 1980 calendar years). As a result, the average of the 1979 and 1980 **calendar** year figures for each port was assumed to be 84.4 per cent of the 1979-80 **fiscal** year bunker sales at that port. The final estimates of bunker fuel loaded in the fiscal year 1979-80, by port, were made by weighting the above figures to represent in total the volume of bunker fuel consumed in that year in Australia, as reported by the Australian Institute of Petroleum (AIP 1980).

1. The average number of spills refers to the arithmetic mean number of spills throughout this appendix.
2. Based on spill information up to 30 June 1979.

APPLICATION AND VALIDATION OF THE MODELS USING 1979-80 EXPOSURE VARIABLE DATA

Average number of spills

The oil spill rates presented in Chapter 3 were applied to the actual 1979-80 figures for oil handled, bunker fuel sales and cargo handled at each port, to produce the theoretical average numbers of various types of spills at those ports in that year. Table VI.1 shows a comparison between the actual spills which occurred at a number of ports in 1979-80, and the number of spills that would have been estimated based on average spill rates.

The average number of spills of each type, by port, can be appropriately summed to give the average number of all spills of any type by port, the average number of each type of spill for a group of ports or the average number of all types of spills for any group of ports. Details are given in Appendix VIII.

Table VI.2 gives a summary of the projected average number of oil spills of all types for 1979-80 by capital city and rest of State. Based on the statistical models discussed in Chapter 3, a confidence interval and the associated probability of the number of spills occurring in this interval, are given. Table VI.2 also gives the historical annual average for the study period and the actual number of oil spills reported in 1979-80. The calculation of the probabilities associated with these average numbers of spills are described in Appendix III.

Table VI.1 shows that in 1979-80 Botany Bay and Geelong experienced significantly more miscellaneous spills than the projected average. However, the aggregate projections for ports in New South Wales and Victoria outside the capital cities are reasonably compatible with the projected averages shown in Table VI.2. The model underestimated the number of spills occurring in 1979-80 in South Australia as a whole. In fact, it can be shown that with an average annual spill frequency of 2.8 (as shown in Table VI.2 for South Australia), the probability of seven or more spills actually occurring (as happened in 1979-80) is only 0.024, which represents quite a small statistical chance. If it was possible to calculate exact 95 per cent confidence intervals (ranges) for each projected number of spills, 5 per cent of these ranges would not include the actual number of spills which occur, even though the model used to derive the ranges was correct.

Average volume spilled per spill

Table VI.3 shows the intervals in which the 1979-80 average spill volumes should fall, with 95 per cent confidence, based on the statistical distributions derived previously. The simulation technique used to calculate these intervals is the same as that for calculating limits on the total amount spilled in a port in a year and is presented in Appendix IX.

The actual average spill volume for each spill type was inside the 95 per cent confidence interval based on the derived statistical models. Consequently, the actual spill volumes in 1979-80 do not invalidate the derived spill volume models.

Spills of a specific volume

Appendix VII gives the formula for the average number of spills in a port of volume greater than a specified amount. This average number can be calculated for any time period, all spill types, and for spills at one or a group of ports. The occurrences of various numbers of spills **of a specific size** also follow a Poisson distribution and can consequently be obtained as previously described.

Table VI.4 shows the probabilities that spills of more than 20 000 litres and 120 000 litres would have occurred at various ports in the year 1979-80, based on the models previously derived and the values of the exposure variables for that year.

