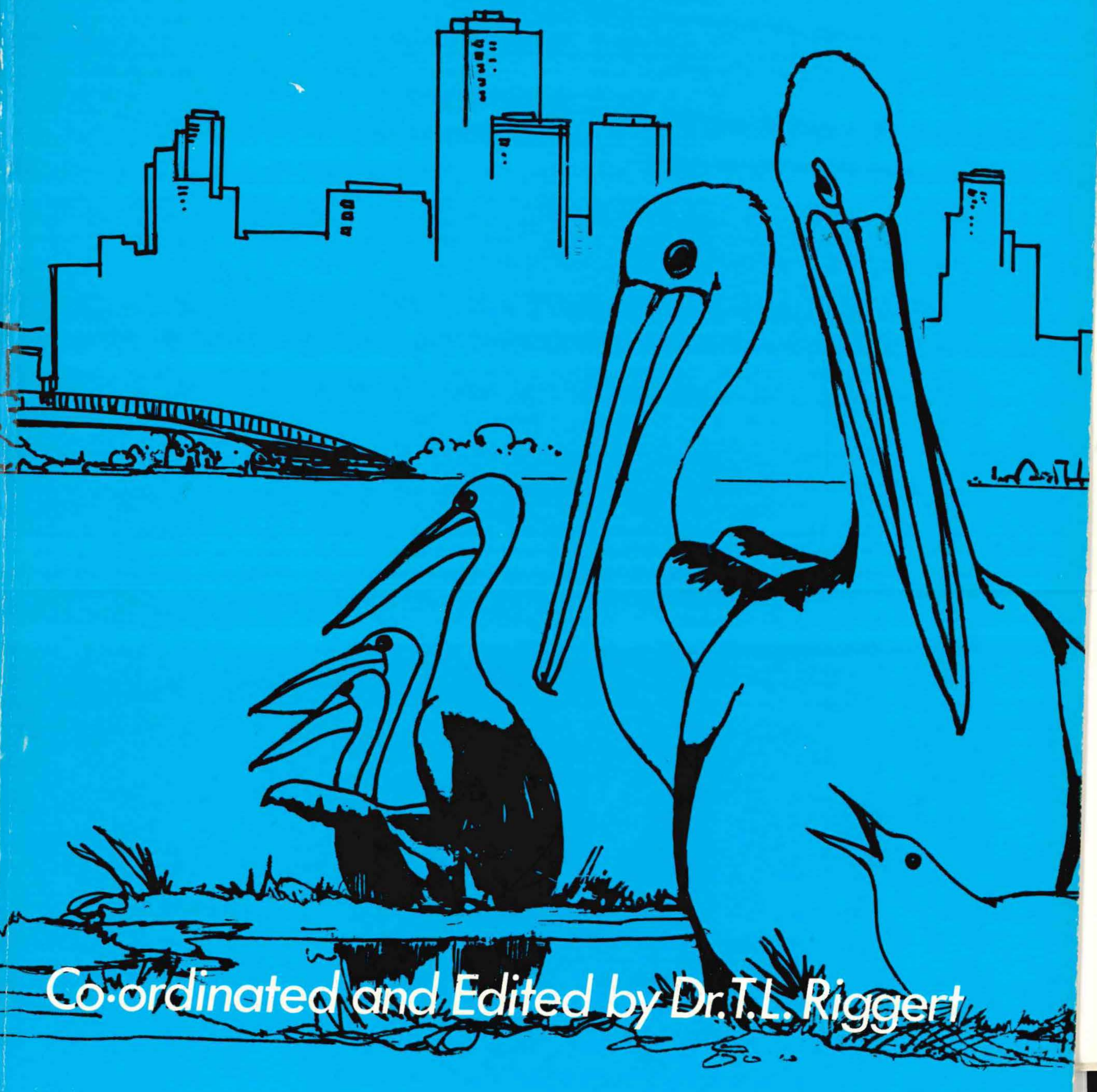
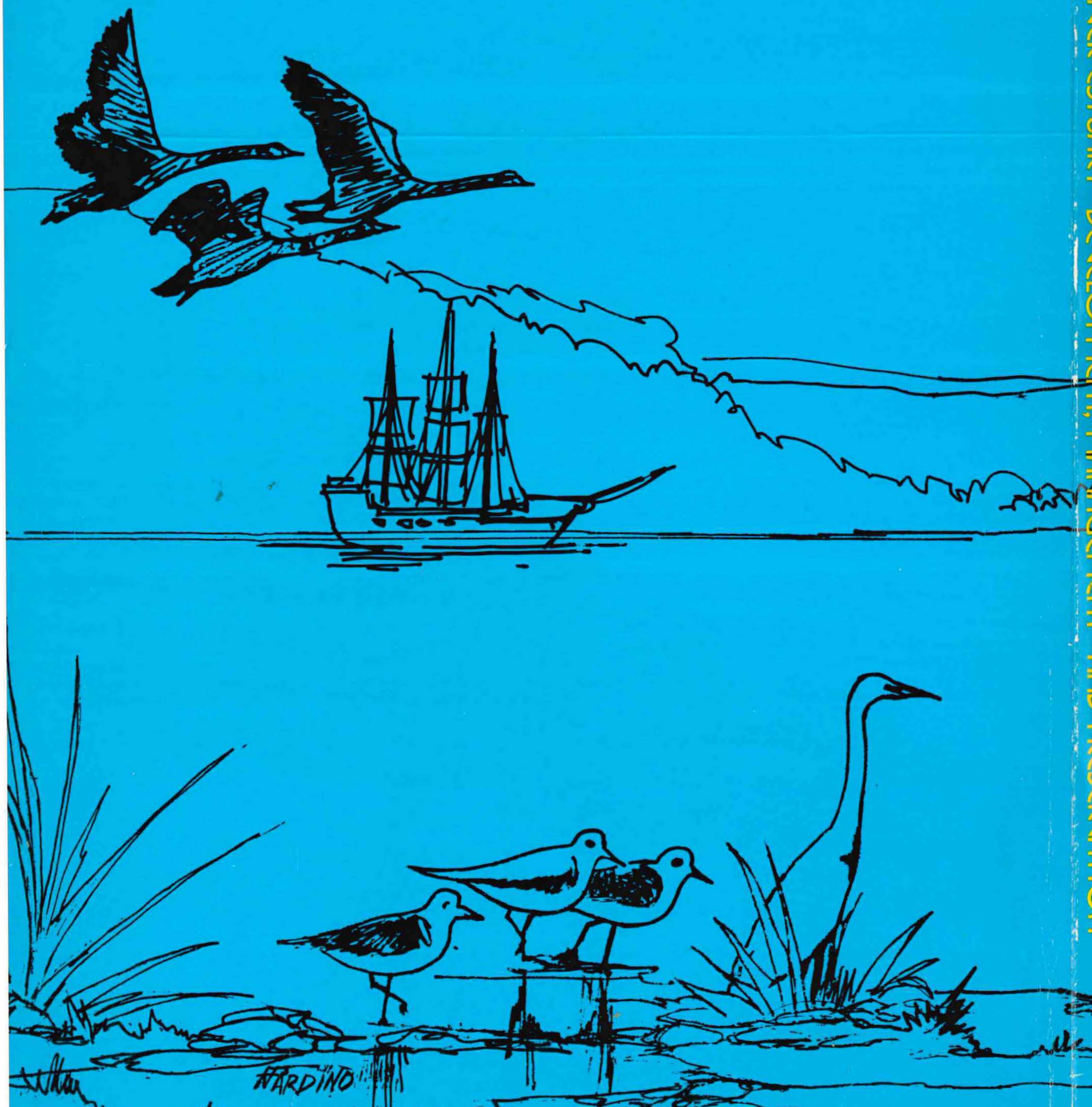
THE SWAN RIVER ESTUARY DEVELOPMENT, MANAGEMENT AND PRESERVATION



Co·ordinated and Edited by Dr.T.L. Riggert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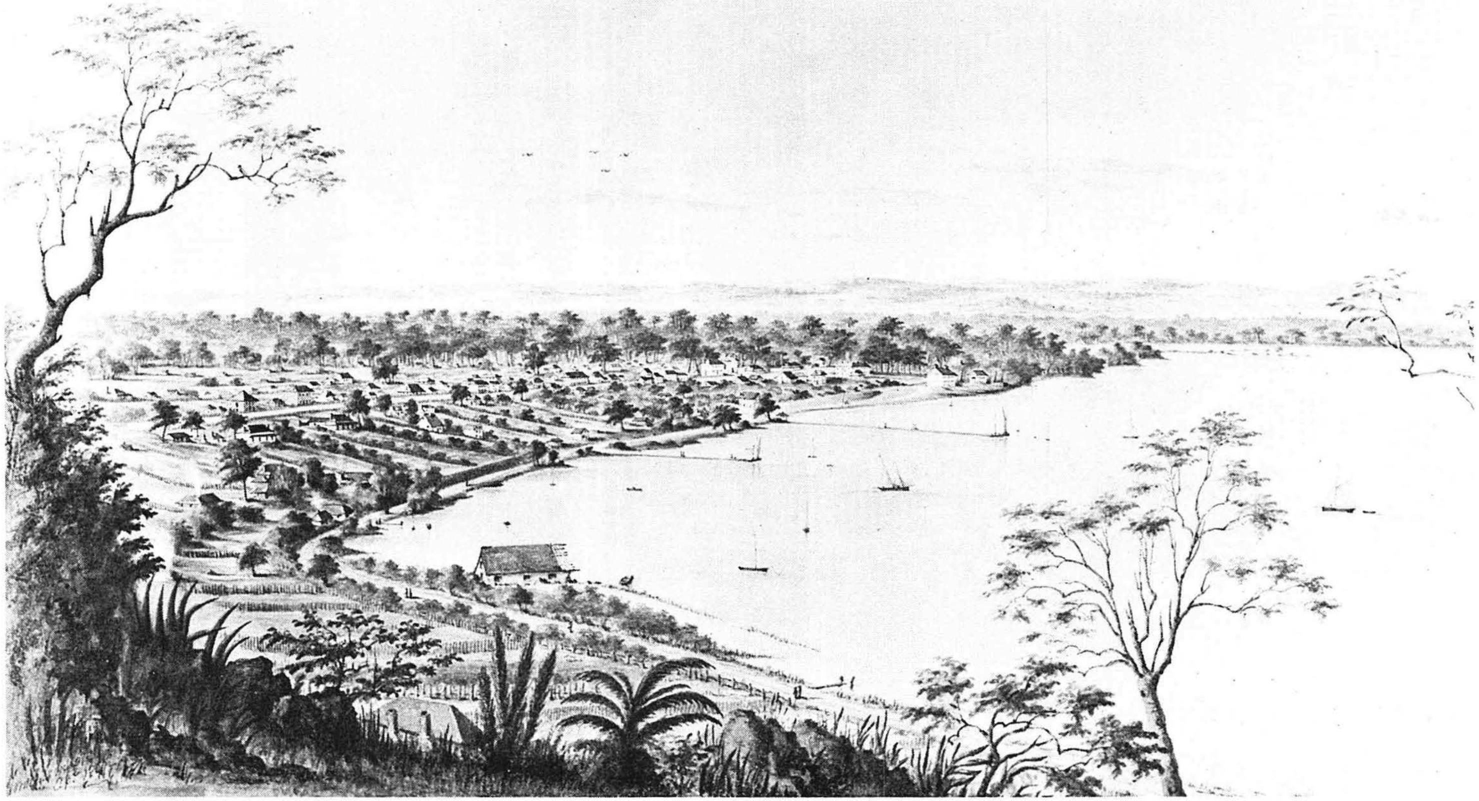

Swan River Conservation Board
1958-1976

The Swan River Estuary Development, Management and Preservation

Co-ordinated and Edited by
Dr. T.L. Riggert

Perth
Western Australia
1978

Frontispiece
Perth, Western Australia 1847 by Horace Samson
Collection: The Western Australian Art Gallery, Perth.

This book has been prepared under the auspices of the Swan River Conservation Board, Biological Committee.

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FOREWORD

Perth, the capital city of Western Australia, is dominated in its appearance by the Swan River Estuary. This estuary is extensively utilised, since it is the most readily available recreational area for over 800 000 people now living in the metropolitan region. The river has undergone many changes since the arrival of the first European settlers nearly 150 years ago. Unfortunately there are very few accurate records of these numerous changes.

The objectives of this research project were to have a thorough look at the Swan and Canning Rivers, to assemble information about the changes, and to attempt to establish the sequence of events that have taken place in the development, management and preservation of the Swan River Estuary. This work seemed timely as the Swan River Conservation Board, which had met on 209 occasions over 20 years, is now replaced by the Waterways Commission.

With the phasing out of the Board, it was possible that the policies and accumulated data could become lost and the public would not be aware of the efforts undertaken by the Government to manage and preserve the estuary. In this book an attempt is made to assemble scientific data and general observations accumulated by the Swan River Conservation Board during the period of its operations (1958-1976).

To provide the reader with sufficient information to show the complexities of managing this dynamic natural resource it was necessary to describe the physical environment as well as the biological characteristics of the estuary. It should be understood that this work is not a complete and detailed assessment of the entire physical, chemical or biological character of the estuary. However, great care has been taken to collect information which is based on scientific research and years of observations by persons working on the estuary or its inland tributaries.

This work is for the interested person, student and research worker to assist in formulation of ideas and to direct them towards those people or publications which deal in greater detail with specific items than it has been possible to present in this book. It is hoped that the publication will stimulate interest or further research into varying aspects of the Swan River Estuary and its tributaries, as much fundamental information is lacking on the river's ecology which is required for management decisions to preserve the estuary for future generations.

J.A. MATTINSON, O.B.E.
CHAIRMAN,
SWAN RIVER MANAGEMENT AUTHORITY

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INTRODUCTION

The first settlers to arrive in Australia, the world's driest continent, soon faced the reality of the country's aridity, hot temperatures and lack of permanent supplies of fresh water. This probably accounts for the pattern of settlement, favouring sites on the country's waterways, and this was the case with the establishment of the Swan River Colony in 1829 in Western Australia.

There is little wonder that the first settlers wrote such glowing reports of the fine river and surrounding foreshores, after surviving a hazardous and uncomfortable voyage through the Indian Ocean. The landscape seemed reminiscent of their homeland with its park-like appearances and green marshland bordering the river. Stirling, in 1827, on the first exploration upstream, remarks that as the party "advanced along the banks; its open forest-like character afforded no impediment to their march". Moore in 1831 described the Perth area as having "open plains that resemble well ordered parks" (Moore, 1884).

Early European impressions and later archaeological data have provided evidence of regular patterns of occupancy and hunting by the aboriginal people (Hallam, 1975). These people depended upon fishing in the estuary and game from the surrounding ranges. The game was attracted to areas of green vegetation which was encouraged by regular firing of the bush. This cycle of landuse by the aboriginal people accounts for the well-tended appearance of the land and the great abundance of wildlife.

The Swan River initially provided a sheltered and attractive site for the colony and natural food source for the settlers. The river was a convenient transport system that enabled people to move freely from the harbour at Fremantle to the settlement upstream.

It was soon apparent that the river was much different in character from the rivers of the northern hemisphere from where the first settlers came. The lower reaches of the river were saline and had a tidal influence while the upper reaches were fresh water, but the source of the river was in arid country with some of its tributaries being saline or brackish and only flowing after heavy rains.

Perth developed quickly into a business centre, with Fremantle as its port of trade. By the 1840s there was a booming export trade in kangaroo skins to the United States and timber to Britain. Other industries quickly sprang up along the banks and the role of the river changed from one of transport to being used as a water supply and drain for waste.

The rapid changes which occurred over the following 100 years of settlement not only altered the landscape, but brought changes to the biological character and water quality of the river. Many people in Western Australia became greatly concerned at the rapid deterioration of the Swan River and its foreshores. This concern led to the Government establishing the Swan River Reference Committee in 1943, to advise the Minister for Works on matters relating to protection and preservation of the river. This initiative paved the way for the passing of the Swan River Conservation Act in 1958 by Parliament to provide statutory power for the management of the river, and the Swan River Conservation Board was formed.

Through the last 20 years the Swan River Conservation Board has developed a management and conservation programme which has inspired all other conservation organisations responsible for a major waterway in Australia. This bold statement was confirmed by the Senate Select Committee on Water Pollution in 1970, which stated that "the composition of this Board is of interest as a model for a body controlling a stream system". In the following pages of this book it is our intention to describe the actions and policies which have been developed by the Swan River Conservation Board to preserve and manage the river prior to the proclamation of the Waterways Conservation Act of 1976, on 22nd July, 1977.

Chapter One

The Physical Environment

THE CLIMATE

The weather of the Swan and Canning River systems is controlled largely by the movement of the anticyclone belt. This has its east-west axis off the south coast in the summer, and moves northward across the State in winter to a position over the southern half of Western Australia.

In summer, easterly winds prevail over most of the State. The sun produces high temperatures in the north. This often results in a monsoonal depression which occasionally may extend cloudiness as far south as Perth. No matter how hot a summer day may be, reliable sea breezes refresh the hot summer afternoons along the river.

In winter the anticyclonic system moves northward, bringing clear skies and fine sunny days in the tropics, but on the southern side of the anticyclone, westerly winds bring cold, cloudy weather and rain. The westerly winds are strengthened by a series of depressions; low pressure systems with clockwise winds which move eastward to the south of the State, having originated in the Indian Ocean, and move along in a south-easterly path past Cape Leeuwin. The winds and rain of winter depend on the intensity and position of these depressions but between the lows there are fine bracing sunny intervals. As winter progresses the anticyclone system moves southward, until it lies with its axis south of the southern cross and summer conditions with easterly winds prevail once more. The westerlies are then too far south to have any influence on Western Australia.

Summer is warm to hot, and the winter cool and wet. The hottest month is usually February. The average number of days over 40°C per year is 1.5 and under 2°C is 0.3. The lowest recorded minimum was 1.2°C in July 1916 (Bureau of Meteorology, Perth, 1976). Ground temperatures just below freezing have been recorded.

Relative humidity is comparatively high during the cool winter months when it causes no discomfort. In summer, when temperatures are high, relative humidity is generally low.

Sunshine and Cloud

The Perth region has the highest number of hours of sunshine per year of any other Australian capital city. Cloudy days are rare, as shown by the figures in Table 1.

TABLE 1. Hours of sunshine in Perth based on 79 years of data.

Month	Sunshine (Hours)			
	Daily		Monthly	
	Possible	Normal	Possible	Normal
January	14.0	10.6	433.5	324.9
February	13.2	10.0	370.5	281.1
March	12.3	8.9	381.0	274.6
April	11.3	7.0	339.2	215.6
May	10.5	5.9	325.3	182.5
June	10.1	4.8	303.1	145.2
July	10.3	5.3	318.3	163.5
August	11.0	6.2	339.8	191.3
September	11.9	7.2	356.2	215.2
October	12.8	8.3	398.3	256.2
November	13.7	9.7	412.5	289.9
December	14.2	10.8	440.7	327.2
Year	12.1	7.9	4 418.4	2 867.2

Courtesy — Bureau of Meteorology

Rainfall

The gradual rise of the coastal plain causes a slight increase in the rainfall between the coastline and the base of the Darling Scarp. From the base of the scarp to the top, the winter rainfall increases by over 100 mm in 5 km. Once on the plateau, the rainfall decreases with distance towards the east. The rain falls mainly between the months of April and October; the wettest month is usually June or July. In Figure 1 the total annual rainfall for the 26 year period 1950-1976 is shown with monthly distribution.

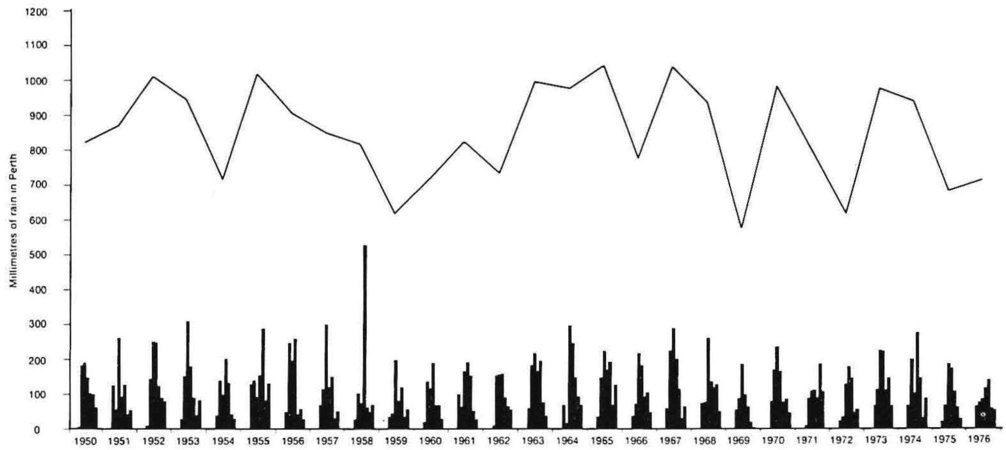


Figure 1. Rainfall for 1950-1976 showing annual total and monthly totals for April to October.

Wind and Inversions

In general terms, winds in the region of Perth vary from east to south-east in summer, with a reliable sea breeze being evident by about 3 o'clock continuing to the evening. The wind pattern of winter is much more variable, with east and north-easterlies changing to the stronger north-west winds which bring in the rain.

Wind rosettes for Guildford and Fremantle are shown in Figure 2.

The combination of temperature effects and turbulence gives rise to inversion conditions of two types:

(1) A surface inversion occurs at night when the ground is cooled, leaving a dense layer of cold air which may be a few hundred metres thick. In Perth this usually occurs on one in three mornings, especially in the spring and autumn following a clear, calm night. The inversion layer may also contain fog or mist.

(2) A subsidence inversion occurs when a high pressure system settles 1 500-2 000 m above Perth. This is a fairly common occurrence and frequently forms a 'lid' which traps smoke and other air pollutants beneath.

Dry Spells

The frequency of dry spells for Perth is shown in Table 2. The effect of a long dry spell is to increase the salinity of the water. The onset of winter rains has a great impact on the estuary after a period of drought by bringing in fresh runoff water and silt which adds a lot to the turbidity of the stream.