TABLE VI.1—COMPARISON OF PROJECTED AND ACTUAL NUMBERS OF SPILLS BY SPILL TYPE FOR SELECTED PORTS[a], 1979-80

	Handling spills		*Bunkering spills*		*Miscellaneous spills*	
Port	*Projected*	*Actual*	*Projected*	*Actual*	*Projected*	*Actual*
New South Wales						
Sydney	1.01	—	5.49	5	3.12	4
Botany Bay	1.41	2	0.06	—	0.23	4
Newcastle	0.06	—	1.14	—	0.46	—
Port Kembla	0.03	—	1.54	—	0.39	1
Victoria						
Melbourne	0.43	3	6.19	5	2.45	3
Geelong	0.40	1	1.16	1	0.30	3
Portland	0.01	—	0.11	—	0.08	—
Westernport	1.31	1	0.32	—	0.25	—
Queensland						
Brisbane	1.19	—	0.71	—	1.27	2
Cairns	0.01	—	0.06	—	0.03	—
Gladstone	0.02	—	0.04	—	0.09	—
Mackay	—	—	0.05	—	0.05	—
Townsville	0.03	—	0.19	—	0.09	—
South Australia						
Port Adelaide	0.01	—	0.94	1	0.53	2
Port Stanvac	0.51	2	0.36	—	0.08	1
Port Pirie	0.01	—	—	—	0.06	1
Whyalla	—	—	—	—	0.14	—
Western Australia						
Fremantle	1.25	1	7.33	9	2.14	1
Albany	—	—	0.10	1	0.05	1
Dampier	—	—	—	—	0.20	—
Port Hedland	—	—	0.02	—	0.18	—
Port Walcott	0.01	—	—	—	0.07	1
Yampi Sound	—	—	—	—	0.01	1
Tasmania						
Hobart	0.02	—	0.42	—	0.41	—
Launceston	—	—	0.07	—	0.20	—
Northern Territory						
Darwin	0.02	—	0.12	—	0.08	—
Australia						
All ports[b]	7.93	10	26.47	22	13.79	25

a. Ports presented are selected on either of two criteria; ports for which an average number of all spills of 0.1 or more was projected for 1979-80 on the basis of the actual 1979-80 exposure variables, or ports which experienced at least one actual spill in 1979-80.
b. These totals are for all ports in Australia and are not equal to the column totals, due to rounding and inclusion of ports with less than 0.1 projected spills.

Sydney experienced the greatest risk of large spills in 1979-80. Quantitatively, there was approximately one chance in ten of at least one spill of volume in excess of 20 000 litres occurring in Sydney during that year, and one chance in 1000 of at least one spill of volume in excess of 120 000 litres occurring.

Overall, Australia experienced a risk of approximately two chances in five of at least one spill in the year of volume in excess of 20 000 litres occurring and five chances in 100 of at least one spill of volume in excess of 120 000 litres occurring.

By way of comparison, in 1979-80 there was one spill of volume in excess of 120 000 litres (131 000 litres was spilled in Botany Bay by a tanker engaged in an operation other than loading/discharging oil and bunkering). The probability of the occurrence of a spill of this size in the whole of Australia was just less than 1 chance in 20[1]. Based on the previous seven years experience, a spill volume of this size would only occur one year in every 20 years, on average, given the same levels of the exposure variables.

TABLE VI.2—HISTORICAL AVERAGE[a], PROJECTED, RANGE OF PROJECTED AND ACTUAL ANNUAL NUMBERS OF OIL SPILLS, BY CAPITAL CITY PORT AND REST OF STATE, 1979-80

Port location	*Historical annual average*	*Projected number of spills (1979-80)*	*Confidence[b] interval*	*Exclusion[c] probability*	*Actual number of spills (1979-80)*
		New South Wales			
Sydney	11.6	9.6	4 to 16	0.033	9
Rest of State	4.1	5.4	2 to 11	0.037	7
Total	15.7	15.0	8 to 23	0.038	16
		Victoria			
Melbourne	10.7	9.1	4 to 15	0.044	11
Rest of State	4.0	3.9	1 to 9	0.027	6
Total	14.7	13.0	7 to 21	0.040	17
		Queensland			
Brisbane	5.0	3.2	0 to 7	0.017	2
Rest of State	2.6	0.9	0 to 2	0.063	—
Total	7.6	4.1	1 to 8	0.041	2
		South Australia			
Port Adelaide	0.6	1.5	0 to 4	0.019	3
Rest of State	1.4	1.3	0 to 4	0.011	4
Total	2.0	2.8	0 to 6	0.024	7

1. It is commonly taken in statistical analysis that an event which has less than 5 per cent chance of occurring is an unlikely event and that the correct conclusion to draw is that the model used to calculate its probability of occurrence is incorrect.