THE LAND

Landscape

The Swan Coastal Plain is flat but gently undulating country made up of two broad belts. The seaward part is made up of old dunes covered in vegetation, while the alluvial part of the plain to the east is wooded with taller trees which come down to the riverside.

Looking from the sea towards the east, the Darling Scarp rises to over 300 m above the plain. From the top of the plateau extends eastward to the wheat growing region. The Swan and Canning Rivers course through the ranges in valleys which have been cut down over millions of years. From the foothills of the scarp the estuary flows across the plain, opening into vast expanses of water such as Freshwater Bay and Melville Water. The river flows from here through the narrower Blackwall Reach, Rocky Bay and Fremantle to the sea. Limestone cliffs topped by scrubby vegetation rise from the water.

The navigator J. Lort Stokes (1846) noted in his log under the date 1837:

> "That arid appearance which first meets the settler on his arrival and to which allusion has already been made, cannot but prove disheartening to him, particularly if as is generally the case, his own sanguine expectations of a second paradise have been heightened by the interested description of land jobbers and emigration agents. However, when he ascends the river towards the capital, his feeling of despondency will gradually wear away; its various windings bring to his eager and anxious eye many a bright patch

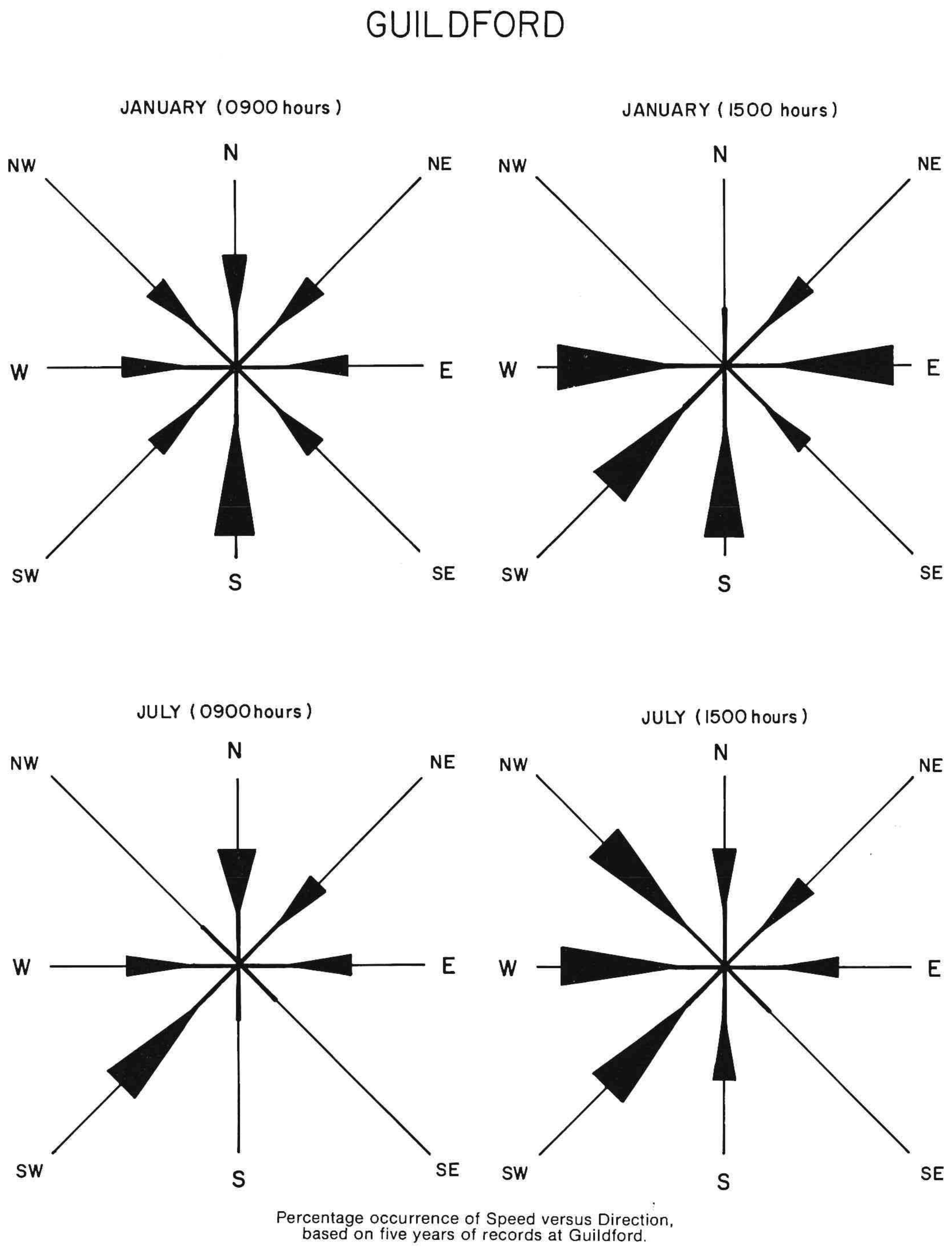


Figure 2a. Wind rosettes for Guildford for January and July at 0900 and 1500 hours.

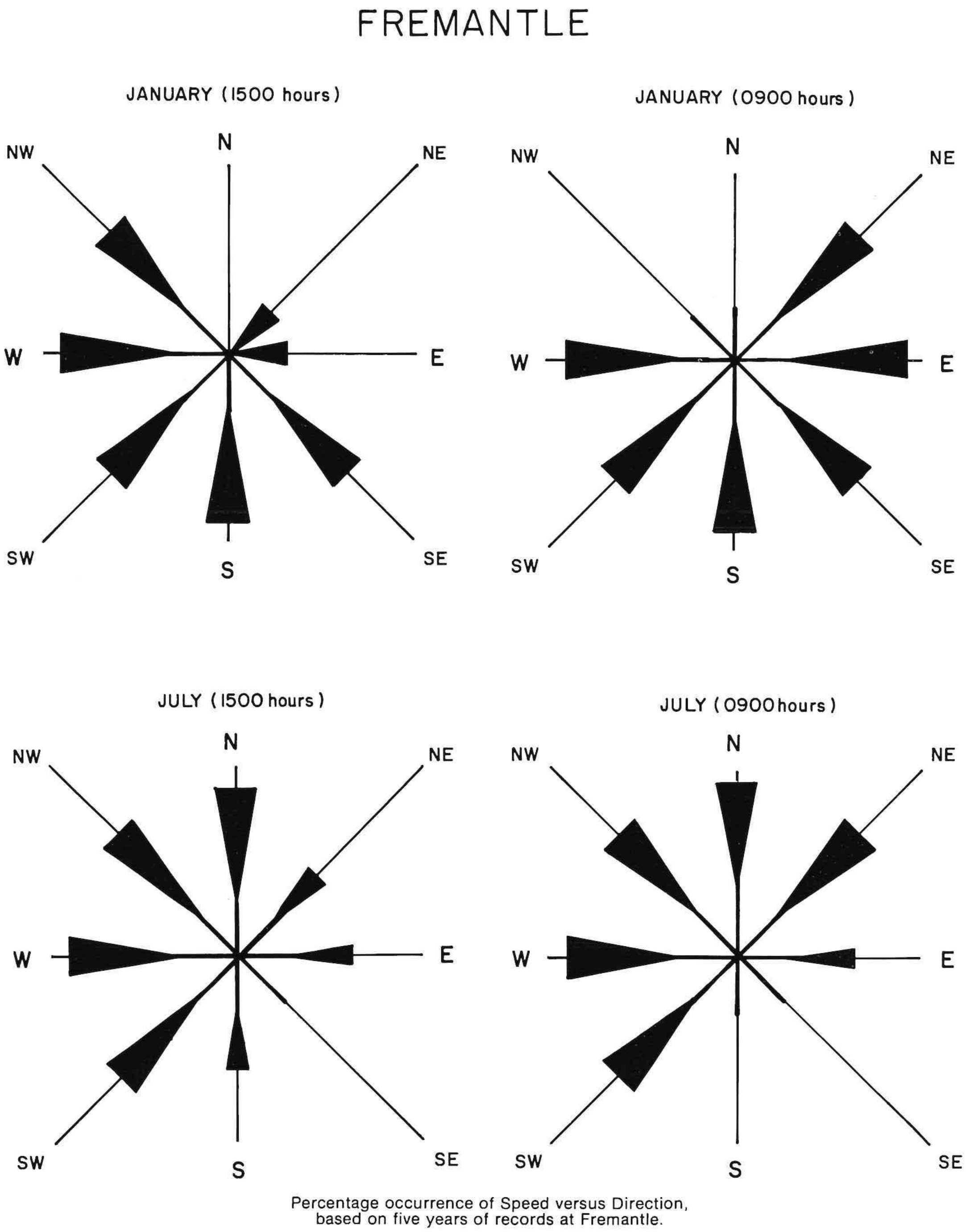


Figure 2b. Wind rosettes for Fremantle for January and July at 0900 and 1500 hours.

of park-like woodland. While the river expanding as he proceeds till the beautiful estuary of Melville water opens out before him, becomes really a magnificent feature in the landscape and the boats passing and repassing upon its smooth and glassy bosom, give the animation of industry and suggest all the cheerful anticipations of ultimate success to the resolute adventurer. From about the centre of this lake-like piece of water, the eye first rests upon the capital of Western Australia, a large straggling village, partly concealed by the abrupt termination of a woody ridge, and standing upon a picturesque slope on the right bank of the river, thirteen miles from its mouth. The distant range of the Darling Mountains supplies a splendid background to the picture and the refreshing sea breeze which curls the surface of Melville Water every afternoon adds to the health, no less than the comfort of the inhabitants."

TABLE 2. Frequency of dry spells — Perth, 1880-1964
(consecutive fine days)

Length in Days	Month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
6-8	19	24	34	48	53	42	30	33	43	54	45	39
9-11	21	15	20	25	16	8	10	7	15	25	39	19
12-14	20	8	20	9	5	1	3	2	3	10	16	17
15-17	18	16	15	7	2	—	2	1	2	6	11	16
18-20	12	14	14	8	1	—	1	2	1	1	7	10
21-23	8	8	5	3	1	—	—	—	—	2	6	7
24-26	3	5	2	4	—	—	—	—	—	1	4	5
27-29	8	5	3	—	—	—	—	—	—	—	1	5
30-32	1	2	1	—	—	—	—	—	—	—	3	2
33-35	4	1	1	—	—	—	—	—	—	—	3	6
36-38	6	2	1	—	—	—	—	—	—	1	1	1
39-40	3	1	—	—	—	—	—	—	—	—	—	—
41-45	—	3	—	—	—	—	—	—	—	—	3	1
46-50	1	1	—	—	—	—	—	—	—	1	1	2
51-55	—	3	—	—	—	—	—	—	—	—	1	—
56-60	2	—	—	—	—	—	—	—	—	—	—	—
61-65	2	—	—	—	—	—	—	—	—	—	—	3
66-70	1	—	—	—	—	—	—	—	—	—	—	1

Courtesy — Bureau of Meteorology

Figure 3 (see pocket inside back cover) is the Admiralty chart of 1896 showing the original form and detail of the river and the depth soundings recorded at the time.

Physiography

The Swan River is a typical estuary of the south-west region of Western Australia. It has a scoured channel which after expanding into broadwaters discharges into the sea over a sill or a sand bar. These systems are characterised by a seasonal pattern of river flow, which makes the river fresh at the surface in some winters and brackish or marine in summer.

The Swan Estuary receives fresh water from a catchment of 190 000 km^2. This area includes many small salt lakes in the wheatbelt district situated east of Northam. The Avon River, which becomes the Swan when it flows onto the Coastal Plain, has its main source at Wickepin. This is some 370 m above sea level on the Darling Plateau. From its source the river flows 288 km through the Darling Range down to the Coastal Plain.

The descent from near Toodyay to the plain is a gorge falling 127 m in 80 km, which rejuvenates the stream before it reaches the plain. The estuarine section is actually a drowned river valley zig-zagging for 50 km across the Coastal Plain to the Indian Ocean.

The major tributaries of the Swan River are the Dale River at the head waters, the Mortlock River below Northam Weir, and Toodyay Brook and Brockman River which flow in upstream of the Coastal Plain. Ellen Brook from the north, the Helena, Canning and Southern (a tributary of the Canning) Rivers all feed directly into the Swan River on the Coastal Plain. Several smaller brooks such as Wooroloo on the Avon and Bickley on the Canning contribute fresh water from surrounding wetlands during the winter months.

Geomorphology

The natural processes which have shaped the landform of Western Australia have been occurring for a long time. It is difficult to imagine the millions upon millions of years it has taken to shape the marvellous rivers and coastline of today. This landscape is truly ancient.

Playford, Cockbain and Low (1976) hypothesise that during Proterozoic time, when the earliest forms of life were evolving on earth, an extensive sea existed along the western side of the upthrusted Yilgarn Block. Great slabs of the earth's crust slid over each other at this time, but movement upwards of the block occurred during Ordovician or early Silurian (about 430 million years ago) and again during middle Triassic to early Cretaceous (200-100 million years ago). These movements may have been associated with continental drift.

Rivers flowing off the upthrust block deposited up to 15 000 m of sediments over this long period of time, and a further 500 m of sediment, including the Kings Park Shale, were laid down in the vicinity offshore of the ancient Swan River 50 million years ago. These sediments are described by Johnstone, Lowry and Quilty (1973). The old plateau is much eroded by river courses, and McArthur and Bettenay (1974) reported that the surface still retains a mantle of laterite formed during the warmer, humid Tertiary time about 65-54 million years ago. Since then sediments have been washed off the plateau and deposited in the valleys, most notably at Bullsbrook (Geological Survey of Western Australia, 1975).

The events which shaped the present Swan Coastal Plain took place during the last two million years, when sea level fluctuations caused the coastline to change position from the Darling Scarp to west of Rottnest Island. This is well illustrated by Seddon (1972). The region of the Swan River may be considered as made up of two main structural features:

(1) The Darling Range made up of granite and gneiss is more than 2 000 million years old. The original Fault is now a short distance west of the weathered scarp; the highest hills are farther east.
(2) The Swan Coastal Plain has been built up by various coalescing units. Foothill, lake, river and estuarine deposits were laid down west of the scarp (Fairbridge, 1954). At the same time fluctuating sea levels produced dune systems, beaches and estuaries which interfinger with the landward deposits. These are summarised by Johnstone, Lowry and Quilty (1973).

Geology

To describe the geology of the Swan River locality, it is necessary to understand that layers of rock are deposited during certain periods of time and have independent characteristics.

These distinct rock formations are known as 'geological units', and form a basis for describing the processes of sedimentation and erosion. Several geological units of the Kwinana Group described by Playford, Cockbain and Low (1976) form outcrops along the course of the Swan River. Their relationship to the river can be seen in Figure 4.

(1) Much of the Darling Range plateau is made up of ancient granite and dolerite rocks which are overlain by laterite soils. Colluvial deposits occur in the valleys of the Darling Range. The *Ridge Hill Sandstone* described by Prider (1948) and the more recent *Yoganup Formation* described by Low (1971) are believed to be leached and laterised beach and dune deposits of the early Pleistocene, and are at least two million years old. The granite rock and the latter two units can be observed at Walyunga National Park.

(2) The *Bassendean Sand* (Playford and Low, 1972) is formed of grey to yellow quartz sand, which probably represents aeolian dunes deposited in the middle Pleistocene (Kendrick, pers. comm.).

(3) The *Guildford Formation* introduced by Low (1971) interfingers with the Bassendean Sands. At the base of this formation, estuarine and shallow marine beds occur. These are overlain by intercalating beds of river origin. Two marine phases can be determined, one from 20 m below modern sea level to present sea level which contains fossil molluscs described by Darragh and Kendrick (1971). The other marine transgression occurred to 5 m above mean sea level with a different fossil

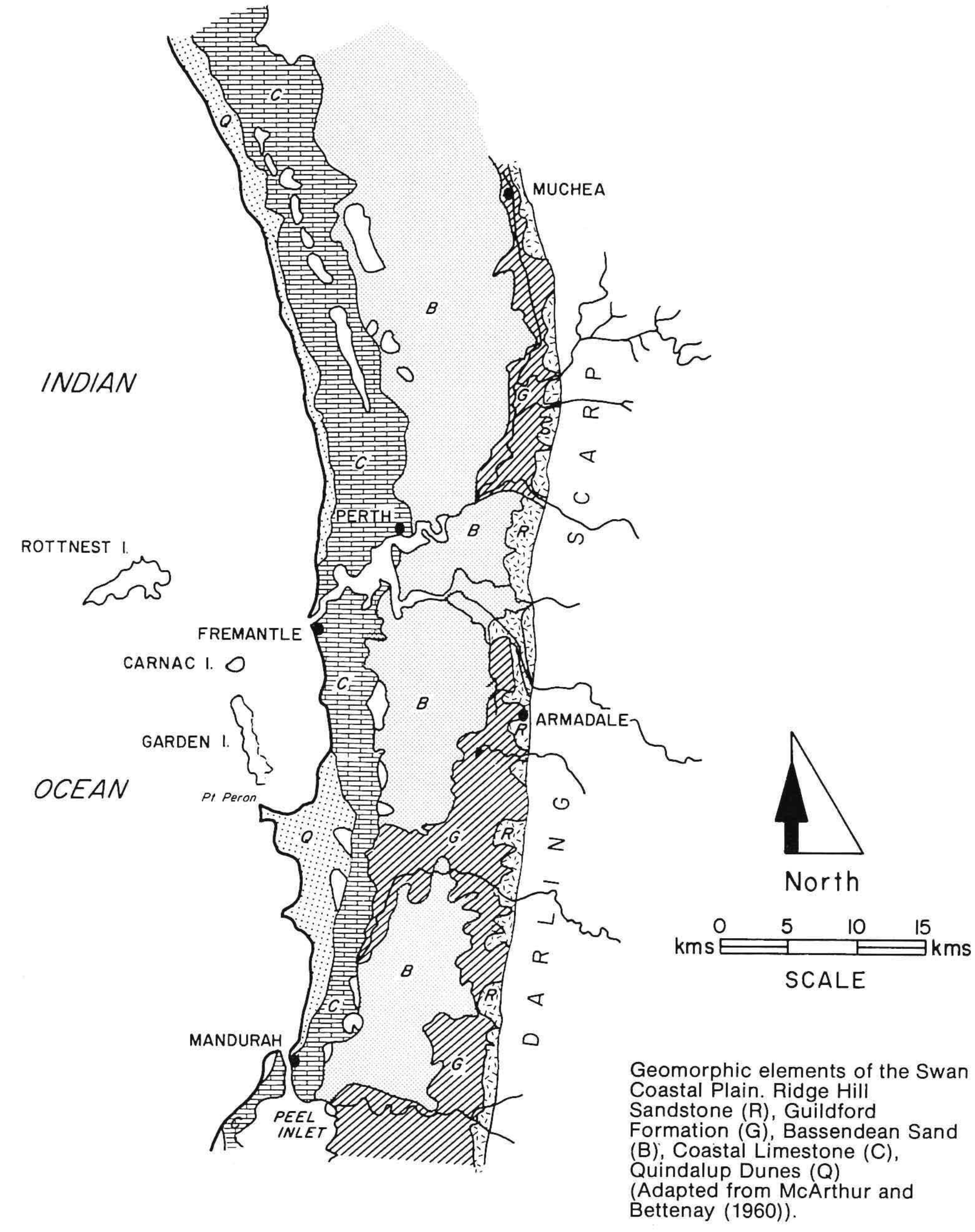


Figure 4. Geological units which outcrop along the Swan River Estuary.

assemblage described by Fairbridge (1953). All faunal studies indicate Pleistocene age.

(4) Several units occur in the coastal limestone and structures such as capstone, aeolian bedding, marine cross bedding, beach rock and fossil shell beds can be viewed along the river. Only some units have been defined and fully studied. The *Peppermint Grove Formation* described by Fairbridge (1953) containing fossil shell is similar to the deposit seen at the Combe in Mosman Park. Overlying these beds is the Tamala Limestone which has been studied by Logan (1968) and is probably dune and beach deposits.
This is the limestone which outcrops along the cliffs of the lower estuary. Tamala Limestone was formed about 10 000 years ago, before the sea was at its lowest level, at which time the mouth of the Swan River was just north-west of Rottnest Island.

(5) Evidence of the most recent, or Flandrian, transgression is seen at Point Waylen. Using radiocarbon dating of shell, Kendrick (1977) ascertained that 6 000-4 500 years ago the level of water in the estuary was 0.5 m higher than at present. The sea subsequently receded to its present level. During this time the recent *Quindalup Dunes* described by McArthur and Bettenay (1974) were formed by the processes of deposition which are still evident today. Recent alluvial deposits of silt and sand occur along the course of the river, and lagoonal deposits can be observed behind coastal dune systems.

Fossil Sites

To study the geological history of this region from fossil deposits, there are three main fossil sites. Each is related to a transgression by the sea and is listed in order of age, youngest to oldest. All these sites occur as natural outcrops on the foreshore of the river.

(1) At Point Waylen a raised shell deposit is evident on the extremity of a large bed lying beneath Melville and Perth Waters. This bed also extends up the Swan River to Midland Junction and up the Canning River to Cannington. These deposits are dated by Kendrick (1977) as Holocene, or within the last 10 000 years.

(2) In the cliffs at Minim Cove several lenses of fossil shell can be seen. This bed has minor extensions downstream in Blackwall Reach and upstream at Caversham. There is tentative evidence that other sites, e.g. Queens Park and Cannington, may be of the same age. These deposits indicate a large marine gulf centred on the present estuary for about 100 000 years. Fairbridge (1954) has described the fossil fauna of this marine gulf.

(3) The shell beds seen at Peppermint Grove and at Keanes Point are rather

more vague in extent; however, similar deposits occur on the western side of Mosman Bay and Blackwall Reach. The precise relationship of these sites to Peppermint Grove is not clear. These deposits occurred in a sheltered marine environment, probably blocked from the open sea by land barriers and reefs. These shell beds are described by Fairbridge (1954) and probably relate to an earlier transgression (Kendrick, pers. comm.).