TABLE VI.2—HISTORICAL AVERAGE[a], PROJECTED, RANGE OF PROJECTED AND ACTUAL ANNUAL NUMBERS OF OIL SPILLS, BY CAPITAL CITY PORT AND REST OF STATE, 1979-80 (Cont)

Port location	*Historical annual average*	*Projected number of spills (1979-80)*	*Confidence[b] interval*	*Exclusion[c] probability*	*Actual number of spills (1979-80)*
		Western Australia			
Fremantle	6.9	10.7	5 to 18	0.033	11
Rest of State	0.6	1.0	0 to 3	0.019	4
Total	7.5	11.7	6 to 19	0.042	15
		Tasmania			
Hobart	0.1	0.9	0 to 3	0.013	—
Rest of State	0.3	0.4	0 to 2	0.062	—
Total	0.4	1.3	0 to 4	0.011	—
		Northern Territory			
Darwin	—	0.2	0 to 1	0.017	—
Rest of State	—	0.1	d	d	—
Total	—	0.3	0 to 1	0.037	—
		Australia			
Total	47.9	48.1	34 to 61	0.043	57

a. Over the period 1 July 1972 to 30 June 1979.
b. An inclusive interval a to b is chosen such that the probability of the occurrence of a number of spills outside this range is small. If these intervals are to have integer upper and lower limits the probability of the number of spills being outside the intervals cannot be set at 5 or 10 per cent, as is normal statistical practice. The intervals were chosen to obtain a probability of exclusion as close as possible to the usual 5 per cent (ie to 95 per cent confidence limits).
c. Given that the projected average is correct this is the probability that the actual number of spills is outside the confidence interval. Appendix III provides the information from which these probabilities are derived.
d. The probability of zero spills is greater than 0.90.

TABLE VI.3—COMPARISON OF AVERAGE VOLUMES OF ACTUAL SPILLS WITH 95 PER CENT CONFIDENCE INTERVALS DERIVED FROM MODELS, 1979-80

Spill type	*95 per cent confidence interval on the average spill volume[a]* Lower limit (litres)	Upper limit (litres)	*Number of spills[b]*	*Actual average spill volume (litres)*
Handling	110	10 000	3	1 074
Bunkering	110	2 000	10	188
Miscellaneous	210	13 000	12	11 679

a. These intervals were calculated using the actual number of spills which were reported in 1979-80, and for which spill volumes were recorded.
b. Number of spills for which spill volume was recorded.

TABLE VI.4—PROBABILITIES OF THE OCCURRENCE OF AT LEAST ONE SPILL OF VOLUME IN EXCESS OF 20 000 LITRES AND 120 000 LITRES BY PORT[a], 1979-80

Port	*Probability of a spill of volume in excess of:* 20 000 litres	120 000 litres
New South Wales		
Sydney	0.094	0.0099
Botany Bay	0.025	0.0015
Newcastle	0.014	0.0014
Port Kembla	0.012	0.0012
Victoria		
Melbourne	0.073	0.0076
Geelong	0.015	0.0012
Portland	0.002	0.0002
Westernport	0.025	0.0017
Queensland		
Brisbane	0.047	0.0045
Bundaberg	0.001	0.0001
Cairns	0.001	0.0001
Gladstone	0.002	0.0003
Hay Point	0.002	0.0002
Mackay	0.001	0.0002
Townsville	0.003	0.0003
Weipa	0.001	0.0002
South Australia		
Port Adelaide	0.014	0.0016
Port Stanvac	0.009	0.0005
Port Lincoln	0.001	0.0002
Port Pirie	0.002	0.0002
Thevenard	0.001	0.0001
Wallaroo	0.001	0.0001
Whyalla	0.004	0.0004
Western Australia		
Fremantle	0.079	0.0072
Albany	0.002	0.0002
Barrow Island	0.001	0.0000
Bunbury	0.002	0.0002
Dampier	0.005	0.0006
Esperance	0.001	0.0001
Exmouth Gulf	0.001	0.0001
Geraldton	0.002	0.0002
Port Hedland	0.004	0.0005
Port Walcott	0.002	0.0002
Tasmania		
Hobart	0.011	0.0013
Burnie	0.002	0.0002
Devonport	0.001	0.0001
Launceston	0.005	0.0006

TABLE VI.4—PROBABILITIES OF THE OCCURRENCE OF AT LEAST ONE SPILL OF VOLUME IN EXCESS OF 20000 LITRES AND 120000 LITRES BY PORT[a], 1979-80 (Cont)

Port	Probability of a spill of volume in excess of: 20000 litres	120000 litres
Northern Territory		
Darwin	0.002	0.0002
Gove	0.001	0.0001
Australia		
All ports	0.400	0.046

a. Ports for which the probability of at least one spill of volume in excess of 20000 litres is less than 0.0005 are not included in this table.

Total volume spilled at a specific port

An estimate of the total annual volume of oil spilled at a port in a particular year was calculated from the estimated number of spills of each type in that year and the average volumes spilled in each type of spill[1].

The probability that the total volume spilled at a port, in a year say, will exceed a specific amount cannot be calculated directly. These probabilities were estimated using a combination of simulation and regression techniques. The procedure is outlined in Appendix IX. Based on these techniques, Table VI.5 shows the volumes which were expected to be exceeded 10 and 5 per cent of the time (or at 10 and 5 per cent of the ports in 1979-80), the actual volume spilled in recorded spills and the estimated volume spilled in all spills in the fiscal year 1979-80.

From the recorded spill volumes shown for selected ports in Table VI.5, three ports out of a total of 76 ports (or 4 per cent) exceeded the 5 per cent volume and 5 ports (or 7 per cent) exceeded the 10 per cent volume. Since the recorded spills account for less than 100 per cent of spills this result does not invalidate the models.

TABLE VI.5—TOTAL ANNUAL VOLUMES SPILLED WHICH ARE EXCEEDED ONLY A SPECIFIED PER CENT OF THE TIME BY PORT[a], 1979-80

(litres)

Port	Volume expected to be exceeded a specified per cent of the time: 10 per cent	5 per cent	Volume spilled in recorded[b] spills	Estimated volume spilled in all spills[c]
New South Wales				
Sydney	28 900	46 350	808	6 736
Botany Bay	7 750	13 085	131 147	138 199
Newcastle	3 700	7 400	—	—
Port Kembla	3 870	7 300	455	455
Victoria				
Melbourne	23 100	37 700	na	18 084
Geelong	4 850	9 000	na	11 548
Portland	—	950	—	—
Westernport	7 800	11 700	na	2 044

1. The estimated average volumes spilled per handling, bunkering and miscellaneous spill, at any port, were 2044 litres, 612 litres and 2964 litres.

TABLE VI.5—TOTAL ANNUAL VOLUMES SPILLED WHICH ARE EXCEEDED ONLY A SPECIFIED PER CENT OF THE TIME BY PORT[a], 1979-80 (Cont)

(litres)

Port	*Volume expected to be exceeded a specified per cent of the time*		*Volume spilled in recorded[b] spills*	*Estimated volume spilled in all spills[c]*
	10 per cent	*5 per cent*		
		Queensland		
Brisbane	14 050	25 200	25	2 989
Cairns	—	350	—	—
Gladstone	100	900	—	—
Mackay	—	450	—	—
Townsville	300	1 450	—	
		South Australia		
Port Adelaide	3 850	7 800	4 191	4 191
Port Stanvac	3 100	5 850	6 253	6 253
Port Pirie	—	500	50	50
Whyalla	50	1 150	—	
		Western Australia		
Fremantle	25 950	40 900	1 425	2 027
Albany	—	550	na	3 576
Dampier	350	1 550	—	—
Port Hedland	300	1 400	—	—
Port Walcott	100	500	1 000	1 000
Yampi Sound	—	—	na	2 964
		Tasmania		
Hobart	2 650	6 000	—	—
Launceston	450	1 900	—	—
		Northern Territory		
Darwin	700	2 750	—	—
		Australia		
Remaining 50 ports	—	—	—	—

a. Ports presented are selected on either of two criteria; ports for which an average number of all spills of 0.1 or more was projected for 1979-80 on the basis of the actual 1979-80 exposure variables, or ports which experienced at least one actual spill in 1979-80.
b. Spill volumes were recorded for only 25 of the 57 spills occurring in 1979-80.
c. Based on the calculation of average volumes spilled for each type of spill.