THE RIVER

Hydrology

Hydrological investigations of the Swan River have been undertaken for many years by the Government and academic institutions in Western Australia. A summary of the unique hydrological conditions based on 15 years of study by Dr. E.P. Hodgkin is given below.

The hydrological condition of the estuary changes seasonally, the volume of the river flow being the principal factor that determines the hydrological status of the estuarine water. In the winter conditions the upper estuary is fresh throughout. However, in the lower estuary surface salinity varies from year to year between about 3 ppt (parts per thousand) in a wet year and 20 ppt in a dry year. Deep water in the lower estuary remains of seawater salinity and is cut off from the surface so that it becomes deoxygenated. With decreasing river runoff in spring, salinity increases again and a salinity gradient develops along the estuary and progresses upstream. In the full summer condition there is no effective river runoff, the lower estuary is of marine salinity throughout and there is a gradient along the upper estuary. The time and duration of these phases and the actual salinities experienced depend on the time of onset, duration and intensity of rainfall in the catchment.

Salinity

The estuary of the Swan River, like most estuaries, is a region of mixing between fresh water and sea water. The two waters are of very different chemical composition. For example, Avon River water contains about 50 times as much dissolved silica as does sea water, 3 000 and 50 ugSi/l (micrograms of Silica per litre) respectively. However, the hydrological component which is in greatest quantity and which most affects both the dynamics of the estuary and the life of its waters is the salt ($NaCl$). The salinity of sea water is 35 ppt, and by contrast water is only considered drinkable if the salinity is less than 6.5 ppt. Water is generally described as 'fresh' if the salinity is less than 3 ppt.

The density of sea water is so much greater than that of fresh water that the two do not mix unless some force is applied, such as wind stress to the surface or current flow, and waters of different salinities tend to behave as independent bodies of water. Temperature also affects density, but this is minor compared with the salinity effect. The resulting layers of water of different salinity is called a halocline.

The Swan Estuary and other estuaries of south-western Australia are unusual because the extreme seasonality of river flow causes the hydrological character of the estuary water to differ grossly between summer and winter. In summer the water of the lower estuary (downstream of Perth Water) is of seawater salinity while, in the upper estuary, salinity decreases progressively towards the head of the estuary, at All Saints Church, Upper Swan. Heavy winter rains, such as those of 1965, cause the whole estuary to be virtually fresh for several months (Figure 5). More often, while winter runoff flushes the upper estuary it is only sufficient to dilute surface water in the lower estuary or make it fresh briefly (Figure 6).

When runoff decreases in spring, sea water is 'pumped' into the estuary by the tides and it flows upstream beneath the still outflowing fresh water which it displaces because of its greater density. The two are gradually mixed by wind stress in the open water of the basin and the salinity of surface water increases. With continued decrease in runoff this mixed water progresses further upstream until the full summer condition is established.

Evaporation from the surface further increases salinity and estuary water is sometimes more salty than the sea. (The annual evaporation at Perth is nearly twice the rainfall, 1 678 and 883 mm respectively.)

It is relevant to note that the relatively high salinities often found near the head of the estuary in autumn result from inflow of river water rather than the mixing of fresh and sea waters. At this time Avon River water may have a salinity of over 5 ppt (Figures 5 & 6). Other tributaries to the estuary have a salinity of less than 0.5 ppt.

Temperature

Water temperature also changes seasonally, vertically and locally. In the lower estuary surface water is 12°-14°C in winter and 22°-24°C in summer. In the upper estuary the range is greater, from 10°-13°C in winter to 28°-30°C in summer.

More extreme temperatures are experienced in the shallows and it is here that the most dense populations of bottom living animals are found. The temperature inversion experienced in the upper estuary in autumn is discussed later in relation to the development of the halocline there (Figure 7). Solar heating in spring may cause a rapid rise in temperature of surface, low salinity water while the deep water remains almost unchanged (Figure 8).

Currents and Water Movement

The deep water of the basin is seldom if ever flushed out and in winter it remains as a pool of stale sea water overlain by a layer of low salinity water about 5 m thick; this is the depth of the sill at Fremantle (Figure 9). The change in salinity between the two bodies of water is often abrupt, with no mixing taking place across the halocline. In this stratified situation the deep water is isolated from the surface and little or no light penetrates to it for plants to

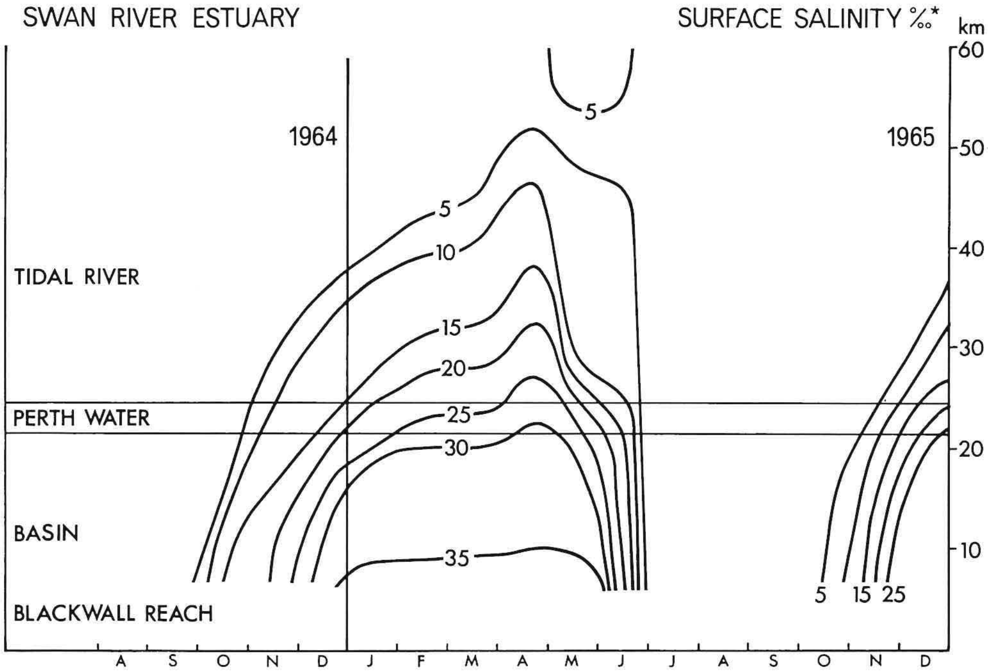


Figure 5. Surface salinity in the Swan River Estuary, 1964-65. *Courtesy — E.P. Hodgkin*

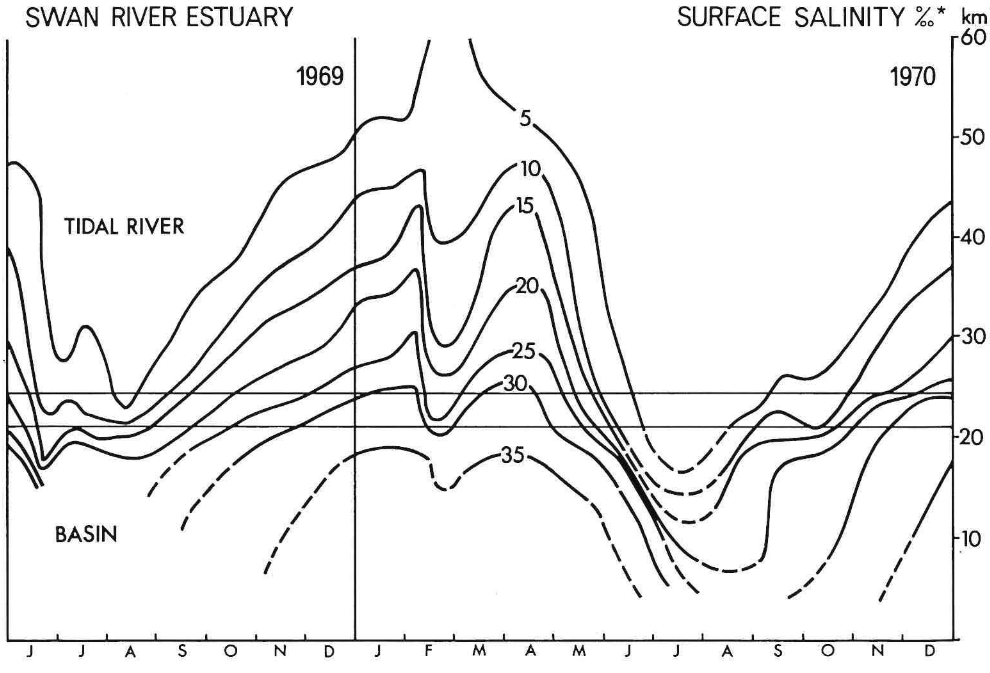


Figure 6. Surface salinity in the Swan River Estuary, 1969-70. *Courtesy — E.P. Hodgkin.*

* (ppt — parts per thousand)

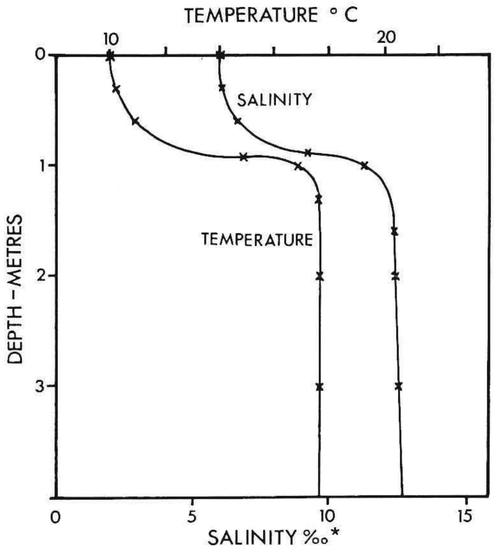


Figure 7. Temperature and salinity profiles at Middle Swan Bridge 1st June, 1964. *Courtesy — E.P. Hodgkin.*

photosynthesise and produce oxygen. It becomes deoxygenated as the result of biological activity.

This stratified condition is a normal late winter condition (July to October). Occasionally the deoxygenated deep water is pushed to the surface and catastrophic fish deaths occur as the result. The best documented of these happened in 1955, when fresh water from unseasonal rains in February flowed over the salt water and sealed it off. In April the deoxygenated water upwelled in Perth Water causing fish mortality there (Middleton, 1955).

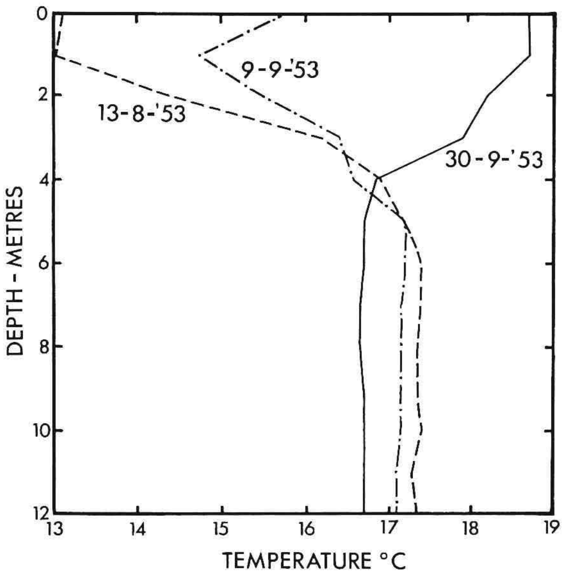


Figure 8. Temperature — depth profiles in the basin of the Swan River Estuary (off Applecross) during the recovery period, 1953. *After Spencer (1956).*

* (ppt — parts per thousand)

A similar condition sometimes develops in the shallower upper estuary as the result of more moderate rains in autumn (April to June). The anomalous situation then occurs of a layer of cold, fresh water lying on top of warm, brackish water (Figure 7). This is a common condition in other estuaries of the south-west, but the halocline is seldom so marked in the Swan, nor does it persist for so long. Again this results in deoxygenation of the deep water, a situation which is well documented by Jack (1977).

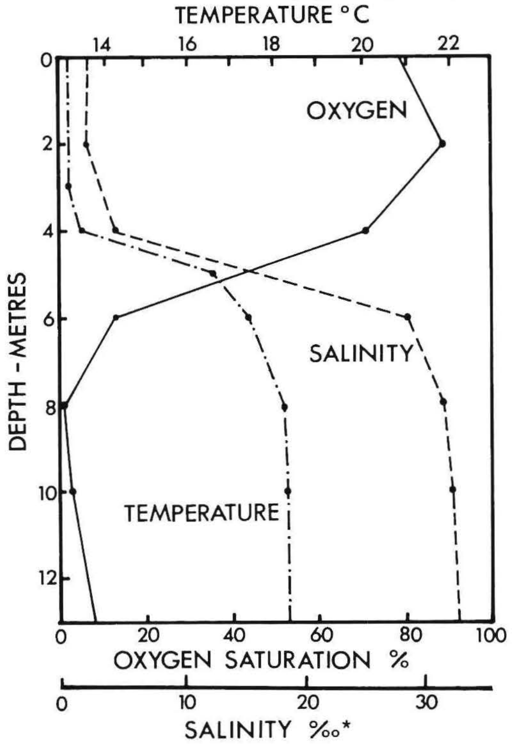


Figure 9. Depth profiles in the basin of the Swan River Estuary (off Armstrong Spit, Dalkeith). 1st July, 1953. *After Spencer (1956).*
* (ppt — parts per thousand)

Tidal movements also cause hydrological change. In Fremantle Harbour and Blackwall Reach fresh and sea water alternate over the daily tidal cycle when there is moderate river runoff. In contrast, in the upper estuary salinity fluctuation caused by tidal movement probably seldom exceeds 5 ppt at any point. Longer period variation (5-10 days) in water level, caused by changes of barometric pressure, may have a spectacular effect. For example, the passage of a low pressure system can cause water levels to rise half a metre or more. When such a rise is associated with the first heavy winter rains, fresh water is first banked up and then rapidly released when the barometer rises again and the water level falls. In these circumstances the estuary may change from its summer condition to the winter condition in a few days, with a drop of 20 ppt of salinity or more (Figure 10).

The lower estuary is sometimes described as being 'an arm of the sea' in late summer because the water is of seawater salinity. This is misleading, because salinity apart, the composition of the water is very different from that of the sea. For example, the silica content is at least ten times that of sea water. Silica is an important requirement for diatoms which are microscopic algae. Other plant nutrients are also in much greater concentration in estuary water, and in consequence there are often dense blooms of diatoms and other plant plankton.

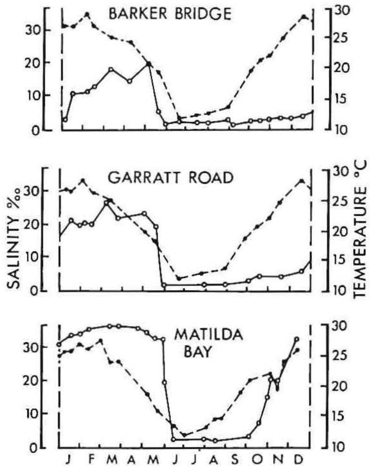


Figure 10. Surface water salinity and temperature at three localities in the Swan River Estuary during 1963. *After Wilson (1968).* Solid line — salinity; broken line — temperature.

Inflow to the Swan Estuary

The Public Works Department of Western Australia maintains river gauging stations at Walyunga, Wooroloo Brook, Ellen Brook, Jane Brook, Lower Helena River and the Canning River for the purposes of recording stream flow and monitoring water quality. The results of monitoring are given in Figure 11. The top section of each histogram represents flow from the Avon and the Brockman Rivers and Wooroloo Brook above Walyunga pools. This water is generally fresh. The middle section of each histogram represents inflow from the Darling Range, and Ellen and Jane Brook, which is sometimes fresh but generally brackish. The major contribution from the Upper Avon, Helena and Canning Rivers shown in the lower portion of each histogram is brackish water.

Thus the inflow of water to the estuary in winter is not really 'fresh' but brackish. There is evidence documented by Kendrick (1976) that the water of the Avon has become increasingly saline, particularly within the last 30 years.

Tides

Before the rock bar across the mouth of the estuary at Fremantle was removed in 1897, there existed a channel about 1.8-2.5 m deep and 15 m across the entrance. At low tides the rocky bar was visible as a broad crest, and as the tide rose, water would flow over it and through the narrow channel up the river. The tide in the river would have been influenced by the following factors:

(1) the ocean tide at Fremantle;
(2) fluctuations due to meteorological effects, and
(3) fresh water flowing down the river.

No reliable tidal information was kept by the Public Works Department before the 1930s, but it can be assumed that the mean tidal range at Fremantle was approximately 0.8 m as it is today (Wallace, pers. comm.). Notes on the chart of the Swan River from H.M.S. "Beagle", dated 1841 state:

> "The time of H.W. (high water) takes place at Perth during the summer months about 10 am on the F. and C. (full and changing moon) day at which time the rise is nearly a foot, in winter both the rise and time of H.W. are very irregular depending on the freshes down the river and N.W. winds at the entrance."

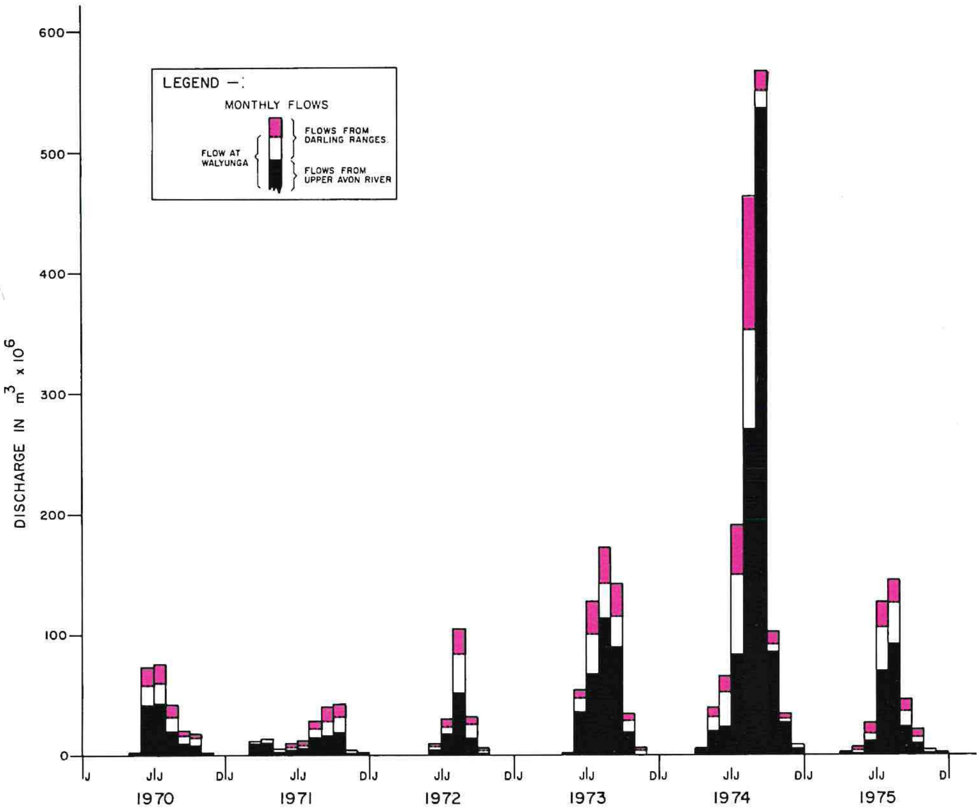


Figure 11. Estimated monthly inflow to the Swan River Estuary, showing the contributions from different sources. *Courtesy — P.W.D. (Water Resources)*

Thus the bar acted as a low pass filter so that an 80 cm rise and fall at Fremantle resulted in a 30 cm difference at Barrack Street. This is similar to the tidal situation at Peel Inlet where the sandy banks at the channel dampen the oceanic tide.

Fremantle Harbour was opened to shipping in 1897 and dredging of the harbour continued for many years. Canning Dam was completed in 1940 and Mundaring Weir in 1902 (added to in 1951 and 1959), so that freshwater flow to the estuary was reduced. The Railway Bridge at North Fremantle, which was totally removed in 1968, had acted as a submerged weir, distorting the lower levels of the tide and lessening the high water in the estuary. The outflow of water was also restricted and the boats could 'surf' down on the outgoing tide. Figure 12 shows North Fremantle Railway Bridge in 1868.

Figure 12. North Fremantle Railway Bridge 1868.

The graph shown as Figure 13 compares the tidal influence at Perth and Fremantle in 1962 and 1972, and clearly shows the effect of the removal of the

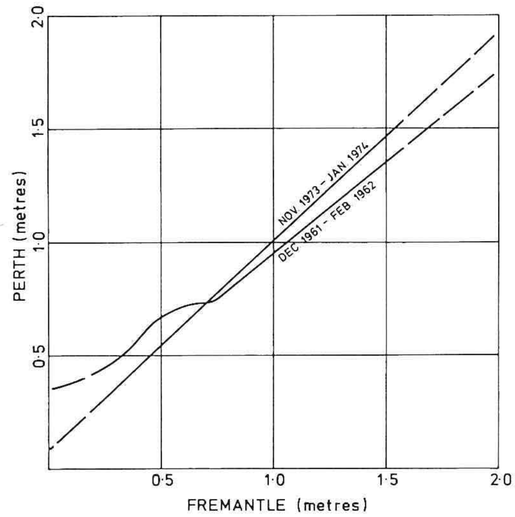


Figure 13. Comparison of the tidal influence between Perth and Fremantle for the years 1961-62 and 1973-74. *Courtesy — P.W.D. (Harbour and Rivers)*

old Fremantle Railway Bridge. In 1972 the tidal influence shows a linear effect, with mean tidal range at Fremantle, Mosman Bay, Perth, Woodbridge and Clontarf all being approximately 0.8 m. The tidal effect may be slightly attenuated by the restriction of Blackwall Reach (Wallace, pers. comm.). There is a time lag as the tidal wave moves up the river, and some seasonal variation of about 0.3 m which occurs in winter due to the north-westerly wind at Fremantle. The tidal influence probably goes as far as Upper Swan.

A recent find by the Public Works Department showed a rise in mean sea level of approximately 0.1 m between 1972 and 1973. Present studies will ascertain future trends, as preliminary evidence shows a rising water level in recent years. Tidal changes resulting from this will affect the stability of the river banks and location of some sediment deposits.

Sediments of the Estuary

Clearing of rich agricultural land in the Avon Valley has accentuated silt deposits in the estuary. Apart from this effect, most of the existing sediments have been deposited in the 18-20 m channel (Churchill, 1959) from the last glacial time. These sediments range in character from grey shelly sand to black gelatinous muds (Baker, 1951).

The light coloured sands consist of clastic grains and broken shell with low organic content. Sand is found in the lower estuary, around the foreshores to a depth of 1.5-3 m and on sand spits and sand banks of the middle and upper estuary. The sandy areas support large populations of fish and other wildlife.

The dark muds are made up of silt particles and organic matter. The electrolytic effect of saline water on the fine suspended sediment washed down from the catchment probably resulted in coagulation or flocculation of larger particles which then became deposited. The organic matter is of mixed origin and includes large amounts of faecal pellets (Quality, 1976). The silt smells of hydrogen sulphide and contains living molluscs. These muds are generally confined to the deeper and upstream parts of the estuary. Perth Water has a floor of deep dark mud which was analysed by the Government Chemical Laboratories in 1976, and it was found to contain several useful minerals such as kaolin and calcite, but the complex mixture and alkaline content make commercial utilisation difficult.

The grey silty sands are a mixture of fine and coarse particles which are probably derived from the offshore sea floor and relocated by tidal movements on to such areas as Karrakatta Bank in Freshwater Bay.

The submarine sand spits such as those at Point Walter and Preston Point are underlain by ridges of aeolianite which acted as buttresses against which river-borne sand sediments have been gradually built up. The shape and position of these spits indicate that they were formed during the last low sea level and have been deposited since then.

Floods

Floods are natural to the river. They were mentioned in letters written by

Figure 14. Hamersley's Pyrton Homestead in the 1860s collection: The Western Australian Art Gallery, Perth.

settlers as early as 1830, including a great flood at Guildford in 1872 (see Figure 14 of Hamersley's Pyrton Homestead). The outstanding floods in the recorded history of Perth are shown on Table 3. These floods often had distinct causes.

(1) Local or flash flooding occurs when metropolitan drainage systems are not capable of handling large volumes of water following sudden and heavy showers.

(2) Inundation of low-lying land, especially in the Bassendean and Guildford area, occurs following prolonged rain. Floods of this nature occurred in 1917, 1926, 1945 and 1955.

(3) Flooding in Perth and Fremantle frequently occurs due to a rise in the level of the river. This effect is severe if there has been heavy rain in conjunction with westerly winds or a high tide, as happened in 1946 and 1963.

In the past, people upstream at Guildford and Toodyay considered they had a flood if they had to move all their stock, and a big flood if the water stayed long enough to kill the grass, which could have been up to six weeks. The 1926 flood was memorable as it brought the North Fremantle Railway Bridge down just after a passenger train had passed over. At Guildford the river was 5 km wide and in one day 12 729 million litres of water crashed over Mundaring Weir. The vicinity of Mill Point resembled Venice as the locals went about their business in small boats. Passengers for the ferry service 'Mayflower' were transported across the flooded Esplanade on drays.

TABLE 3. Significant floods in the Perth area, 1830-1974.

Year	Date	Comments
1830 May		Swan 6.1 m above usual level
1847 July	7	Perth jetty and low land submerged
1857 Aug	18	All brooks and streams overflowing
1860 Aug		Low-lying land flooded
1861 June		Low-lying land flooded
1862 July		Widespread damage; 2-2.5 m of water over the Causeway
1863 Aug		Swan 3.7 m above usual level at Guildford
1867 Oct	4	Low-lying land near river flooded
1870		All river flats flooded
1872		Very large flood at Guildford
1889 Apr	20	Heavy rain flooded Market and High Streets, Fremantle
1904 June	25	River 1.5 km wide at Woodbridge; storm flooded Fremantle streets
1905 May	24	Three hour storm flooded low-lying parts of Fremantle
1905 July	7	Rain squalls flooded low-lying land
1906 May	28	Thunderstorm flooded low-lying parts
1907 June	19	Very heavy rain flooded low-lying Perth and Fremantle
1907 July	30	Low-lying land near river flooded
1908 May	20	Low-lying land near river at Perth flooded
1909 Aug	6	Low-lying land flooded at Guildford
1914 Feb	17	Heavy rain flooded streets of Perth
1915 Aug	8	Swan overflowed at Guildford during high tide and westerly gale
1917 July	17	Floods at Guildford; Northam flooded
1920 June	10	Perth and Guildford flooded by torrential rain
1920 Aug	17	Swan overflowed at Guildford
1926 July	21-23	Severe and widespread flooding; Fremantle Railway Bridge and Upper Swan Bridge collapsed
1928 July	18	Swan within 30 cm of 1926 level
1930 June	23	Swan overflowed at South Perth and Victoria Park
1930 July	9	Severe flooding; Swan at highest level since 1926
1931 Jan	6	North Fremantle streets flooded
1932 June	30	Swan overflowed; Mounts Bay Road, South Perth and Applecross flooded
1932 July	18	Mounts Bay Road, South Guildford and Crawley flooded
1933 June	27	North Fremantle streets flooded
1934 March	8	Swan overflowed at Guildford
1939 July	7	Swan overflowed at Guildford
1939 July	26	Canning overflowed at Gosnells-Kelmscott
1939 Aug	29	Swan overflowed at Guildford
1945 June	21	Severe and widespread flooding in Swan and tributaries; Perth Esplanade under water; river 3 km wide at Guildford
1945 June	24	Conditions around Upper Swan approached those of 1926
1946 June	24	Large area flooded at junction of Swan and Helena Rivers
1946 July	16-30	Severe and widespread flooding; Barkers Bridge covered; Riverside Drive covered; Garratt Road impassable
1955 Feb	18	Low-lying areas flooded at Guildford and Bassendean
1962 May	30	Riverside Road flooded at East Fremantle
1963 July	2	Swan reached highest level for 5 years and stayed high for 2 months; local flooding, especially Bassendean-Guildford area
1963 Aug	25	Serious flooding in eastern suburbs — families evacuated; conditions almost as bad as in 1926.
1964 July	13	River flooded roads in Bassendean-Guildford area
1965 July	7	Low-lying land flooded at Guildford
1967 May	8	Traffic chaos in Perth after 28 mm fell in 24 hours
1967 July	10	Perth roads awash from 19 mm in 1 hour (2-3 pm)
1967 July	28	30 vineyards flooded and 20 sheep drowned in Midland, Guildford-Upper Swan area.
1969 May	19	28 mm in 18 hours flooded low-lying land near the Swan; Fremantle streets flooded from 54 mm in 18 hours
1970 Feb	7	Cloudburst at City Beach

Year	Date	
1970 June	11	Severe street flooding in Mosman Park area from 82 mm in 24 hours, mostly from midnight till 3 am
1970 June	12	102 mm in 24 hours flooded Rockingham streets
1970 June	17	Worst traffic chaos in Perth's history 53 mm from 7-8 am; many 60 cm pools and a utility flooded to the windows in Subiaco Subway
1971 Oct	21	Midland streets flooded to 60 cm after thunderstorm
1972 Aug	25	Attadale streets flooded to 60 cm in rain/hailstorm
1973 Apr	28	Roe Street and Marine Parade, Cottesloe, flooded after 30 mm of rain in 24 hours (19 mm in 2 hours)
1973 May	12	City roads awash from 11 mm in 3 hours; races and trots abandoned
1973 July	18	Supreme Court Gardens flooded from 10 cm to 41 cm of rainfall in 24 hours
1974 July	25	Heavy morning rainfall (25 mm from 9 am-noon) flooded most suburbs; subways flooded to 30 cm; Riverside Drive flooded
1974 Aug	4	Severe flooding in Beckenham; roads covered for days, houses surrounded by water for weeks
1974 Aug	15	Swan, Canning and Helena Rivers in flood; Middle Swan Brickworks isolated; one Swan Valley barn covered to its roof

Courtesy — Bureau of Meteorology

It is unlikely that these extra big floods will occur again. The Helena and Canning Rivers have been dammed, reducing the volume of river flow. Extensive dredging upstream of the Causeway, downstream at Fremantle, and river training on the Avon, allow water to drain to the sea more rapidly. In recent years, there has been increased runoff due to clearing in the wheat belt and in the Darling Range. These conditions in time of high rainfall may cause short term flooding in low-lying areas.

Floods are devastating, though they have refreshing effects on the ecology of the river. Silt is deposited on the banks and swamps are flushed of accumulated weed and dead marine fauna from previous summers. In flood years the fresh conditions may last 3-4 months instead of the 10-12 weeks in a normal year.

Sediment Transport

The movement of sediment in streams is so complex a problem that it may never have a completely rational solution. The amount of sediment borne along will depend upon catchment conditions, intensity and pattern of rainfall, changes in the river bed and physiography.

Sediment moves in streams in two modes:

(1) as suspended load in the flowing water, and
(2) as bed load along the channel bottom.

These two processes are not independent, so that bed load may become suspended load or vice versa as the river changes velocity. A third process of sediment flow is 'saltation' which is rolling or bouncing along the river bed. In sampling sediment it is normal practice to add 10% of suspended load to give a total sediment load.

The total sediment load is expressed as tonnes per day, which when graphed against discharge, gives a sediment rating curve as seen in Figure 15. The accompanying sediment rating curve for Walyunga pools is based on

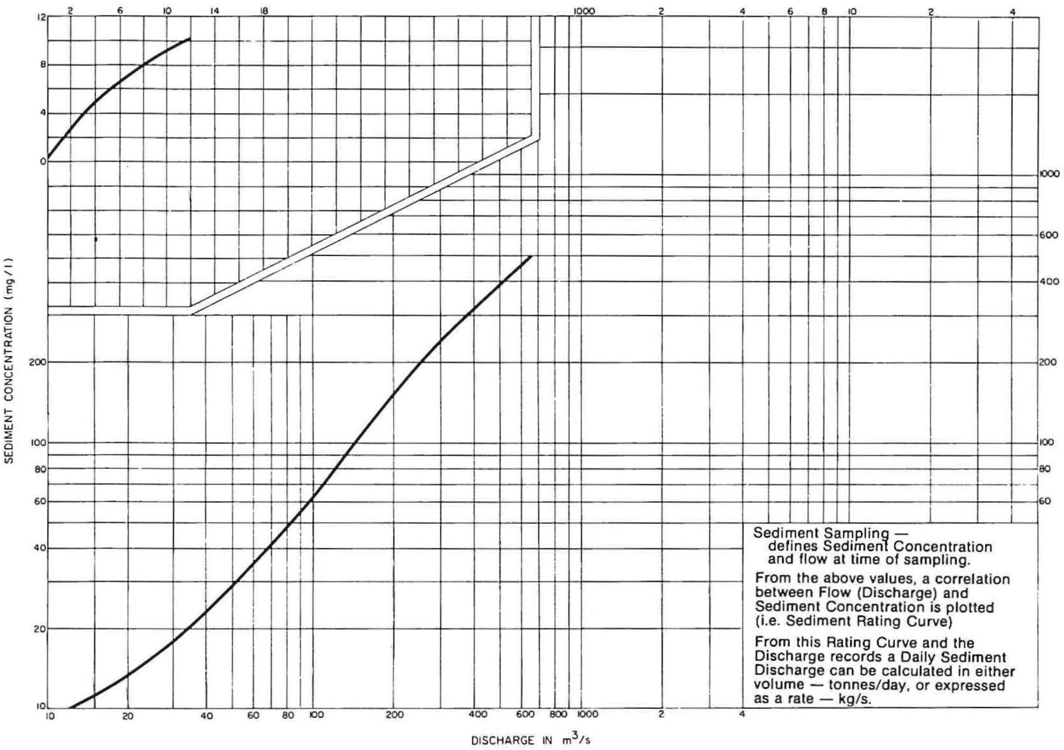


Figure 15. Sediment rating curve at Walyunga pools, 1970-1976 (logarithmic scale).
Courtesy — P.W.D. (Water Resources.)

sampling from 1970-1976. The Avon is the greatest contributor of water to the Swan. It appears that the finer material is being deposited throughout the middle and lower estuary as the river widens and slows down. The bed load moves more slowly, filling courses and pools as it proceeds.

Chapter Two

Works

CHANGES IN THE RIVER

With the arrival of the first settlers immediate alterations were made to mud banks and foreshores for navigational purposes. From that time, a series of major and minor works has changed the Swan River in many ways from its original state.

Initially the work was to aid navigation but subsequently it was to provide material for buildings and roads. Some of the largest works involved dredging, and though not visibly apparent, caused considerable changes to the river's currents, water flow and tide levels. The effects have not always been detrimental, and much of the environmental significance of these works is not fully understood even today.

In the following chapter information on the changes which have occurred through man's effort are presented, to enable the reader to gain a better understanding of the processes of change within the estuary and its tributaries.

Figure 16 (see pocket inside back cover) is a map which shows all dredging, reclamation and foreshore walling done by the Public Works Department up to and including 1976.

Early Navigation and Dredging

In 1827 Stirling explored the river as far as it was navigable in small boats, which was as far as Ellen Brook in Upper Swan some 56 km from the sea. Both Fréycinet of the French vessel "Naturaliste" in 1801 and the botanist, Fraser, in 1827 reported that their company had to drag the boats over the mud banks around and upstream of Heirisson Island. Governor Stirling had a channel cut through the banks at Heirisson Island in 1831. A small canal was also dug under Stirling's direction across the neck of Burswood Peninsula — this has only recently been filled in.

By 1833 a punt ferry service at the "Narrows" was operating between Perth and the Canning, for it was not until 1843 that the Causeway was spanned by a bridge. This added to the normal Perth-Fremantle river traffic which made the "Narrows" very congested.

The Canning River was not navigable upstream of Mount Henry due to snags, sandbanks and jutting rocks, except by small flat bottomed barges. During the 1860s the Canning River became the main outlet for the jarrah industry. Logs were drawn by bullock dray or tramline from the Darling Range to Cannington, necessitating dredging of the river from Salter Point to Riverton for the passage of large barges from Fremantle. New and larger landings needed construction.

These 'public works' were carried out by convicts who drove sharp jarrah stakes into the river bed along the proposed channel in order to construct a fence. The silt was then scooped up in buckets and deposited on the other side. Convict labour was withdrawn in 1869 and the channels quickly silted up, but were maintained later by the dredge "Black Swan". The timber industry from the Darling Range ceased by the end of the century and the Canning quickly silted up once more.

The Rocky Bar at Fremantle

Captain Fremantle of H.M.S. "Challenger" landed on the southern headland of the Swan River entrance on 2nd May 1829, and in the same year 21 trading ships arrived at the colony. Four years later, the colony was exporting wool; six years later, timber, and in 1845 the first shipment of sandalwood from the hinterland left for London.

From the very beginning there was the problem of ships' anchorage, especially when a north-westerly wind was blowing. The mouth of the river was blocked by a rocky bar, so that larger shipping had to use Gage Roads opposite the river mouth, or Owen Anchorage and Cockburn Sound to the south. Many vessels came to grief on "Success" and "Parmelia" banks.

In 1849 the first attempt to remove the rocky bar by blasting was made, so that small craft could enter the estuary. This work, which probably formed what was known as Trigg's Passage, was abandoned for lack of blasting powder.

Originally, Governor Stirling proposed a channel between the sea and Rocky Bay on the river. There were many other plans for a harbour at Fremantle, but most were considered too costly, too difficult, or likely to cause sanding up of the river.

In 1891, Mr. C.Y. O'Connor, Engineer-in-Chief to the State of Western Australia, presented a bold plan to the Governor, Sir John Forrest, which was completed in 1896. The plan necessitated the chiselling and blasting of the bar, building a north and south mole, and dredging a 130 m channel to a depth of 9 m. This process is shown in Figure 17. The channel and harbour were subsequently deepened to 11 m between 1914 and 1922.

The port facilities have proven to be a brilliant piece of engineering, as small tidal fluctation, lack of currents and littoral drift have not necessitated regular dredging. The inner harbour has been servicing ships of up to 45 000 tonnes for 60 years. Since 1956 the larger oil tankers and grain carriers have had to use Cockburn Sound facilities.

Use of Materials on Foreshores

Many of the 9 700 male convicts transported to the Western Australian colony between 1850 and 1868, were engaged in building some of the finest limestone buildings in Perth and Fremantle. The cliffs at Mosman Heights, Minim

Cove and north of Rocky Bay were extensively quarried for limestone. Even the scarp of Mount Eliza where Kings Park is situated was once quarried for building materials.

Inspection of the cliffs at Devils Elbow in Freshwater Bay and of Blackwall Reach shows the original condition of the beautiful foreshores which were admired by the botanist, Charles Fraser in 1827.

Seddon (1970) noted that the cliffs of Mosman Bay prior to quarrying in 1850 were probably once as steep and high as those in Blackwall Reach. The limestone blocks went by barge to Perth and were used in the construction of the old Perth Boys' School, the old Court House and part of Government House.

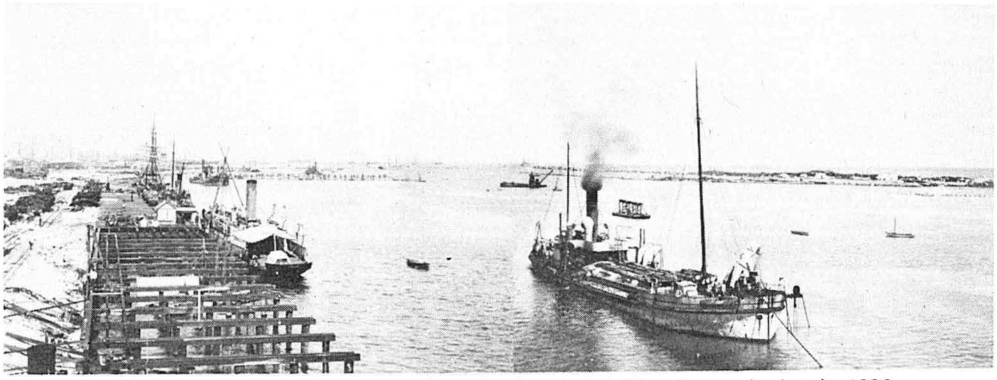


Figure 17. Workmen on scaffolding, blasting and drilling the rocky bar in 1896.

The hill at Rocky Bay in its original state is estimated to have been nearly 70 m high, but was levelled by quarrying. The sugar refinery, superphosphate works and State Engineering Works now occupy this position. This quarrying was in operation from 1890, supplying stone for the groynes at Fremantle Harbour, and later to the University of Western Australia and for the Fishing Boat Harbour at Fremantle. Quarrying at Minim Cove nearby, went on for a longer period as limestone from this area was used in the 1920s for construction of the Fishermen's Harbour at Fremantle, and later supplied all the river walling at South Perth and Riverside Drive.

These cliffs have been grossly modified, as Mosman Heights is severely eroded. Rocky Bay is an industrial site and Minim Cove is a municipal garbage dump.

Channel through Point Walter Spit

In the early days of settlement before the railway, the only road between Perth and Fremantle (as shown in Figure 18) was a treacherous one. The quickest form of transport was by boat. "In 1844, to save four miles in each return trip, a channel was dug through the Point Walter Spit close to the shore" (Weekend News 1.2.75). This channel was no more than 1.3 m deep, which was the draught of the river ferry, but not deep enought to encounter the limestone beneath the sand. There were problems associated with the channel, as it continually silted up and had to be frequently dredged. It was eventually abandoned and the spit returned to its original shape. The Admiralty Chart (Figure 3, see pocket inside back cover) shows the original position of the 'old' channel, which had presumably silted up by 1896.

Figure 18. The Perth-Fremantle road at the end of the last century. *Courtesy — West Australian Newspapers Ltd.*

DREDGING AND RECLAMATION BY THE PUBLIC WORKS DEPARTMENT.

The original dredging done between 1892 and 1896 involved the bucket dredge "Parmelia", and the suction dredges "Premier" and "Governor", in the formation of Fremantle inner harbour. Much of the sand spoil was used in the construction of Victoria and North Quays, while the rock was dumped on Halls Bank opposite Leighton Beach. By 1922 the harbour had been dredged to a depth that equalled the Suez Canal.

During the early part of the century numerous barges were using the river and it became necessary to dredge many shallow channels. This was done mainly by grab dredges working in the Canning River and in Perth Water, where there were channels dredged between Barrack Street, Mends Street and Coode Street. Later the channel through the Causeway was improved to relieve traffic congestion on the river.

The Swan River Improvement Act (1925) provided for the following works:

(1) improvement of the foreshore upstream of the Causeway;

(2) provision for reclamation of an island to be called Heirisson Island, and
(3) for reclamation of both eastern and western sides of Perth Water.

This work was designed to improve the river flow, eliminate the mosquito problem and canalise the river. For this purpose the dredge "Stirling" was purchased in 1928 and with the assistance of barge mounted dredges the work commenced in 1929.

For the years 1929-1950, with the exception of inactive periods during the financial depression and World War II, "Stirling" worked on the Swan River improvements and also the reclamation of Nedlands foreshore. Mill Point and Miller's Pool were filled in 1939. The dredge operated on Bunbury Harbour during the period 1950-52 and then returned to complete the Swan River improvements.

From 1954-59 the "Stirling" assisted by the dredge "Throsby", completed the programme of reclamation necessary for the construction of the Narrows interchange and the Kwinana Freeway.

Reclamation in Mounts Bay Road and Mill Point was 28 ha and 17 ha from Mill Point to Canning Bridge. In 1959, 4 ha of foreshore at Applecross was filled with dredged sand. The Main Roads Department required further reclamation for the Mitchell Freeway extension, which was carried out from 1960-67, assisted by the "Throsby". The "Throsby" also worked on the Canning River from 1960-64. The Shire of Canning paid royalties for the spoil and afterwards subdivided the area.