APPENDIX VII—SPILLS OF MORE THAN A SPECIFIED VOLUME

TIME-BASED RISK OF A LARGE SPILL

If S is the number of spills of volume greater than a specified y litres, then the probability that at least one spill ($P(S \geqslant 1)$), of volume greater than y litres, will occur at a port[1] in a given time period is given in the following equation:

$$P(S \geqslant 1) = 1-e^{-\lambda_1 V_1(1-p_1)-\lambda_2 V_2(1-p_2)-\lambda_3 V_3(1-p_3)} = 1-e^{-\mu} \qquad \text{(VII.1)}$$

where λ_i = appropriate spill rate for spills of type i (i = 1, 2, 3 for oil handling, bunkering and miscellaneous spills);

V_i = amount of oil (i=1), bunker fuel (i=2) and cargo (i=3) handled in the period;

p_i = $p_i(y)$ and is the probability that a spill of type i is of volume y litres or less (from Figures IV.1, IV.2 and IV.3 in Appendix IV); and

μ = average number of spills of volume greater than y litres

$$= \lambda_1 V_1(1-p_1)+\lambda_2 V_2(1-p_2)+\lambda_3 V_3(1-p_3)$$

The probability of exactly s spills ($P(S=s)$) of volume greater than y litres is given in the following equation:

$$P(S=s) = \frac{e^{-\mu}(\mu)^s}{s!} \qquad \text{(VII.2)}$$

These probabilities can be obtained from Figure III.1 for any value of μ, or from a Poisson probability table (Burington and May 1958).

SPILL-BASED RISK OF A LARGE SPILL

Given that a spill of any type occurs, the probability that its volume (Y) exceeds y litres is given in the following equation:

$$P(Y>y) = \frac{\lambda_1 V_1(1-p_1)+\lambda_2 V_2(1-p_2)+\lambda_3 V_3(1-p_3)}{\lambda_1 V_1 + \lambda_2 V_2 + \lambda_3 V_3} \qquad \text{(VII.3)}$$

where λ_i, V_i and $p_i = p_i(y)$ are as defined in Equation VII.1 above.

1. The subscript j (for port j) has been dropped. Equation VII.1 applies to one specified port only.

APPENDIX VIII—SUMMARY OF EQUATIONS TO PRODUCE MODEL RESULTS

Estimates of the average numbers of spills and the probabilities associated with the occurrence of any particular number of spills can be obtained for a single port, groups of ports, a single type of spill, all types of spills and any combination of ports and spill types. Each estimate is dependent on the value of the exposure variable for a particular period, and is the estimate for that same period. Usually the period concerned will be a year but the models apply for any period provided the exposure variable is defined for that period.

The symbols used in this appendix are defined as follows:

λ_{ij} is the appropriate spill rate for spills of type i at a port j (Table VIII.1 indicates the appropriate spill rate for each port type);

V_{ij} is the value of the exposure variable **in a given period** for spills of type i at port j;

μ_{ij} is the average number of spills of type i at port j **in a given period;**

m_{ij} is the average number of spills of type i exceeding y litres at port j, **in a given period;**

p_i is the probability that a single spill of type i is less than y litres in volume (obtained from Figures IV.1, IV.2 and IV.3);

$\overline{y}_i$ is the average volume spilled per spill of type i; and

S_{ij} is the number of spills of type i of volume greater than y litres at port j.

Where a quantity (μ_{ij} say) is summed over an index j the resulting sum is written as $\mu_{i.}$, the dot indicating summation over that index.

The formulae for various estimates of oil spill characteristics refer to the period for which Vij is the value of the exposure variable, and are given in Table VIII.2.

The average number of spills, with no restriction on volume, is calculated as the product of the appropriate spill rate and the value of the appropriate exposure variable. If the type of spill is further defined (for example, of volume less than 10 000 litres), then the above product is multiplied further by the proportion of (probability of the occurrence of) spills in this more restrictive category (that is, the probability of a spill having a volume less than 10 000 litres). The distribution of the actual number of spills which occurred was shown in each case to follow a Poisson distribution. Probabilities of the occurrence of specific numbers of spills can be obtained from Figure III.1, given that the average number of spills of the type of interest has been calculated.

In this study the upper limit (w_j) on the total volume spilled in all spills at a port were simulated and then estimated as linear functions of the exposure variables. This process was time-consuming and estimates were only made for spills of all types at a single specific port, using annual values of the exposure variables.