In the early and middle 1960s the "Stirling" carried out several large works of dredging and reclamation, mainly for improvement of yachting and other recreational facilities. This included work at Preston Point, Point Walter, the foreshore of Point Walter to Point Waylen and a rowing course for the Empire Games in 1962. The foreshore of North Fremantle was also improved to allow commercial usage and boat slips in the area.

In 1968, local authorities upstream of the Causeway required a dredge to 'clean out' the river bed and alleviate flooding. The problem for the "Stirling" was that movement upstream and downstream of Garratt Road Bridge was limited by tidal conditions, so that the dredge could only pass upstream between October and March. In 1968 the area between Bunbury Bridge and East Street, Maylands, was dredged to make more water available for yachting activities. In the period 1968-73, the "Stirling" worked intermittently upstream of Garratt Road Bridge, creating elevated recreational ground on the left bank, a navigation channel and an island at Garvey Park, as well as clearing sand from the mouth of the Helena River which was used to provide Guildford Grammar School with a playing field.

In 1968 the Belmont Park area was completed, and from 1971-73 the dredge worked on elevation of Maylands Peninsula by removing about 14 ha of the left bank. During these years other projects were undertaken at Nedlands, Point Walter and Point Waylen for yacht clubs and water skiing facilities.

TABLE 4. Summary of dredging by Department of Public Works, 1892-1976.

	cubic metres
Navigation	11 651 583
Construction	8 488 337
Flood control and foreshore protection cement	6 773 544
Mosquito control	3 636 929
Recreation	2 424 541

The summary presented in Table 4 is based on information in Appendix A1. This information is not absolute but has been extracted from the files and log books of the Public Works Department, Harbours and Rivers Branch, and gives a comprehensive summary of the work undertaken in dredging and reclamation over the past 84 years.

RIVER TRAINING AND FLOOD ALLEVIATION

The Public Works Department undertook river training on the Canning River in the 1930s and more recently on the Avon River, in order to reduce the risk of seasonal flooding. The Avon River is a braided river which had vegetated sand bars along the bed. During past floods, the river spilled over onto agricultural land and flooded the towns of Brookton, Beverley, York, Northam and Toodyay. In the 1930s there was pressure for the Public Works Department to remove silt from the river bed to alleviate the flooding. The floods of 1945 renewed public agitation, though the programme was suspended as the Shires involved would not agree to meet the costs of annual maintenance. Flooding in 1955 brought the Shires to agreement and in 1958 the Public Works Department began clearing downstream of Toodyay.

Clearing consisted of removing vegetation from the dominant channel to estimated flood width with a bulldozer and ripping the sand banks. By 1961 clearing had progressed to the Northam Weir, but Northam Town Council expressed concern about silting up of the reservoir and would not support any further clearing. In 1964 the Northam Town Council decided to replace the Weir and the clearing programme continued. By 1971 the river bed had been cleared to Brookton and to Aldersyde on the Southern Arm. Since then, annual maintenance has been carried out using a bulldozer and in later years with the weedicide, 2,4,5 — Trichlorophenoxyacetic acid.

Although the immediate benefits of river training were reduction of some flooding to private property, concern has been expressed at the long term effects. Clearing of the river bed and banks has accelerated movement of silt downstream, filling the once deep clear pools and destroying the summer refuges of many species of fauna (Kendrick, 1976). A local resident, Mr. Jim Masters, whose family has occupied property on the banks of the Avon River between Northam and West Toodyay for 67 years, has kept meticulous notes of his observations in this region of flora, fauna and climatic conditions for the period 1930-1976. The 46 years of records has enabled him to note changes in abundance of waterfowl in the district. His observations have led to the conclusion that destruction of river habitats and water salinity during this time have had the following results.

Black Duck *(Anas superciliosa)* has become greatly reduced in numbers, though the Grey Teal *(Anas gibberifrons)* has maintained its breeding population. White-eyed Duck *(Aythya australis)* has maintained its small numbers while the Blue-winged Shoveler *(Anas rhynchotis)* and the Chestnut Teal *(Anas castanea)*, formerly rare, are now even more so. The Mountain Duck *(Tadorna tadornoides)* and the Wood Duck *(Chenonetta jubata)* have become abundant species which depend on fresh water sources from surrounding farms. The Dusky Moorhen *(Gallinula tenebrosa)* has become scarce, while the Swamphen *(Porphyrio porphyrio)* and the Black Bittern *(Dupetor flavicollis)*, both formerly in moderate numbers, are now absent. The last examples show the extreme results of habitat changes since 1930 on the Avon River. Records such as these are of immense value to science, as they provide the only evidence of long term changes brought about by works on the river.

The engineering research section of the Public Works Department has ascertained that this large bed load of sediment has proceeded seven miles past Toodyay. Further data is necessary to establish the amounts and rate of flow of this material.

HISTORY AND NECESSITY OF FORESHORE TREATMENT

The major river walling was done before the Second World War. These structures were straight or freeform and designed without thought of the natural configuration of the river or of wind and wave energy. Consequently, walling has become the division between land and water, since formation of sandy beaches has been inhibited by the reflection of waves.

Early this century the river bank between Barrack Street and the Causeway was muddy with thick growths of reeds and introduced bamboo. The current idea of aesthetics was to 'clean it up' by walling with limestone masonry from the Causeway around to Crawley. The original section around Mounts Bay Road was filled during the construction of the Narrows Bridge. A fairly stable sandy beach now extends from the Narrows to Barrack Street.

In the 1930s use of limestone masonry was replaced by precast concrete slabs. This type of treatment was used on the foreshore from Nedlands to Armstrong Spit. Precast concrete walling placed from Queen Street to Mends Street in the early 1940s collapsed through foundation failure. This has been gradually filled and restored as a natural beach. A small section of foreshore from Ellam Street to Coode Street was never walled and is a fairly stable beach.

The whole of Mill Point foreshore was walled during the construction of the Kwinana and Mitchell Freeways, to prevent erosion by tides and waves during westerly winds and the encroachment of sand onto the Freeway. The area from the Narrows Bridge to the Canning Bridge, originally sandy with reeds, was replaced with dredged sand.

The foreshore upstream of the Causeway has been reclaimed on both sides by dredged sand and rubbish fill. On the eastern side of Burswood there is now an eroded limestone bund and shell bank wall and on the western side near Trinity College there is a shelly bank. The deteriorated appearance of this foreshore as far as the Bunbury Bridge is under consideration for rehabilitation.

From 1967-69 the north side of Goodwood was bunded 30 m from the foreshore and filled with sand and mud. Provision was also made for wetland rehabilitation along the river side of the bund wall. Similar treatment occurred on the east and south side of Maylands Peninsula from 1972-74. Both areas are still in the process of stabilising before being recolonised by plants.

A new wall of shell was constructed around Heirisson Island and was allowed to form its own natural slope. The last walling work was completed around Perth Water in 1975.

At present, foreshore walling is not popular, but the alternatives to walling to reduce erosion are not free from problems. Gabions or wire baskets filled with stone tend to abrade the limestone banks. Sandbags look unsightly, though those around the Western Australian natural gas line are becoming covered in vegetation and appear less conspicuous. See Figure 16 (see inside back pocket) for areas of foreshore with man-made banks and walls.

PAST POLICY OF PUBLIC WORKS

In the past, works downstream of the railway bridge at East Perth were related to improvement of waterways. This was done by dredging and reclaiming low-lying areas adjacent to the river, in accordance with the Swan River Improvement Act, 1925-1960. Flood control upstream of the railway bridge at East Perth was initiated mainly by local authorities.

Works of this nature were subsequently extended to include the improvement of waterways for both navigational and aquatic recreational purposes, and the elevation of low-lying land adjacent to the river for both active and passive recreation. The increasing need for motorways resulted in yet another requirement of the river in providing a source of material. This material was used for reclamation of river foreshores for roads and bridges.

In all cases of dredging and reclamation, the requirement was initiated by either local authorities or other government departments, with the Public Works Department acting as consultant, co-ordinator and construction authority. Feasibility studies carried out were oriented more to an engineering rather than an environmental aspect.

PRESENT POLICY AND DATA COLLECTION

Present policy of the Public Works Department is to carry out research investigation prior to any projects on the river being implemented. This is in response to the needs of future planning for Perth to ensure the multiplicity of uses of the river for the people of Western Australia.

Gauging stations at seven locations on the river are used to record stream flow and to monitor water quality (salinity) throughout the year. This data is associated with a much larger project to trace the history of landuse and changes in salinity of the river since European settlement. A study of sediment movement in the upper estuary, currently being undertaken, also uses stream flow data.

At present a research programme on flooding is directed to plotting flood recurrence intervals for 25 and 100 year periods on a map. The Metropolitan Region Planning Authority will not recommend any development within the 25-year flood boundary and only recreational use within the 100-year boundary. This data is at present available for the Eastern Corridor Development along the Canning River and should be available for the entire Avon River by the end of 1978.

New wave and tide measuring equipment is in use for a study which will help predict the changes occurring in the sea level. This data is necessary for the correct design of all engineering works along the Western Australian coastline and to anticipate the effect of water level changes in the Swan River Estuary. Data and analysis of tidal information for this study involve recordings from the entire State's coastline.

FUTURE ROLE OF PUBLIC WORKS

With the changing attitudes towards dredging and reclamation works on the Swan and Canning Rivers, a policy is evolving which rightly places a much greater emphasis on the environment and ecological aspects of these works. With the introduction of the Waterways Conservation Act (1976), it is likely that the role of the Public Works Department in connection with river works will change, to the extent that the planning and programming of works on the river and foreshores will be carried out by the Waterways Commission and Management Authority.

The public has become more concerned over the years with the preservation of the natural beauty of the Swan and Canning Rivers, and it is apparent that any moves to carry out further major dredging and reclamation projects in or adjacent to the river would be strongly opposed. There is strong opposition to the construction of rock and concrete foreshore walls, as it would tend to make the river look like a canal. It is apparent that future works on the river will need to be concentrated on the prevention and rehabilitation of foreshore erosion, particularly upstream of the Causeway.

Chapter Three

Formation of the Swan River Conservation Board

The necessity for some centralised control of the river became apparent with the upsurge of industrial activity and recreational needs of the community following the financial depression of the 1930s. In 1943 the Director of Works, Mr. R.J. Dumas, along with five other members, formed the Swan River Reference Committee. This was an advisory body constituted to co-ordinate works on the river and to deal with such problems as purity of the water and cleanliness of the foreshores. The committee was gradually extended to 15 members and all acted in a voluntary capacity. In 1952 the Swan River Reference Committee appointed a sub-committee consisting of the Deputy Commissioner of Public Health, the Chief Engineer of Metropolitan Water Supply, Sewerage and Drainage Department and the Deputy Government Analyst. Their terms of reference were to:

(1) define pollution;
(2) suggest methods of control.

The report of this sub-committee was published in 1955.

At this time the general public and news media were voicing their concern at the possible deterioration of the river through industrial waste and other forms of pollution. The consternation of the public is reflected in the cartoon which appeared in the Daily News in 1957 (Figure 19).

The deliberations by the members of the Swan River Reference Committee and most of the recommendations put forward by the sub-committee formed the basis of ideas which were used in the drafting of the first legislation for the conservation of the Swan River.

The initial Act, Swan River Conservation Act (1958), has proved a workable and effective piece of legislation. At the time this legislation was the first of its kind in Australia and was framed to give the Board wide powers, subject to the Minister for Works and Water Supplies and to appeal to the Courts. Regulations were approved by Parliament in May, 1961.

In 1964 the area of control on the Canning River was extended from Kent Street Weir to Nicholson Road Bridge, and in 1966 the Act received two important amendments which were as follows:

(1) The membership was increased from 17 to 19 to include a biologist nominated by the Minister for Fisheries and Fauna and an additional member to represent the Local Government Association in the Canning River area.

(2) In addition to Board approval it was necessary to obtain parliamentary sanction in order to reclaim any area in excess of 2 acres (0.8 ha).

These two amendments followed the public outcry and concern after reclamation of the river for the construction of the Narrows Bridge interchange resulted in the river and foreshore being turned into two large car parks.

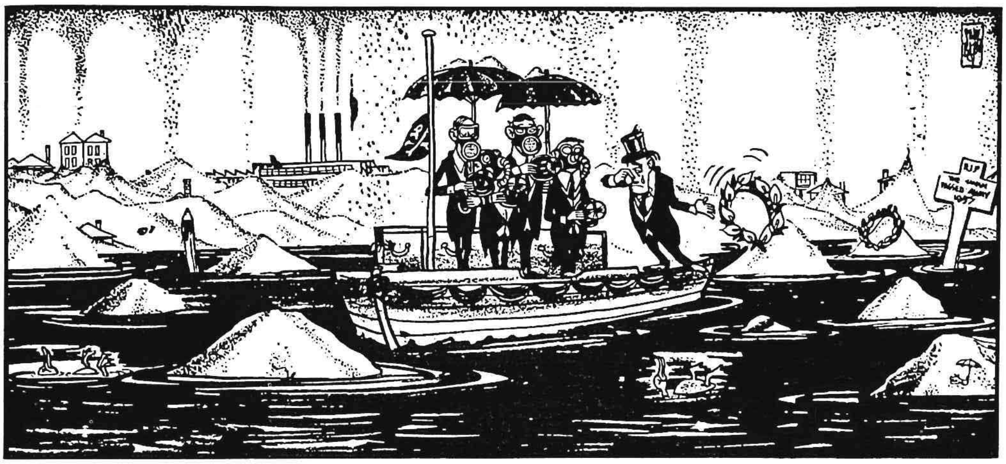
At this time the boundaries of the jurisdiction of the Swan River Conservation Board were:

(1) Swan River to Fremantle Traffic Bridge upstream to Middle Swan Bridge.
(2) Canning River to Nicholson Road Bridge.
(3) Helena River to Scott Road Bridge.

In the following years many agricultural 'intensive feeding' businesses were operating upstream of these boundaries and caused concern to the Board. The Proclamation of 7th July, 1971 extended the boundaries:

(1) To the confluence of the Swan, Avon and Gatta Rivers.
(2) Lower Helena River Diversion Weir.
(3) Brookton Highway Bridge on the Canning River.

ON A NATIONAL HERITAGE



". . . and so it is with regret that we say farewell to the beautiful Swan — rich in rare perfumes and rubbish dumps."

Figure 19. Rigby cartoon 1957. *Courtesy — West Australian Newspapers Ltd.*

The purpose of the Act was to maintain the waters and foreshores within the boundaries in a clean and pure condition. The legislation provided control over reclamation and structures on the river and foreshores. Any industry using river water or discharging effluent could only do so under the authority of a permit issued by the Board. Penalties were prescribed for those who polluted the water, undertook work, discharged without a permit, or did not conform with the conditions set out in the permit.

Under these amendments to the regulations the Swan River Conservation Act of 1958-1975 operated its statutory powers until this Act was repealed on 23rd March, 1977.

Swan River Conservation Board and Sub-Committees

The activities of the Board were based on co-ordination of effort and co-operation between a number of government departments and local authorities holding interests in the river, its uses, improvements, public jetties, bridges and the purity of the water for recreational purposes. The Board probably achieved more by co-ordination of effort than through its own direct projects.

The Board consisted of an independent chairman, 18 members and staff. Staff consisted of a secretary, 2 stenographers, 4 inspectors, 3 field hands and a mechanic. Casual labour was occasionally engaged, though most heavy or emergency work was done with the co-operation and assistance of the Public Works Department and all the local authorities. The Chairman formed a link between the Board, the staff and the various committees. The committees had defined areas of responsibility and each operated within Board policy.

The committees were as follows and each met at least once a month:

Works and Structures
Industrial
Planning
Biological

Works and Structures Committee

Applications by government or private interests to carry out works such as jetty structures, bridges or dredging required a permit from the Board. The Works and Structures Committee considered such aspects as quality of the proposed structure, aesthetics and location. The permit to carry out structural development was issued only on the recommendations of this committee to the Board. All proposals had to be accompanied by a properly produced plan and conform to engineering standards approved by the engineer of Harbour and Rivers Branch of the Public Works Department.

The Board set a high standard and each application was treated on its merits. All jetties and boatsheds were licensed annually and before a licence was renewed the structure was inspected. There were a great many dilapidated and sub-standard structures when the Act came into operation. Many of these have been demolished and others have been brought up to standard. Licences for new structures to private individuals were issued on a very restricted basis and priority was given to yacht and boat clubs wishing to improve their harbour facilities.

The Board also examined closely each request for dredging and associated reclamation. Some of the minor work such as dredging for beach renourishment was initiated by the Board and undertaken by the Public Works Department. Major schemes arising from suburban development and involving more than 0.5 ha of reclamation required the approval of Parliament.

Industrial Committee

The policy of the Swan River Conservation Board was to reduce the amount of industrial waste discharged into the river and improve the quality of that which was being discharged under permit.

When the Board commenced operations a considerable number of industries were discharging wastes, including cooling water into the river. It was necessary for these industries to apply to the Board for a permit to discharge. The permit application was required to contain details of the chemical analysis of the waste. Over the years many of these industries have diverted their waste to other points. Most of the diversions have been to sewer, but some have been used for spray irrigation. For the industrial waste that had not been diverted from the river, it was Board policy to insist on improvement of the quality of the discharge which in some cases required treatment before it could be released into the river. The Board did not rigidly oppose the entry to the river of industrial wastes from new industries, but considered each application on its merits. In each case the Board applied the following criteria:

(1) The possibility of other places to discharge waste, e.g. availability of sewer or an alternative site for the industry in a sewered area.
(2) The treatment of industrial waste to avoid polluting the river.
(3) The volume and quality of the water discharged to be controlled and maintained.
(4) The flow of the river at the point of discharge to be sufficient for effective dilution of the volume of waste.
(5) The discharge to the river of sewage wastes, treated or untreated, to be refused.

Planning Committee

The river is an integral part of the city and suburban development. The population growth, expanding industrial activity and the ever increasing problem of provision of road systems to handle the traffic, all have some direct or indirect effect on river purity and usage.

The Planning Committee of the Board had this problem constantly under review and combined with the Metropolitan Region Planning Authority, the Town Planning Board and the Town Planning Department to ensure that adequate public space was reserved on all foreshores. At the request of the Board many areas of foreshore have been purchased for future public open space; others have been incorporated in a plan and will be acquired when opportunity and finance permit.

Biological Committee

This committee considered sources of possible pollution which may affect the ecological or biological qualities of the river and its foreshores. Special consideration was given to proposed sanitary landfill sites or industrial waste disposal areas which can produce leachates or other contaminants that find their way to the river via groundwater, storm water, wind action or human negligence.

The Biological Committee was required to furnish additional information to the other committees when there may have been a direct influence on the river's ecology as a result of a proposed project.

Initiation of long term surveillance studies on the river which would aid in furnishing background information for an environmental impact statement associated with major works such as highways, traffic bridges, marinas and dredging, was an important undertaking of this committee.

Inspectorial Staff

The Swan River Conservation Board employed four inspectors who were responsible for maintaining the waters and foreshores in a clean and tidy condition. The staff had the use of a building on the foreshore where the vehicles, boats and other heavy equipment were kept and maintained.

Each inspector was associated directly with a committee, thus allowing specific actions to be undertaken by the inspector on a continuing basis. The success of the work, however, depended upon liaison between all the staff, to share information and co-ordinate programmes. Forward planning was of great importance, as factors such as tide levels or the presence of summer swimming classes caused great difficulties in the performance of the inspectors' beach maintenance duties.

All inspectors worked on general details such as cleaning up rubbish on foreshore areas. This became more time consuming each year as the amount of discarded rubbish was compounded. Other general duties were desnagging the river and transplanting vegetation. Of particular importance were the regular reports submitted by each inspector to the committees and the Board, thus maintaining an up-to-date liaison between the Board, industry and the general public.

Water Sampling

Since 1948 the river has been systematically sampled for chemical and bacteriological analyses.

Water sampling was done by the inspectorial staff quarterly and it was ensured that this did not occur in the same month each year by rotating the sampling periods. Samples were taken from a boat at 49 locations between Wooroloo Brook and Fremantle Traffic Bridge. Sampling was done with the assistance of a chemist from the Government Chemical Laboratories, who recorded temperature at each location and a separate sample was taken for bacteria to be analysed by the Public Health Department. The water samples were analysed by the Government Chemical Laboratories and the results are described in Chapter II.

The purpose of the sampling was to determine the presence of pollution. The results were considered by the committees and if pollution was present the inspectorial staff undertook further investigations.

Sampling was also undertaken by the Public Health Department for the purpose of monitoring the purity of water in swimming areas. Each month 37 locations were sampled from the shore. The analysis of these areas was of considerable use to the Board to determine presence of sewage or other organic pollution which could be detrimental to the biology of the river, or present a health hazard to swimmers.

Chapter Four

Flora and Fauna

NATURAL HISTORY DISCOVERY

Every traveller from the earliest times has expressed his enthusiasm for the aesthetic appeal of the Swan River Estuary, its prodigality of animal life and the opportunities for pleasurable recreation. There are other cities in Australia built on similar rivers and inlets, but none has been able to retain these attributes in as unimpaired a state as the Swan; industrial and other pollution and various deteriorative consequences of urbanism having reduced the quality of the original appeal. The Swan River Estuary itself has not escaped unscathed from these perils; however, the effects have not been disastrous. The animal life of the estuary and its foreshores is still largely as it was. All of the aquatic bird species still remain, though a few of the land birds of the verges have gone; only one important fish species has vanished, but fishing activity, both amateur and commercial, can still be carried on.

An early settler, E.W. Landor (1847), vividly describes how to him "the large estuary of the Swan affords ample scope for boating or sailing in small pleasure craft". He and his brother "would frequently rise at a good hour, and having supplied our little vessel with a stock of provisions, and a few bottles of ale or other drinkables, hoist the sails, and bear away upon a cruise". As a newly-arrived Englishman he was elated at the sight of his first free-living pelicans "upon a sand-spit which ran far into Melville Water"; as a boy he had only known these as menagerie exhibits.

Fishing continues almost unimpaired both as amateur recreation and a commercial proposition, as described later in this volume. The most notable fish absentee is the snapper. The early writers were impressed with its abundance along the local coast and it used to be caught in the lower Swan River Estuary. The annual spawning concentration in November at Safety Bay was one of the local fishery wonders (Abjornsson, 1910) and the opening of the commercial fishery on it resembled the opening of the duck shooting season: A Fisheries Department inspector hoisted a flag each day when fishing was allowed and hauled it down when it had to stop. A gun was fired on the last day of the restricted season. Some good-sized snapper would be caught in lower Melville Water. The W.A. Museum has records of a 12.7 kg (28 lb) fish taken at Blackwall Reach in April 1916, and Abjornsson tells of a 14.3 kg 31½ lb) 'Old Man' snapper caught in Freshwater Bay. Sea mullet schools are still plentiful in the estuary, despite a scare during the 1940s that the species was being disastrously over-fished and harsh catching restrictions were imposed. These were lifted when it was shown that the measurement statistics of marketed fish had been misinterpreted. As mullet is virtually uncatchable by most anglers, there should always be a place for commercial netting of them in the estuary.

Fish-eating birds have always attracted attention. Captain C.H. Fremantle of H.M.S. "Challenger" expressed his amazement at the big flocks of Little Black Cormorants he saw (Parry, 1971:145). Of all the four species of cormorant to be seen on the estuary, this one excites the most interest because of the spectacular community-fishing technique it has adopted when feeding on atherines in the broadwaters (Serventy, 1938, 1939). This cormorant may be fewer in numbers than it was in Fremantle's day, nearly 150 years ago, but if so it is probably due to the reduction of the birds' nesting habitat in the neighbouring freshwater swamps.

Reduction of suitable feeding areas within the estuary itself is the reason why other birds whose numbers impressed the early visitors have declined locally. Captain James Stirling (as recorded by his botanist-companion, Charles Fraser) saw a flight of over 500 Black Swans in 1827 (Hay, 1906). It is many years since such a sight would have been possible in the estuary, but equivalent or even higher numbers are still present on Peel Inlet and other local waters where sufficient feeding shallows have been allowed to remain; nowadays on the Swan River swans can only find suitable feeding grounds at Lucky Bay and above the Causeway. The shallows at these places and Pelican Point, together with the flats along the Como foreshore and the spit, are the main surviving haunts of the hordes of migratory waders; the Asiatic-breeding sandpipers and their kin, almost 30 species of which migrate to the estuary in summer. Their presence makes Pelican Point the best bird-watching station for these of any capital city in Australia. No species is known to have ceased its visits to the estuary.

Of the bushland birds once known on the verges of the estuary, several have vanished. Stirling's party in 1827 saw large flocks of the Long-billed Corella by the river eastward of Perth, feeding "on the roots of orchideous plants, for which they scratch to a considerable depth". Later, after settlement, they were troublesome on wheat crops grown at Guildford. This cockatoo now survives only in a few scattered colonies in the south-west. When Willem de Vlamingh visited the Swan River in January 1697 and proceeded upstream he heard the song of what he took to be the Nightingale ("hoorden ook een Nachtegaal") (McClymont, 1920, Robert, 1972). There has been some speculation as to what bird this might have been. The Reed Warbler and the Brown Honeyeater have been suggested, but it is more likely it may have been the Noisy Scrub-bird. The rich, vibrant song of this bird, so like a Nightingale to European ears, is so loud and penetrating as "to produce a ringing sensation in the ears" and John Gilbert, its scientific discoverer in 1842, considered it to be "without exception the loudest of all song-birds inhabiting Western Australia". To casual lay observers, like Vlamingh's party, the comparatively low-key notes of the Reed Warbler and the Brown Honeyeater would scarcely have warranted special mention in the party's journal. The Noisy Scrub-bird was obviously a vanishing species by the time the first colonists arrived in 1829; there were good naturalists among them and it is clear the bird was not present near Perth at that time. Between 1842 and 1889 it was encountered in several places in the south-west, south of Drakes Brook, but is today only known from Two People's Bay near Albany. Another riverside species which was present at the Swan River in 1829 has suffered an almost parallel, but not so catastrophic, decline. This is the Western Bristle-bird, now confined to the south coast. The remainder of the Swan River avifauna still survives.

Of the animals formerly known from the estuary environs one other creature deserves some mention. At Upper Swan, not far from the Darling Scarp, James Stirling's botanist, Charles Fraser, made the following note: "The ridges on the banks are perforated with immense numbers of deep pits, the original cause of which we could not at first ascertain. They proved to be made by the natives for the purpose of catching land tortoises, with which these ridges abound" (Hay, 1906:29). This may be an early reference to the Short-necked Tortoise which at the season of the year when Stirling made his visit would have been aestivating underground in the vicinity of the ephemeral swamps it inhabits in the winter. The species is now known only from two swamps in the Bullsbrook area, some kilometres to the north.

A chronological survey of selected early observations on the wildlife of the estuary and its environs made between 1696 and 1860 is tabulated in Appendix 2.

Formal studies on the biology of the Swan River did not begin until the present century. However, it is pertinent to mention an important record by the Quaker-naturalist, James Backhouse, who visited the colony from December 1837 to February 1838. He noted two species of jellyfish during a boat trip from Perth to Fremantle and illustrated both in his book (Backhouse, 1843:548). One was the always abundant *Aurelia aurita,* the other the brown jellyfish *(Phyllorhiza punctata),* which was first accurately identified from Western Australia by Dr. Maurice Blackburn of the C.S.I.R.O. Division of Fisheries in 1953. This species appears to be subject to periodic fluctuations in abundance in the estuary and when it reappeared in strength in the summer of 1947-48 speculation was rife as to its origin. One curious but commonly-held explanation at the time, was that it was transported here on the floats of Catalina aircraft which the U.S. Navy operated in the war years from a base at Crawley. *Phyllorhiza* has continued plentiful since that time. Other species exhibit long-term cyclic fluctuations in abundance. These include the common blowfish, the Perth herring and the scaly mackerel. Other species invade the estuary irregularly, as did the southern fish, the Barracouta, between 1903 and 1907; in 1903 it penetrated the estuary as far as the Narrows (Abjornsson, 1904).

The first survey of the Swan River fauna on modern, professional standards was made by the Hamburg South-Western Australian Research Expedition of 1905, when Dr. W. Michaelsen and Dr. R. Hartmeyer visited the State between May and October. Their operations included the Swan River and the collections were studied by various specialists and published in *Die Fauna südwest - Australiens,* in five volumes from 1907 onwards. The expedition concentrated on the invertebrate groups and the Swan River material included Polychaetes, Crustacea and Mollusca. The chapters on them were a notable base from which later local studies developed.

The foundations of a permanent, institutional scientific study of the Swan River were laid when W.B. Alexander, a Cambridge zoologist, joined the staff of the Western Australian Museum in 1912 and by the appointment of Professor W.J. Dakin to the first chair of biology in the newly founded University of Western Australia in 1913. Both had academic training in marine biology. Alexander vigorously expanded the collections of the museum and after he left in 1920 his example was followed by the equal collecting zeal of L. Glauert. Dakin at once began a plankton survey of the estuary, some of the results of which he referred to in his first presidential address to the newly reorganised Royal Society of Western Australia (Dakin, 1916). He discovered the nauplius larva of the Swan River school prawn and considered that it would be possible to work out the complete development from a series of plankton catches—an anticipation that was not realised until recent work by the Fisheries Department's biologists. He also began work on the life history of the common jellyfish *(Aurelia),* finding the appearance of its Ephyrae in large numbers each June. He also established the cause of the phosphorescence in the Swan River and in Cockburn Sound, it being associated with a ciliate protozoan of the family Tintinnidae. Dakin threw himself into a number of research projects involving marine and limnological studies elsewhere in the State. Unfortunately such research on the Swan River remained suspended for many years after he left the university in 1920, to take up an appointment in England — the same year which saw Alexander's departure.

Later work on the natural history of the estuary by D.L. Serventy and workers at the University of Western Australia, the Western Australian Museum and the Fisheries and Wildlife Department is elaborated in the following pages. It is now accelerating in a gratifying manner, as research workers in other tertiary institutions are becoming involved in individual and co-operative programmes (Hodgkin and Majer, 1976).

Observations and speculations on the biological 'pre-history' of the estuary, as it were, had begun with the earliest visitors. The abundant fossil and sub-fossil Mollusca (and other invertebrates, including Echinodermata) had confused some workers as to the status of the molluscan fauna, in particular, of the estuary (Hedley, 1916); actually the living molluscan fauna is quite impoverished compared with the rich sub-fossil assemblages. These have been studied by, among recent authors, Fairbridge (1953) and Kendrick (1960, 1977). Kendrick's latest paper, on the Middle Holocene marine molluscs near Guildford, demonstrated that then "a period of regional aridity is indicated continuing on to some time after 4 500 BP". The Swan River system was then a stable arm of the sea experiencing considerably less winter flooding than now.

Though, obviously, it was known since the time of the first settlers that the Swan River Estuary freshened at the surface as a result of winter rains and flooding of its tributaries — the Helena and Canning — precise studies were not begun until comparatively late in the present century. Apart from the long-term cyclical variations in salinity due to climatic changes, such as those invoked by Kendrick, minor but still significant annual fluctuations became apparent to the settlers and government officials. These were consequent on variations in the annual rainfall. A useful body of observational data on this point is contained in the printed reports of the Chief Inspector of Fisheries between 1889 and 1909 on the state of the estuarine system (Abjornsson, 1900-1910) in which the duration of the winter 'freshet' and its effects on the fauna (mainly fish) are summarised.

The first precise study of the variations in salinity of the Swan River throughout the year was undertaken by Dr. Edward S. Simpson, the Government Mineralogist and Analyst (Simpson, 1925:4, and graph), based on samples collected at 10-day intervals over a period of 3 years, 1922-25, in Perth Water. The graph showed variation in total solids (obtained by evaporation and drying at 180°F) and the chlorine, monocarbonate and sulphate ions. The study revealed a maximum salinity closely approaching that of the open ocean each March and April and a minimum salinity closely approaching that of the hills streams between July and September. The results interestingly complemented the observational data of Abjornsson of two decades earlier.

Simpson recognised that "as in such estuaries there is always an appreciable stratification of the water". He, however, restricted himself to the condition of the surface water, the samples being collected 15 cm below the surface and about 21 m from the shoreline on the Mends Street Jetty, South Perth. As already noted by Abjornsson, he pointed out that his results showed a variation in the duration of the period of low salinity, which was dependent on the amount of winter rainfall.

When D.L. Serventy began studies of Swan River waters at Crawley in 1930, he extended Simpson's work by determining the vertical variations in chlorinity, to establish how deeply the 'skin' of fresh water penetrated in the winter and what was the nature of the bottom water. This was continued in 1931 and resumed in 1934 and 1935.

In 1930 the stratum of fresh water overlying the salt was 2.4m deep at Crawley; in 1935 it was 1.5-1.8m deep (Serventy, 1955). Later work by the C.S.I.R.O.

showed that in winters of heavy flooding almost the entire estuarine basins may be scoured out and filled with fresh water as happened in 1946 and 1965. In low rainfall years, on the other hand, the surface waters may remain of moderately high salinity, as was the case in 1949 (Rochford, 1951; Middleton, 1955; Spencer, 1956).

The bottom salt water, sealed off by the fresh water stratum, loses oxygen and becomes foul and stagnant. Animals trapped in the bottom water perish. The deep channels in the middle of the estuary are most affected and their floors are covered with soft black mud. The considerable expanses of shallow flats under about 3 m in depth may escape being covered with de-oxygenated water; these shallows are thus the productive parts of the estuarine system.

A considerable body of data on the Swan River has been accumulated over the years, beginning with casual observation and ad hoc investigations. Slowly it is becoming realised which factors are crucial ones in the well-being of the estuary and which are likely to be detrimental. For instance, it is becoming apparent that the reclamation of the shallows has greater deteriorative effect on the fauna than its occasional over-exploitation by over-fishing, amateur or professional. Furthermore, the estuary is not a static thing. It is constantly changing, through causes man cannot control. Though we will not experience in our lifetime the drastic situation which Kendrick (1977) has shown to have existed some 6 000 years ago, the present forecasts of a dry cycle, if they eventuate, cannot help but have some effect on the Swan River system.

Whatever may befall, through natural or man-caused factors, the estuary is now being monitored continuously by biologists and physical scientists and laymen lovers of the Swan may be assured that as far as is humanly possible its welfare will be the concern of fully informed administrators. In the final chapter, proposals for future research, to enhance this situation, are discussed.

THE FISH OF THE ESTUARY

Part I — Utilisation of the Fish

Estuarine fish are normally dispersed in one or more of the following ways. They can:

(1) die either from natural causes or those generated by interference to their environment or be devoured by scavenging organisms ranging from birds and other fish to bacteria;
(2) be preyed upon directly by fish and birds, and
(3) be caught by man either professionally or recreationally.

This section is concerned primarily with the human harvest of fishes and the effects of this long-term exploitation on annual levels of both commercial and amateur production. The past history and present status of the fishery in the Swan-Canning Estuary may be summarised as follows:

Licensed Fishermen (Professional and Amateur)

In the period between the initial settlement of the State in 1829 and the introduction of the first fisherman's licence in 1899, everyone was free to catch fish in the estuary for domestic use, barter or sale. From 1899 until 1905, those people who caught fish for sale or who used a seine net to catch fish were required to hold a fisherman's licence. From 1905 until 1940, people who caught fish for sale by any means at all, or who owned a seine net, were required to hold a fisherman's licence. Thus up until 1940 amateur or domestic fishermen, as they were then called, who owned a net other than a seine net to catch fish not for sale, needed no sort of fisherman's licence. From 1940-1949, anyone catching fish by means of any net whatsoever was required to hold a fisherman's licence whether or not the fish were sold.

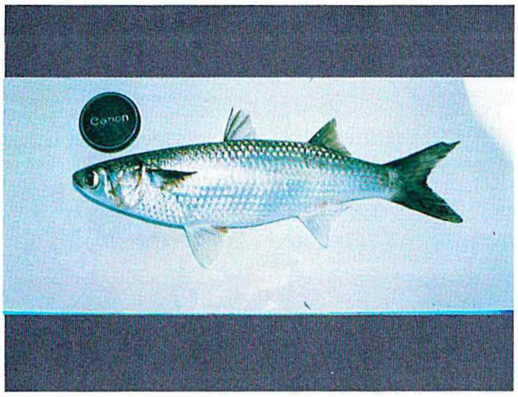
The first actual distinction between professional and amateur fishermen was formally made in 1949 by the issue of separate licences for professional and amateur fishermen. This distinction is still maintained (Lenanton, in prep.).

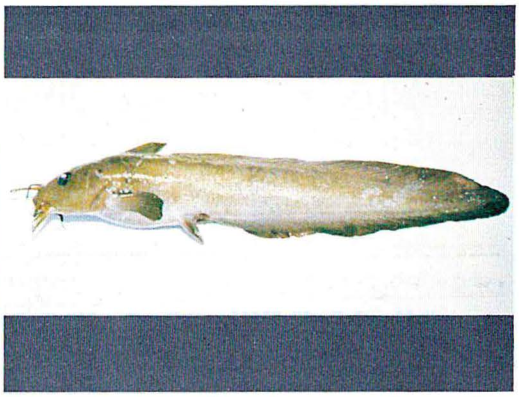
The Professional Fishery

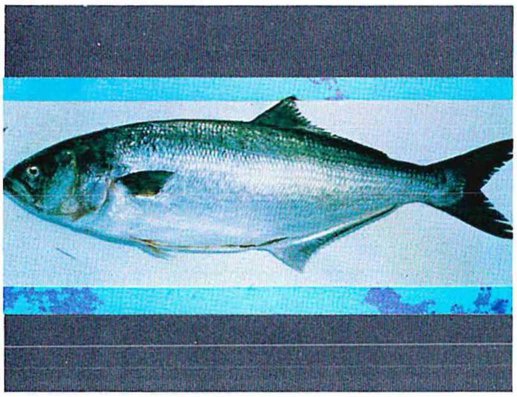
The major commercial species taken are listed in Appendix A3, by scientific and common name. Monthly production data are available for all these species from 1952 to the present day (Lenanton, unpublished). The most important species include sea mullet, cobbler, tailor, mulloway, flathead, crabs and prawns, which are all utilised mainly as food; yelloweye mullet (and some sea mullet) and Perth herring which are caught mainly for rock lobster bait (Morgan and Barker, 1975); and whitebait which are mostly sold as angling bait. Figure 20 shows four of the most important fish species used for food and the common blowfish which is a nuisance to anglers. All the available annual production figures for these 10 species, since the commencement of the licensed fishery in 1899, are presented in Table 5. In this regard it should be noted that the present system of monthly commercial fishermen's returns did not commence until 1941. Prior to this, production statistics were obtained from district inspectors' reports, processing and marketing returns, and returns for fish despatched by rail.

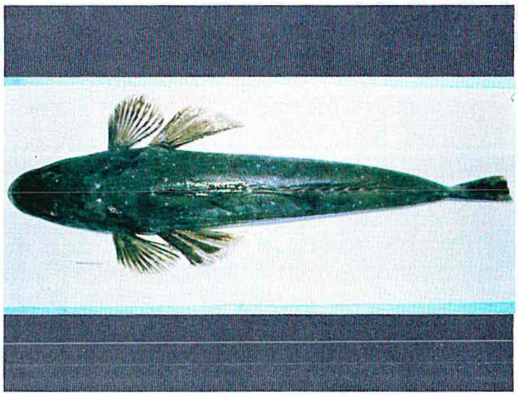
During and immediately after World War I, it was understandably difficult to obtain supplies of fresh food. The community relied to a great extent on the fresh fish supply from the estuary. At times during 1919 up to 130 men, many of whom were returned servicemen, were fishing professionally in 13 km of open water in the Swan. Compared with present levels of effort, this was very high and predicably resulted in uneconomic returns for many fisherman, forcing some of them out of the industry. The most popular species at that time were sea mullet, crabs and prawns (Table 5).

There are virtually no statistics available for the period 1922-1937. In an attempt to alleviate shortages in food supply during World War II, the canning of many species of fish commenced. Perth herring was one species which was very much in demand for this purpose. This is reflected in the increase in the level of production of this species from 1942 onwards. Sea









Top Left: Sea mullet
(Mugil cephalus)

Top Right: Cobbler
(Cnidoglanis macrocephalus)

Centre Left: Tailor
(Pomatomus saltator)

Centre Right: Dusky flathead
(Platycephalus fuscus)

Bottom Right: Blowfish
(Torquiqener pleurogramma).

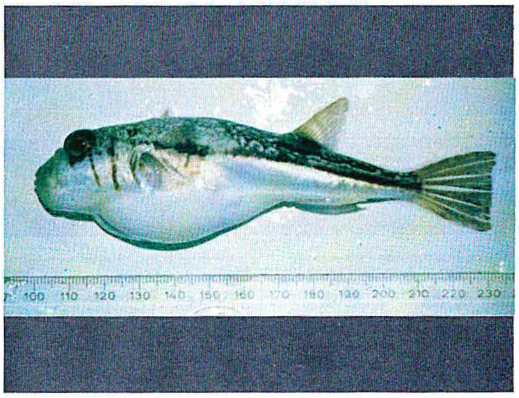


Figure 20. Four species of fish of commercial and recreational importance from the Swan-Canning Estuary. The fifth species, the Blowfish, has become increasingly a nuisance.

TABLE 5. All available annual production data (kg) for most important commercial fish and crustacean species taken from the Swan-Canning Estuary (commercial block 9501) over the period 1912-1974.

		SPECIES										
Year	Perth herring	Mullet		Cobbler	Tailor	White-bait	Flathead	Mullo-way	Prawns	Crabs	Men	Boats
		Sea	Yellow-eye									
1912		118178	2077	496	6241		698	361	*34680	+6870	118	31
1913												
1914		57382	12488	205	3727		283	1191	*25670	+5950	44	22
1915	182	73386	7174	523	6954		795	273	*17785	+4345	46	23
1916				All fish 50182					*32010	+11895	40	20
1917				All fish 105391					*33120	+16800	48	24
1918	42	110205	2250	966	9093		830	4902	*62250	+22035	73	33
1919												
1920		33177	2632	116	3704		800	1367	*17610	+10695	33	18
1921		+126072	+43762	+970	+15541		+856	2606	*25955	+14145		
				Data from 1922-1937 unavailable at this stage								
1938									*10665	+23555		
1939	324	5882	138		3471		909		*3995	+20955	63	32
1940	151	1564	322		1247		155		*180	+26145	61	31
1941	14500	30651	5692	19662	4895		1167	171	510	13601	19	15
1942	79704	12286	1157	19316	2308		1019	172	93	11951	30	20
1943	67783	9972	1515	7594	5945		884	968		3127	20	7
1944	60431	5316	2207	2801	8837		784	506		3958		
1945	50048	10484	7605	11788	6414		5494	679	76	23914		
1946	24630	10101	4034	3143	7045		1332	1861	1996	7370		
1947	9205	19059	3133	305	8390		991	982	3610	5335	31	19
1948		24335	4734	1543	7616		420	306	11150	14838		
1949	13600	18513	1119	769	6377		159	77	2209	16659	25	
1950	6375	24257	2532	1305	5849		379	155	1203	22525		
1951	537	38749	2599	5592	5405		1007	99	2719	18014		
1952	419	20761	1659	1485	4218		618	38	143	9675	16	13
1953	166	19777	2721	1957	2128		990	27	86	16781	18	15
1954		19519	2588	1284	1901		410	43	12	6973	13	12
1955	1871	15386	4631	3861	1710		1726	8	3	7588	14	13
1956	4278	20654	1965	1056	2624		3012	72	5076	8233	15	14
1957	19239	36500	4238	3183	2800	324	1350	67	8854	3899	17	15
1958	9192	86276	4987	5661	3496		956	5	3856	11414	20	19
1959	8422	73883	5657	21523	3195		624	417	16369	10196	24	22
1960	15946	42941	20801	56586	4552		3869	639	7909	51203	30	27
1961	16153	116084	15157	44780	7977		2063	188	1014	10436	34	30
1962	11256	42390	10051	49371	2584		2097	557	1134	8714	23	20
1963	60361	64784	16268	38259	2464	823	4707	3667	607	1734	29	25
1964	65266	17899		23877	2769	2090	2150	638	2599	682	22	19
1965	43434	62761	3624	26098	1857	5833	1157	8452	2304	1745	27	22
1966	52340	74051	6106	13475	1551	4113	2133	2113	2295	1204	25	22
1967	89701	57241	8909	18345	1552	8257	3652	1908	785	8799	29	24
1968	177611	36558	5587	15142	1871	5389	3140	5369	270	15424	31	25
1969	62048	52387	17155	29127	2626	7266	2015	3587	748	7052	34	27
1970	46518	69267	29354	49554	2904	4944	3076	3477	1289	3324	30	25
1971	71454	44941	29406	39738	2330	1588	1996	3884	955	12737	33	27
1972	147432	48044	11241	23596	1684	3470	1017	1461	545	16179	33	27
1973	158606	76162	21045	33480	1899	12701	904	2630	150	12898	33	27
1974	97363	71627	15799	40210	823	5215	1955	2240	78	22700	33	28
1975											35	
1976											33	41

*Converted from gallons to kg — 1 gallon = 3.5 kg

+Converted from dozens to kg

Crabs	1 dozen = 2.7 kg
Tailor	1 dozen = 1.4 kg
Sea mullet	1 dozen = 3.0 kg
Yelloweye mullet	1 dozen = 2.4 kg
Cobbler	1 dozen = 6.3 kg
Perth Herring	1 dozen = 0.6 kg

mullet, cobbler, garfish and blue sprats were also important canning species. Intensive canning of estuarine species continued for eight years. It continued to be practised during the 1950s, but indications were that it was at a relatively low level of production. During the 1950s the fishery was maintained at a reasonably low level of effort. It increased somewhat in the late 1950s and early 1960s and has been maintained at that level until now.