TABLE VIII.1—SUMMARY OF AVERAGE SPILL RATES, BY PORT AND SPILL TYPE

		Handling spills	Bunkering spills	Miscellaneous spills
Port type		*Spill rate*	*Spill rate*	*Spill rate*
Capital city with refinery		0.166	0.011	0.130
Capital city without refinery		0.031	0.011	0.130
Non-capital city ports with at least one refinery	Light[a]	0.115	0.011	0.042
	Medium[b]	0.115	0.011	0.022
	Heavy[c]	0.115	0.011	0.005
Other ports	Light[a]	0.031	0.011	0.042
	Medium[b]	0.031	0.011	0.022
	Heavy[c]	0.031	0.011	0.005

a. Port in which less than 50 per cent of the total weight of cargo is accounted for by minerals associated to one industry.
b. As for a with between 50 and 85 per cent.
c. As for a with more than 85 per cent.

TABLE VIII.2—SUMMARY EQUATIONS USED TO ESTIMATE OIL SPILL CHARACTERISTICS

Quantity estimated	*Formula*	*Equation number*
Average number of spills of type i at a port j	$\mu_{ij} = \lambda_{ij}V_{ij}$	(VIII.1)
Average number of spills of all types at a port j	$\mu_{.j} = \mu_{1j}+\mu_{2j}+\mu_{3j}$	(VIII.2)
Average number of spills of type i at a group of n ports	$\mu_{i.} = \mu_{i1}+\mu_{i2}+ \ldots +\mu_{in}$	(VIII.3)
Average number of spills of all types at a group of n ports	$\mu_{..} = \mu_{1.}+\mu_{2.}+\mu_{3.}$ $= \mu_{.1}+\mu_{.2}+ \ldots +\mu_{.n}$	(VIII.4)
Average number of spills of type i, at a port j, which exceed y litres	$m_{ij} = \lambda_{ij}V_{ij}(1-p_i)$	(VIII.5)
Probability that at least one spill of type i and of volume greater than y litres occurs at port j	$P(S_{ij}\geqslant 1) = 1-e^{-m_{ij}}$	(VIII.6)
Average number of spills of all types, at a port j, which exceed y litres	$m_{.j} = m_{1j}+m_{2j}+m_{3j}$	(VIII.7)

TABLE VIII.2—SUMMARY EQUATIONS USED TO ESTIMATE OIL SPILL CHARACTERISTICS (Cont)

Quantity estimated	*Formula*	*Equation number*
Probability that at least one spill of any type and volume greater than y litres occurs at port j	$P(S_{.j} \geqslant 1) = 1 - e^{-m_{.j}}$	(VIII.8)
Average number of spills of all types, at a group of n ports, of volume greater than y litres	$m_{..} = m_{.1} + m_{.2} + \ldots + m_{.n}$	(VIII.9)
Probability that at least one spill of any type and of volume greater than y litres occurs at a group of n ports	$P(S_{..} \geqslant 1) = 1 - e^{-m_{..}}$	(VIII.10)
Average volume spilled in all spills of type i at a port j	$Q_{ij} = \lambda_{ij} V_{ij} \bar{y}_i$	(VIII.11)
Average volume spilled in all spills of any type at a port j	$Q_{.j} = Q_{1j} + Q_{2j} + Q_{3j}$	(VIII.12)
Average volume spilled in all spills of type i at a group of n ports	$Q_{i.} = Q_{i1} + Q_{i2} + \ldots + Q_{in}$	(VIII.13)
Average volume spilled in all spills of any type at a group of n ports	$Q_{..} = Q_{1.} + Q_{2.} + Q_{3.}$ $= Q_{.1} + Q_{.2} + \ldots Q_{.n}$	(VIII.14)
Annual volume of oil spilled, at a port j, which is exceeded with probability α	$w_j = \gamma_0 + \gamma_1 V_{1j} + \gamma_2 V_{2j} + \gamma_3 V_{3j}$	(VIII.15)[a]

a. Table VIII.3 gives the appropriate values for γ_0, γ_1, γ_2 and γ_3. These values depend on port group and the required level of α. If the calculated value of W_j is less than zero it is to be taken as zero. (This is the case for a port in which the chance of one or more spills is less than α.)

TABLE VIII.3—COEFFICIENTS FOR CALCULATION OF UPPER CONFIDENCE LIMITS ON THE TOTAL AMOUNT SPILLED, BY PORT GROUP

Probability that the value is exceeded (α per cent)	Coefficient symbol	Port type: Capital city without a refinery	Capital city with a refinery	Non-capital city with refinery: Light	Non-capital city with refinery: Medium	Non-capital city with refinery: Heavy	Other: Light	Other: Medium	Other: Heavy
50	γ_0	-745	-2 540	-953	-1 031	-938	-144	-172	-100
50	γ_1	8	260	125	137	133	3	1	1
50	γ_2	5.60	6.64	5.4	6.0	5.9	2.93	3.1	2.6
50	γ_3	94	174	28	11	1	6	4.7	0.5
10	γ_0	151	1 273	-584	-281	-102	-558	-508	-435
10	γ_1	180	750	586	553	542	177	180	160
10	γ_2	13.1	11.2	16.9	16.3	16.3	17.7	17.5	18.0
10	γ_3	630	729	224	113	25	190	99	19.7
5	γ_0	1 830	6 000	580	712	769	-154	-77	-219
5	γ_1	270	960	880	820	820	320	340	340
5	γ_2	16.4	12.4	23	23	24	24.6	24.3	26.3
5	γ_3	1 120	1 180	410	210	50	397	206	44.3

APPENDIX IX—SIMULATION OF THE TOTAL AND AVERAGE VOLUME OF OIL SPILLED

A computer program was written to simulate the spillage of oil, using the estimated parameter values for the fitted distributions. The aim of the simulation was to put statistical bounds on the total amount of oil likely to be spilled per year and the average spill volume at a given port, for given amounts of oil cargo handled, oil bunkered, and total cargo handled. This problem was attempted analytically, but proved to be mathematically intractable, the main problem being the difficulty in obtaining the distribution of a sum of independently distributed lognormal variates.

The overall simulation consists of a program which produces yearly values of total oil spillage and average amount per spill for 10 000 years, followed by a sorting of these values into increasing order to obtain the percentiles of the simulated distribution. The 10 000 simulated total annual and average spill volumes were sorted into numerically increasing order, and the percentiles were read from the sorted file. That is, the 90th percentile was the volume represented by record number 9000 in the sorted file.

The 95 per cent limits on the average volume spilled per spill for 1979-80 are given in Appendix VI. Regression models were estimated to obtain the 95 per cent limits on the total volume spilled per annum.

REGRESSION MODELS FOR TOTAL ANNUAL VOLUME SPILLED

The combinations of port characteristics which gave rise to differing handling, bunkering and miscellaneous spill rates resulted in the eight overall port types listed in Table VIII.1. As shown in the table each of these types had a distinct combination of spill rates.

For each of the eight port types, simulations were performed as described above for between 64 and 125 combinations of values for the three exposure variables (volume of oil handled (V_1), bunker fuel throughput (V_2) and weight of cargo handled (V_3)).

The 50th, 90th and 95th upper percentiles (Y(50), Y(90) and Y(95)) of the total volume spilled per annum were recorded for each simulation of 10 000 years, as described above (that is for each combination of V_1, V_2 and V_3). Linear models, of the form given in Equation IX.1, were then estimated for each of the percentiles.

$$Y(50) = \gamma_0+\gamma_1V_1+\gamma_2V_2+\gamma_3V_3 \qquad \text{(IX.1)}$$

The regression process was performed for each of the eight port types for the 50th, 90th and 95th percentiles. The lowest coefficient of determination (R^2) in the 24 regression models (8 port types x 3 percentile levels) was 0.895 and only three R^2 values were less than 0.98. The γ values corresponding to port type and percentile level are given in Table VIII.3, in Appendix VIII.

It was mentioned before that a Poisson sum of lognormals cannot be examined analytically. The large number of simulations performed and the high R^2 values indicated that this approximate method was a very good estimate of these otherwise unattainable measures of the total volume spilled per annum at a port.

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LEGISLATION

Naviation Act 1912

Beaches, Fishing Grounds and Sea Routes Protection Act 1932-66

Pollution of the Sea by Oil Act 1960

Pollution of the Sea by Oil (Shipping Levy) Act 1972

Pollution of the Sea by Oil (Shipping Levy Collection) Act 1972

Navigation (Protection of the Sea) Amendment Act 1981

Protection of the Sea (Civil Liability) Act 1981

Protection of the Sea (Discharge of Oil from Ships) Act 1981

Protection of the Sea (Powers of Intervention) Act 1981

Protection of the Sea (Shipping Levy) Act 1981

Protection of the Sea (Shipping Levy Collection) Act 1981