Since the last significant increase in effort in the early 1960s, there has been a noticeable rise in the level of production of Perth herring, cobbler and whitebait.

Perth herring production expanded in response to the demand for this species as rock lobster bait. This development corresponds well with the increased level of effort in the rock lobster fishery during the early 1960s (Morgan and Barker, 1974). Cobbler production grew sharply in 1959 and has continued to be maintained at that relatively high level. This improvement reflects a sustained increase in the demand for cobbler as a favoured food. Whitebait, which was never really caught commercially in the early years of the fishery, has gained trememdous popularity in recent years as an angling bait and very recently as a gourmet item in the Perth restaurant trade.

There has always been a demand for the remaining more important species taken from the estuary. Therefore, with the exception perhaps of the two mullet species which have recently been used as rock lobster bait, changes in production probably reflect the variations in spawning success of breeding populations outside the estuary, recruitment into the estuaries, or the suitability of the estuarine habitat for the growth and survival of the different species.

Recreational Fishery

The recreational fishery consists of two components, the unlicensed amateur line and crab fishery and the licensed amateur net fishery for fish and prawns. Old documents, such as Fisheries and Wildlife Department files and the year books of 1829-1929, make reference to the fact that domestic fishermen, both anglers and netters, were very active in the Swan-Canning Estuary as early as 1912.

However, throughout the whole of this twentieth century, there have been no formal surveys undertaken in the estuary to determine the relative magnitudes of fishing pressure generated by each component, or their relative contributions to the total annual recreational catch from the estuary. On the basis of results from recent surevys of amateur fishing in other areas of the State (Lenanton and Caputi, 1975; Lenanton and Hall, 1976; Caputi and Lenanton, 1977), it is likely that the unlicensed component is the major contributor to the total annual recreational catch from the estuary.

Recently, some observations at 70 popular locations around the estuary revealed that more than 1 000 persons fished at these locations on a typical weekend and that an average evening catch (weekday and weekend included) was approximately 600 fish (Forbes and Fitzhardinge, 1977). There are no data available on the amateur crab catches from the estuary. However, it is certainly possible that quantities of crabs taken by amateurs would be similar to those taken by the professionals.

The only data available on the daily fishing effort from the licensed amateur fishery are those collected by the Swan River Conservation Board during the summers of 1975-76 and 1976-77. The Board found that the number of people participating in prawning was only marginally less than the number reported to be angling. There are some data available on the number of people who annually participated in the licensed amateur fishery (Table 6), the species they preferred to fish for (Table 7) and the number of units of gear they owned in order to fish for their preferred species (Table 8).

From these data it is clear that the participation in this licensed fishery is increasing each year and that the majority of people choose to fish for prawns, although there is significant and increasing participation in net fishing. Bearing in mind that the major contribution to the total recreational catch comes not from the licensed but from the unlicensed component, both the total effort and catch of the recreational fishermen are likely to be substantial when compared to commercial production from the estuary. This was also believed to be the case as early as 1919 when the recreational or domestic catch was thought to be equal to 50-60% of the professional catch (Fisheries and Wildlife Department file 19/19).

TABLE 6. The estimated number of Amateur Fishermen's Licences issued from Perth and Fremantle District Offices over the period 1971-72 to 1975-76.

YEAR	NUMBER OF LICENCES ISSUED		
	PERTH	FREMANTLE	TOTAL
1971-72	4 118	1 506	5 624
1972-73	4 487	1 580	6 067
1973-74	5 264	1 905	7 169
1974-75	6 157	2 214	8 371
1975-76	8 680	3 268	11 948

TABLE 7. The percentage of licences issued at Perth and Fremantle Licensing Districts with fish and prawns recorded as a first and/or only preferred species.*

LICENSING DISTRICT	1973-74		1974-75		1975-76	
	PRAWNS	FISH	PRAWNS	FISH	PRAWNS	FISH
Perth	60	18	51	21	62	16
Fremantle	56	25	41	31	54	23

*Rock lobster made up the balance of the preferred species.

TABLE 8. The number of prawn and fish nets owned by amateur fishermen who purchased licences at Perth and Fremantle District Offices.

YEAR	NUMBER OF PRAWN NETS			NUMBER OF FISH NETS		
	PERTH	FRE-MANTLE	TOTAL	PERTH	FRE-MANTLE	TOTAL
1973-74	3 037	1 243	4 280	1 703	755	2 458
1974-75	3 313	1 252	4 565	2 512	1 074	3 586
1975-76	6 024	2 118	8 142	3 879	1 418	5 297

Part II — The Estuary as Habitat for Fish

All the different species of fish which have been recorded from the estuary may be included in one of the following three categories, on the basis of how generally they utilise this estuarine environment.

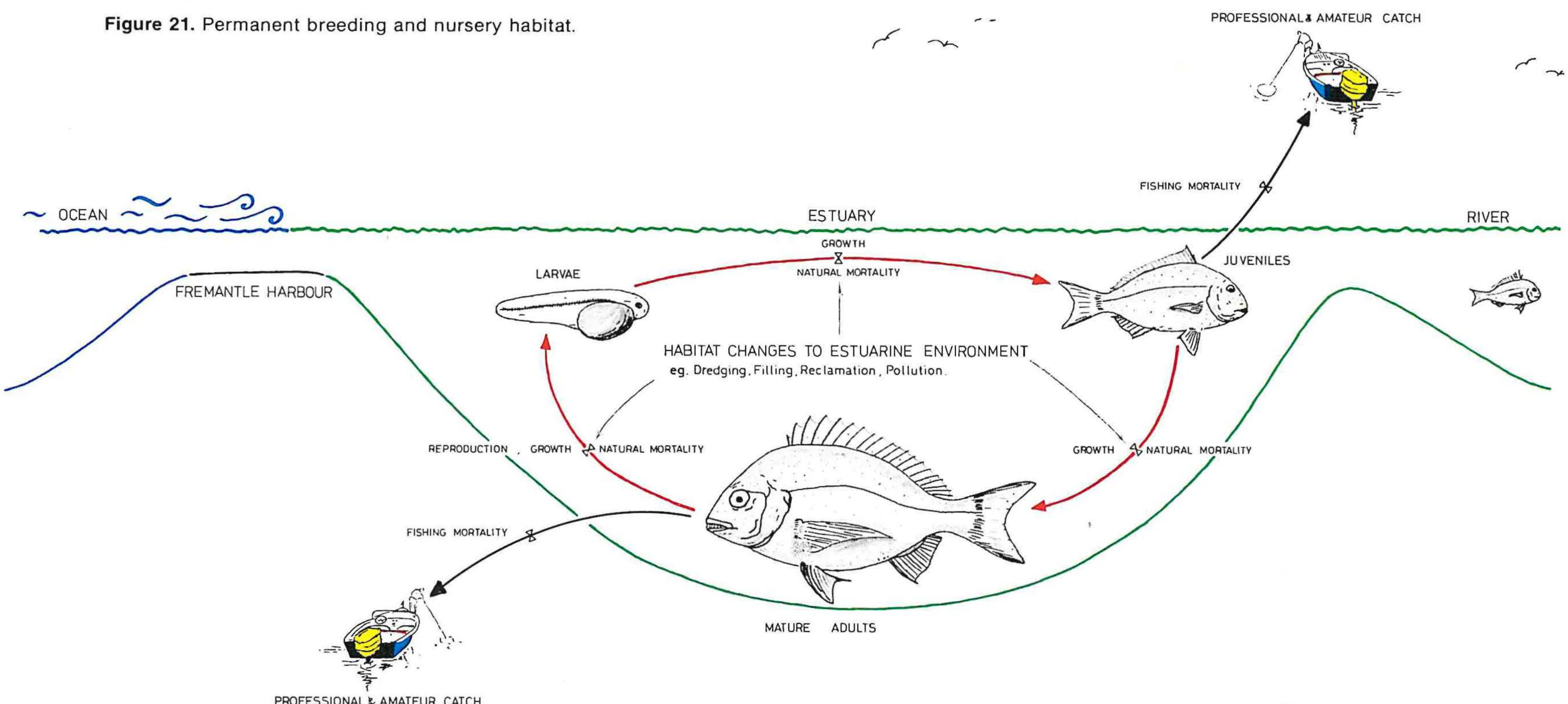
1. A Permanent Breeding and Nursery Habitat (Figure 21)

Species typical of this group include black bream, cobbler, Perth herring, some flathead and flounder, river garfish, yellowtail grunter, some of the non-commercial species such as the hardyhead, gobbleguts and some of the gobies. The only commercial crustacean in this group is the greasyback school prawn or common river prawn. It should be noted that a number of these fish, e.g. cobbler, flounder and flathead are also able to reproduce and live entirely outside the estuary in marine embayments such as Cockburn Sound. Other species such as black bream and Perth herring are capable of making excursions into similar areas, mainly in response to winter flood conditions. Irrespective of the above cases, all species in this group can reproduce and live entirely within the estuarine system. Some, such as the hardyhead, gobies and cobbler, have specialised breeding habits which adapt them to living in such extreme habitats. They produce relatively few eggs, but take rather better care of them than most fish. Hardyheads attach their eggs to sea-grass fronds and gobies actually build their nests under stones and other objects, attaching their eggs to the inner surface of their nests (Lenanton, 1977). The cobbler is also thought to be a nest builder, although the precise details of the nest structure are unknown (Kowarsky, 1975).

2. A Nursery Habitat for Juveniles (Figure 22).

The fish in this group include the bulk of the more important commercial and amateur species. Typical of this group are the mullets (sea and yelloweye), the whitings (King George, western sand and trumpeter), silver bream, tailor, mulloway, some of the flatheads and flounders, sea garfish, striped perch (or trumpeter), roach, whitebait and anchovy, and the commercial crustaceans — blue manna crabs and king prawns. As outlined in Figure 22, they all utilise the estuarine habitat as a nursery area. Abundant food and shelter both from predators and the more boisterous marine environment are important factors

Figure 21. Permanent breeding and nursery habitat.



Drawn by I.L.LETHBRIDGE

Figure 22. Nursery habitat for juveniles.

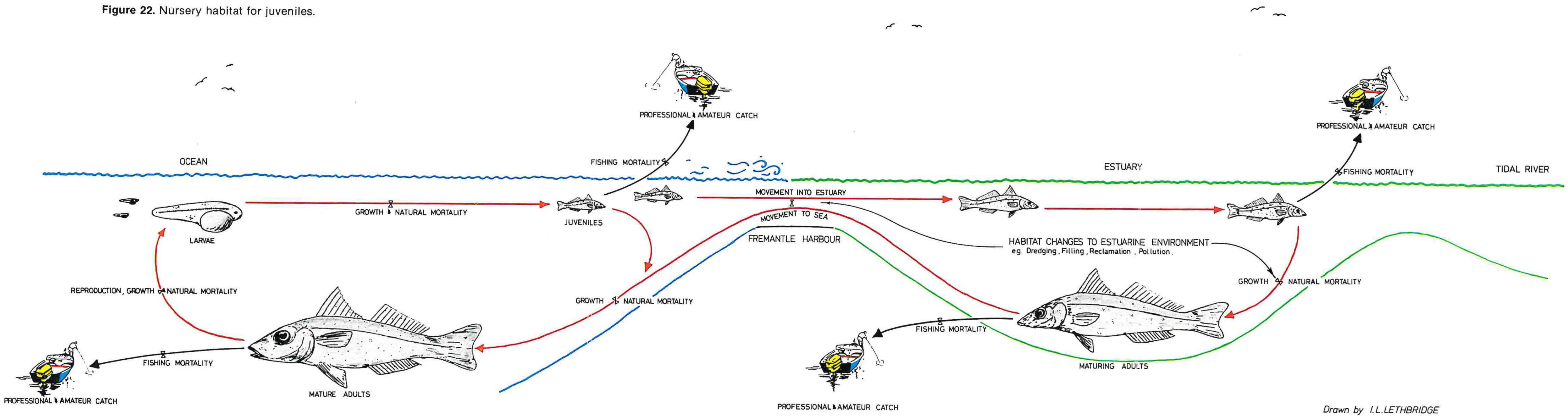
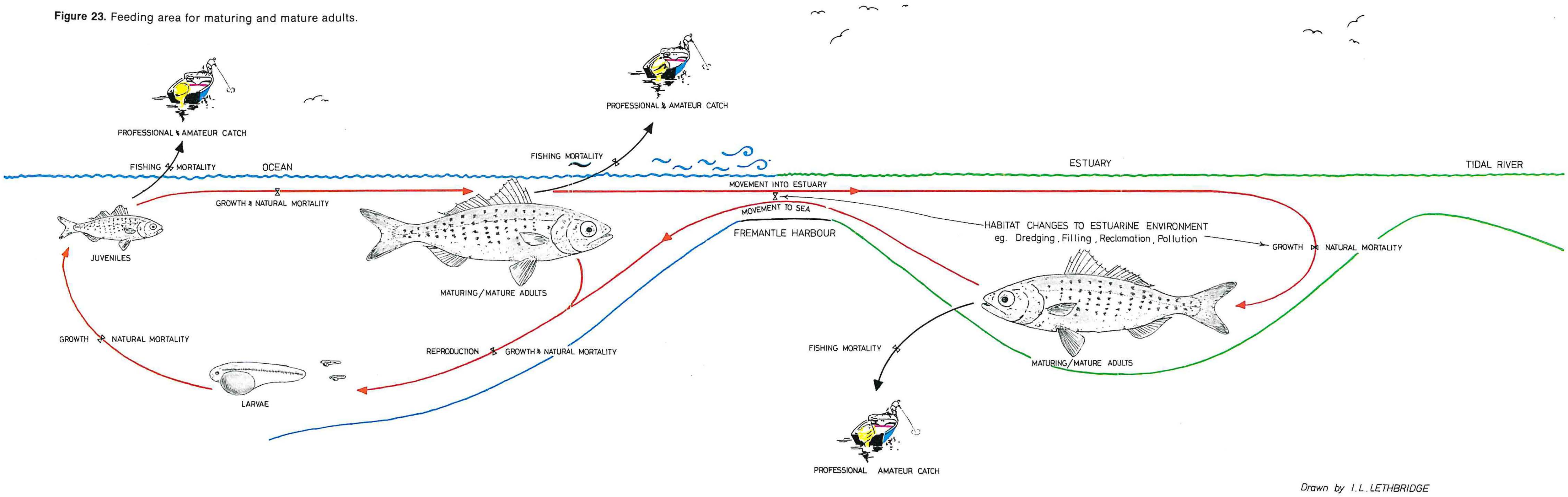


Figure 23. Feeding area for maturing and mature adults.



which encourage the utilisation of the estuaries by the young stage of many of these species. From research in other estuaries (Lenanton, 1977) and preliminary work in the Swan (joint programme on fishes of the Swan by Department of Fisheries and Wildlife and Murdoch University), it is clear that the shallow banks, in particular the sea-grass *(Halophila ovalis)* areas, are the most important nursery habitats for these fish. This is because of the abundant supply of small invertebrate animals which are a principal source of food for these fish (Thomson, 1957, Wallace, 1975). These banks are certainly more productive of potential fish food than the deeper areas (Wallace, 1977), which is reflected in differences in the abundance and distribution of fishes inhabiting the two areas (Chubb, unpublished). However, blue manna crabs do appear to be one exception to the rule, as large numbers were taken in the research samples from the deeper areas in the lower river during 1977.

It should be emphasised that the natural history pattern illustrated in Figure 22 is the one which could be expected during a year when a reasonable freshwater flush was experienced in the winter months. In the years of reduced winter freshwater flushing, species such as trumpeter whiting, tailor, mulloway and crabs may remain in the system all year, particularly in water of the lower estuary which does not become fresh. Conversely, in years of prolonged heavy winter freshwater flushing, the above four species may be forced out of the system for long periods of the year.

3. An Occasional Feeding Area for Maturing/Mature Adults (Figure 23)
Species typical of this group include Australian herring and salmon, skipjack, blowfish, school whiting, scaly mackerel, pilchard (mulie), blue sprat, blue (common) mackerel, and most of the sharks and rays. Species in this group form only a minor part of the commercial and amateur catch from the estuarine system. Of these, most are commonly caught in the marine environment, particularly in embayments such as Cockburn Sound, along coastal beaches and in waters around Rottnest Island. These species only venture into the lower estuary when the salinities are approaching those of sea water, i.e. usually in the summer months; however, in abnormally dry years, they may remain in the system for a number of months, venturing far upstream into the tidal river. The blowfish is a good example of an animal from this group that is able to remain in the system for prolonged periods (see Figure 20 for identification). Past research works (Lenanton, 1977) showed that this species did not reproduce in the Blackwood River Estuary nor utilise the estuary as a nursery habitat during 1974-75. Under estuarine conditions during dry years blowfish may well be able to reproduce in the Blackwood River Estuary, or at the very least utilise the estuary as a nursery habitat, and may be more correctly included under category 2. From the reported catches of this species by prawning parties in the Swan-Canning Estuary, it is clear that the blowfish is able to make good use of this estuary during summer months.

The extent of its seasonal usage of the estuary will not be known until the present research on fishes of this system is completed.

PART III — Natural Factors which affect the use of the Estuary by Fish

The natural environmental factors that collectively influence the manner in which a fish or crustacean utilises the estuarine environment include salinity, temperature, dissolved oxygen, turbidity and available food and shelter (Lenanton, 1977).

Assuming each species of fish has attained successful reproduction and larval survival within a specific set of conditions, then discussion of the use of the estuary by different species is concerned both with the movement of fish between the estuary and the ocean and their distribution within the estuary.

Salinity is the most important factor influencing the manner in which fish utilise the estuary. The species which utilises the estuary as a permanent habitat must be able to cope with the extreme seasonal variations in salinity from almost fresh in winter to saline or even slightly hyper-saline in the summer. Fishes which are able to adjust to a wide range of salinities are known as euryhaline species.

The species of the second category can cope with some dilution of their preferred seawater salinity habitat; however, some species such as the trumpeter whiting, whitebait, anchovies, king prawns and blue manna crabs are forced out of the estuary by the freshwater flush and so are only caught in the summer months. Sea mullet and yelloweye mullet can survive in the estuary all year round. The mullet species are very good osmoregulators (Thomson, 1966, Lenanton, 1977), whereas other species cannot tolerate salinity below 10%. For example, the blue manna crabs are forced down to the waters of tolerable salinity by the first freshwater flush (Meagher, 1971).

Fishes in the third category can tolerate only minor dilution of their external medium. They venture into the estuary only when salinities are around those of seawater, so most are brief summer visitors. Such species include skipjack, yellowtail and blue sprat. Fish which can only live in water of seawater salinity are called stenohaline-marine species.

There are some freshwater fish which cannot cope with any concentration of the external water medium. On one occasion, minnows *(galaxiids)* were taken from the upper reaches of the Canning River during a freshwater flush. The freshwater catfish which is present in some of the more southerly estaurine systems has not been recorded in the Swan-Canning system, but occurs in the Avon pools (Kendrick, 1976).

Temperature is another important factor which affects the fish's utilisation of estuaries. Until recently it has been thought that tailor are forced out of the river by the first winter freshwater flush. However, during summer 1976-77 they left the Swan-Canning Estuary well before the first of these flushes. Indications were that falling water temperatures forced them out of the estuary into the warmer oceanic waters well before the winter freshwater flush. In reality, it could be that either lower water temperature or salinity could force the fish out of the estuary, depending on which of these factors was first to become unacceptable to the fish.

Shallow semi-enclosed embayment areas or isolated bodies of shallow water in the estuary such as Alfred Cove may tend to become slightly hyper-saline and considerably warmer in the still, hot periods of the summer or, conversely, markedly cooler and perhaps of lower salinity than the main body of water in the estuary during winter. In both these situations fish which normally live on these shallow banks may be forced into the deeper areas of the main body of the estuary. Thus to be well adapted to life in an estuary fish must be euryhaline and eurythermal.

Dissolved oxygen also influences the behaviour and distribution of fish within the estuary. There are certain areas, such as the whole of the Swan-Canning estuarine basin, where deep pockets of saline water tend to become deoxygenated during early winter when they are trapped beneath the surface layer of fresh water from the first winter flush. Certain species of fish such as cobbler, which need the higher salinity water to survive will eventually die, because by remaining in the saltwater pocket they lack oxygen. If they choose to leave the high salinity pocket they also perish, not because of low oxygen, but because they cannot cope osmotically with the lower winter salinity of the surrounding water (Kowarsky, 1975).

There are other situations which can result in deoxygenation of estuarine waters. The macrophytic algae and sea-grasses of the relatively shallow weeded areas photosynthesise during the day, resulting in oxygenation of overlying water. During darkness the plants respire, causing a considerable drop in the dissolved oxygen levels of overlying water, sometimes to levels that are unacceptable to fish. It is generally believed that levels below 5 mg/l (milligrams per litre) can cause changes in behaviour, while levels below 3 mg/l can cause death (Perkins, 1974).

Turbidity, particularly that caused by winter flushing or surface-to-bottom mixing of water over shallow banks by persistent strong wind, may affect the distribution of fish within the estuary. Natural turbidity probably would not pose a serious threat to estuarine fish, because from an evolutionary viewpoint they should be well adapted to such situations.

Food and shelter are very important factors which influence the utilisation of the Swan-Canning Estuary by many species of fish and crustaceans seeking protection from predators and the boisterous conditions of the open ocean.

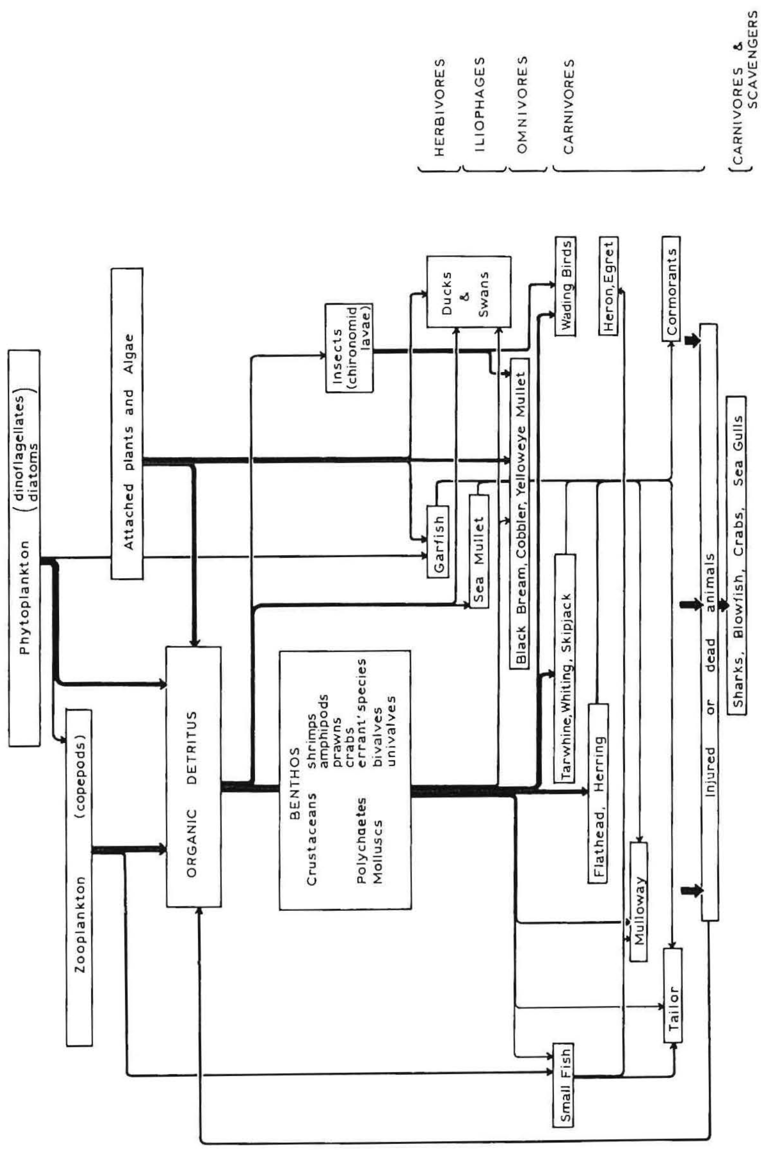


Figure 24. Simplified concept of the food chain in the south-western Australia estuarine environment. *Courtesy — R.C.J. Lenanton.*

This estuarine environment, rich in nutrients, supports an abundant supply of small macrobenthic invertebrate animals, such as shrimps, polychaetes (worms), small molluscs (Chalmer, Hodgkin and Kendrick, 1976) and zooplankton organisms, such as copepods. Most of these invertebrates occur only within the estuarine environment. Many fish species, particularly the juvenile stages, depend on these animals as an essential source of food. A simplified illustration of this estuarine food web is presented in Figure 24.

In addition to the good supply of small macrobenthic organisms, the estuary is rich in organic detritus (decaying animal and plant material) which is utilised directly by species such as sea mullet and Perth herring. These fish are known as iliophages. They derive most of their nutrition from the bacteria which are breaking down the detritus.

Data from some recent work in the Swan Estuary (Wallace, 1977) have revealed that macrobenthic invertebrate animals are much more abundant on the shallow banks than in the deep muddy areas of the estuary. Over the same period a general survey of fishes of the Swan-Canning Estuary (Chubb, unpublished) has revealed that fish species, particularly juvenile stages, were more prevalent on these shallow banks than in the deeper areas. As mentioned earlier, the blue manna crab provides one of the few exceptions, being more plentiful in the deeper areas. Clearly the fish found on the shallow banks are utilising the abundant supply of food found there. The same applies to the Blackwood River Estuary (Lenanton, 1977).

Part IV — Management of the Fishery in the Estuary

It is clear that the bulk of the commercially and recreationally caught fish are mostly juvenile members of a large oceanic stock which utilises the Swan-Canning and other estuaries as nursery areas. Intense fishing in this estuary alone will probably not affect the overall abundance of these species and will bear little relation to the number of fish that will be recruited into the estuary in the following years. Certainly the fishes of the estuary have been able successfully to withstand more than a century of exploitation, with periods of professional exploitation more intense than now. There is every reason to believe that fish populations which utilise the estuary will be able to survive similarly intense pressure in the future.

It is important to remember that many of these species similarly utilise other estuaries of temperate Western Australia. Thus intense pressure applied simultaneously to fish populations in *all* these estuaries may well pose serious problems to many fish stocks.

An important consideration in the question of the exploitation levels in an estuary such as the Swan-Canning is the control of the total level of effort to ensure that all commercial fishermen are able to gain an economic return and all amateurs have a reasonable share of the total catch of fish from the estuary during any one fishing season.

In recent years amateurs have complained that a decrease in their catches is an indication that stocks in the estuary are being overfished. The trends in the catch rates of professionals indicate that the abundance of estuarine stocks has not declined (Lenanton, unpublished); thus decreasing trends in amateur catches do not necessarily indicate that fewer fish are available, merely that more fishermen are competing for a share of a basically constant number of available fish.

A simplistic explanation of this situation is provided in Figure 25. The abundance in any one year of a species of fish that uses the estuary just for a nursery area has little influence on the numbers of that species in the estuary in subsequent years. Catches will fluctuate from year to year depending on factors such as spawning and recruitment successes, larval mortality rates and the like; but these fluctuations are normally around an average level of production which is reasonably constant from year to year. In contrast the total number of amateurs fishing in the estuary is increasing each year. Therefore, each fisherman's share of the total catch would tend to decrease each year as the number of fishermen increases. In other words, a fisherman operating at a given level of effort at time A (Figure 25) would be expected to catch considerably more than a fisherman operating at the same level of effort at time B (Figure 25).

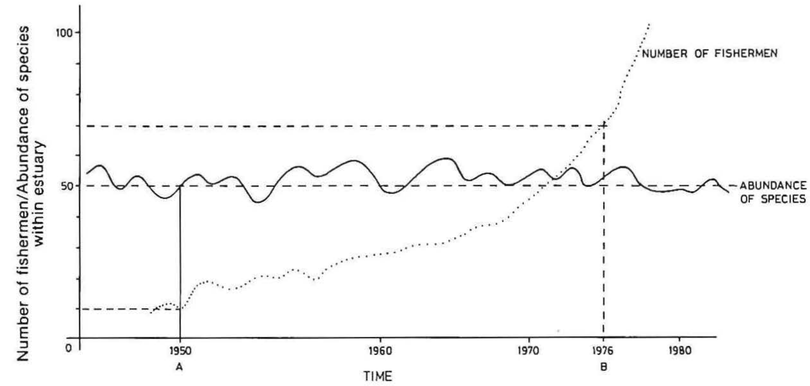


Figure 25. A hypothetical representation of the likely decrease in catch per amateur fisherman as a result of increased levels of exploitation of fish species which uses the estuary only as a nursery area.
Courtesy — R.C.J. Lenanton

The other important aspect of management is to maximise the utilisation of this environment by potentially harvestable fish. This can be best achieved by ensuring that the estuary is maintained as an acceptable environment to fish which choose to utilise it. It is clear from earlier sections of this paper that man has very little control over natural phenomena which operate within the estuary. He is able to minimise the level of disturbance both to the important estuarine fish habitats, particularly shallow banks and foreshores, and to adjacent areas such as water catchments and associated wetlands. This will help achieve maximum utilisation of the habitat by fish, which will in turn maximise the fish available for exploitation by amateurs and professionals.

Finally, juvenile fishes of the Swan-Canning Estuary are derived from large oceanic populations which utilise a number of estuaries and limited areas of marine embayments along the coast of Western Australia.

Deterioration in one or all of these essential nursery habitats could result in a permanent break in the normal life-cycle patterns of many of these species. The ultimate result of this could be a gross change in composition involving marked reductions or, in some cases, the complete elimination of species which once used to be common throughout our estuaries. Thus it is important that the same criteria laid down for management of the estuary be applied to all temperate estuaries of the State, if our estuaries and fish population within them are to be enjoyed and utilised by future generations of Western Australians.

THE BIRDS OF THE ESTUARY

There are 44 species of birds which are common inhabitants of the Swan River. Lenanton (1973) divides these into 4 main groups. Appendix A4 gives a more complete species list.

(1) Ducks and Swans

The species most commonly seen are Black Swan *(Cygnus atratus)*, Grey Teal *(Anas gibberifrons)*, Mountain Duck *(Tadorna tadornoides)*, Black Duck *(Anas superciliosa)*, and occasionally Musk Duck *(Biziura lobata)*, Chestnut Teal *(Anas castanea)* and Blue-winged Shoveler *(Anas rhynchotis)*. These birds inhabit the permanent water of the Swan River during the summer and move out to the inland waters of the hinterland during the wet months (Riggert, pers. comm.). They feed in the deeper areas of the tidal flats during the day, moving off to nearby freshwater lakes in the evening. Ducks and swans are basically herbivores. They sift algae and plants from the detritus of the tidal flats, though if algae is in short supply they will take bottom dwelling invertebrates to supplement their diet.

(2) Wading Birds

The most abundant species are the Red-necked Stint *(Calidris ruficollis)* and 4 000 of these were counted in the summer of 1972 (Lane, 1976). Other species often seen are the Curlew Sandpiper *(Calidris ferruginea)* and Avocet *(Recurvirostra novaehollandiae)*. Godwit, plover, sandpiper, stilt, dotterel and knot, all of several genera, can be seen on the estuary. The majority of these birds migrate to Australia in early September from their breeding grounds in northern Eurasia and above the Arctic Circle. They remain on the estuary during the summer, being largely dependent on the fauna of tidal flats for their food. The bill length of each species determines the depth at which the bird can probe the mud. There are two species of polychaete worms and two species of amphipods living on the tidal flats, so there is some dietary overlap between the different species of wading birds. Dredging and reclamation have left only three significant remaining habitats for wading birds. The tidal flats of Como Beach of approximately 40 ha have been proclaimed an aquatic reserve vested in the Western Australian Wildlife Authority. The tidal flats and salt marshes of Point Waylen and Alfred Cove, approximately 130 ha, and 20 ha of similar habitat at Pelican Point are also preserved.

(3) Birds of the Reed Beds

The most common species of this habitat are Spotless Crake *(Porzana tabuensis)*, Banded Landrail *(Rallus philippensis)* and the Little Grass-bird *(Megalurus gramineus)*. These birds nest and shelter entirely in reed beds, only venturing onto the tidal flats in the late afternoon where they feed until the dawn. These birds are the most threatened on the Swan River since their normal habitat has been almost entirely destroyed.

(4) Fish-eating Birds

This group includes a large number of species, those commonly seen being the White Egret *(Egretta alba)*, White-faced Heron *(Ardea novaehollandiae)*, Nankeen Night-Heron *(Nycticorax caledonicus)*, Pied Cormorant *(Phalacrocorax varius)*, Little Pied Cormorant *(Phalacrocorax melanoleucos)*, Black Cormorant *(Phalacrocorax carbo)*, Little Black Cormorant *(Phalacrocorax sulcirostris)*, Australian Darter *(Anhinga rufa)*, Australian Pelican *(Pelecanus conspicillatus)*, Hoary-headed Grebe *(Podiceps poliocephalis)*, Caspian Tern *(Hydroprogne caspia)*, Whiskered Tern *(Chlidonias hybrida)*, Fairy Tern *(Sterna nereis)*, Crested Tern *(Sterna bergii)*, and Silver Gull *(Larus novaehollandiae)*.

Herons and egrets feed on small fish from the shallow margins of reed beds and tidal flats. Darters, grebes, pelicans, cormorants and terns are all active fishers of deeper water. Gulls are the scavengers. Detailed and earlier accounts of the birds of the Swan River may be found in Serventy (1938, 1944 and 1948) and Tarburton (1974).

OTHER VERTEBRATES OF THE ESTUARY.

Early references to mammals seen on the banks of the Swan River include grey kangaroos *(Macropus fuliginosus)*, quokka *(Setonix brachyurus)*, tammar *(Macropus eugenii)*, brush wallabies *(Macropus irma)*, the bandicoot *(Isoodon obesulus)* and possibly the now rare dibbler *(Antechinus apicalis)*. All these animals would have fed in the low dense vegetation of the river flats. The river foreshore has now been so changed that the area can no longer support these native mammals. The introduced rat *(Rattus rattus)* is frequently seen scavenging on the foreshores.

The only mammal that lives in the river is the water rat *(Hydromys chrysogaster)* which inhabits permanent fresh water in the south-west region of this State. It was last reported to the Western Australian Museum as being sighted near the Helena River in Mundaring in 1966. The water rat feeds on jilgies *(Cherax quinquecarinatus)* and freshwater mussels *(Westralunio* *carteri*), the hard parts of which can be seen on rocks in the water of the upper reaches. Very little is known about this shy fishing rodent.

There are some historical references made to reptiles of the river and foreshores. Fraser (Hay, 1906) noted a brown snake at Point Walter which was probably the dugite (*Pseudonaja affinis*). Moore (1884) in his diary recorded catching a yellow snake with a black head at his home by the river at Guildford in 1831. This was possibly the guardar (*Pseudonaja nuchalis*). These are now rarely seen in the Swan River area. Moore in 1832 also noted that the snake-neck tortoise (*Chelondina oblonga*) usually stole the bait off the fishing lines.

The ever-curious Moore in 1831 ate frogs offered to him by an aboriginal boy and found them delicious. The frogs had been dug from swampy ground near the river, which had dried out. Frogs are still common in the swamps near the river in the upper estuary and, although their chorus can be appreciated at night, they are not properly fauna of the river.

In Appendix A2 a list of the fauna observed by the early settlers and explorers from 1696-1860 is given. This record may be incomplete but it represents the majority of sightings reported.

INVERTEBRATE FAUNA OF THE ESTUARY

The salinity of the water and the nature of the bottom available for colonisation are the dominating environmental factors which determine the composition of the fauna of an estuary. The majority of aquatic animals is adapted to life in sea water and these marine species have varying degrees of ability to tolerate the lower salinities of estuaries. A smaller, but still considerable, number is adapted to life in fresh water and few of these freshwater species tolerate salinities in excess of about 5 ppt (parts per thousand). Only very few species are adapted to the physiological stresses of life in the brackish water of estuaries.

The paramount importance of salinity in determining the number of species is illustrated by Remane's well known diagram (Figure 26). In many estuaries there is a salinity gradient from sea water to fresh water along the length of the estuary; and, as might be expected, the number of resident species decreases from the sea to where the salinity is about 6 ppt.

In the Swan there is just such a salinity gradient in summer; however, here as in other estuaries of the south-west, salinity varies seasonally from fresh to marine or even slightly hyper-saline. A salinity of 6 ppt may be experienced at any part of the estuary for several weeks each year. Many animals can isolate themselves from the surrounding water by closing their shells or retreating into the sediment for a period. The duration of exposure to unfavourable salinities is then as important in determining survival of populations as is the actual salinity experienced.

Fish are highly mobile and can leave the estuary when the water becomes too fresh for them. However, most invertebrate animals, crabs and prawns apart, are relatively immobile and cannot retreat to the sea when salinity is unfavourable. Species which cannot tolerate the low salinity die and new stocks have to be recruited from larvae which settle from the returning sea water in spring and summer. Only the true estuarine species survive the full range of salinity experienced and their populations are recruited from animals which breed in the estuary.

Most of these animals feed on microscopic food: bacteria among decaying plant and animal matter, single-celled algae, and animals such as foraminifera and ciliates. These they take from the water, from the surface of the sand, or find in the interstices between sand grains.

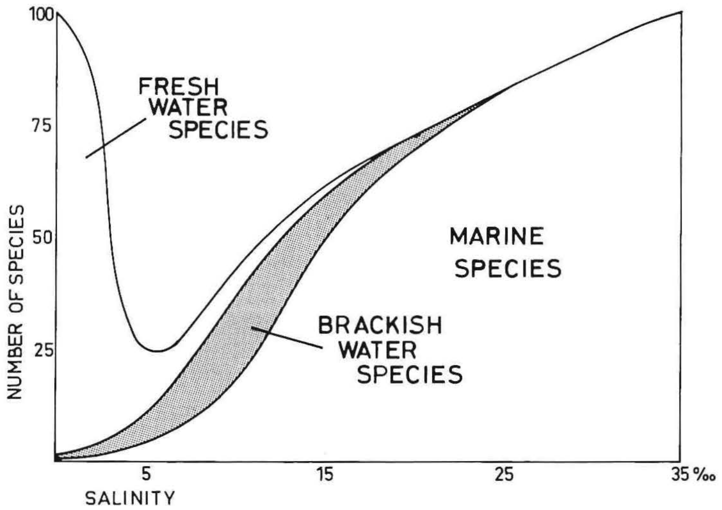


Figure 26. Remaine's diagram of the composition of brackish water faunas. *Courtesy — E.P. Hodgkin.*

The estuarine invertebrates lack the bright colours and strange forms of many seashore animals and therefore have little aesthetic appeal. They are a very important part of the estuarine ecosystem and are the food of most estuarine fish and the wading birds. The few species adapted to life in the brackish waters are very successful and their mechanisms for adaptation are of great scientific interest.

Molluscs

In a recent study by Chalmer *et al* (1976), 97 species of Mollusca were found in the Swan Estuary. These fall into four groups with respect to their response to estuarine conditions:

Group 1 — species of marine affinity, with no more than temporary or sporadic estuarine representation — 64 species (66%);

Group 2 — species of marine affinity, with more or less continuous estuarine representation — 25 species (26%);

Group 3 — species of exclusively estuarine affinity, having neither marine nor fresh water representation — about 7 species (7%); and

Group 4 — species of fresh water affinity, with limited estuarine and no marine representation — 1 species (1%).

Only 13 of the 97 species live continuously in the estuary upstream from Blackwall Reach and have self-maintaining populations there, while another 5 species are found from time to time. It is interesting to note that at least one, *Spisula trigonella,* has only appeared in the Swan Estuary quite recently.

The much greater number of species which live temporarily or permanently in the estuary downstream from the basin only experience low salinities for quite short periods, except in very wet winters.

Upstream from Perth Water, where the water is always fresh for several months, the fauna is even more depleted. Chalmer *et al* (1976) only found 6 species of mollusc there, of which 2 also live in the Avon River. Hydrological conditions in the estuary are unfavourable to freshwater animals and the only species which lives permanently in the Swan is the snail *(Plotiopsis australis).*

There is little rock on the shores but where it occurs it is well used, as are jetty piles and other solid structures. Mussels are especially abundant on timber structures and they are of particular interest. There are three species. The edible mussel *(Mytilus edulis planulatus)* is a marine animal; however, its larvae enter the estuary in spring and the spat settle on jetty piles, rocks and coarse sand. It was abundant at Nedlands throughout 1971 and 1972, when salinity never fell below about 15 ppt, but it died out again in the wet winter of 1973 when salinity was less than 5 ppt.

A smaller species, *Xenostrobus securis,* is confined to estuarine waters and is found on rocks and piles from Blackwall Reach to Guildford. Its upstream limit of distribution seems to be set by the length of time it must stay closed, and so cannot feed, when salinity is below about 4 ppt, as was shown by Wilson (1968). A third and smaller species of mussel-like bivalve, *Anticorbula amara,* overlaps in distribution with *X. securis* and tolerates a salinity of 1 ppt. It also lives in the saline waters of the Avon River. Even though it seldom occurs downstream from Nedlands, this is not because it cannot survive the higher salinities there. Actually, a fourth marine species, *Xenostrobus pulex,* invades the mouth of the estuary and lives on piles in Fremantle Harbour where it is regularly bathed by sea water.

The number of estuarine species is small, but what the fauna lacks in diversity of kinds of animals is more than made up for in numbers of individuals. They are particularly abundant on the sandy shallows of the basin. In a single shovelful of sand there may be a hundred tiny *Arthritica semen* (10 000/m^2), twenty or so of the larger *Spisula trigonella* (1 000/m^2), smaller numbers of two species of snail and hundreds of small worms.

A list of the molluscan fauna of the Swan River Estuary is given in Appendix A5.

Crustacea

There are two large species of crustaceans found in the estuary, both of which are basically marine and so are exploited commercially during the summer. The Western king prawn *(Penaeus latisulcatus)* and the blue manna crab *(Portunus pelagicus)* utilise the estuary as nursery habitats for juvenile stages. Meagher (1970) shows that female *(P. pelagicus)* incubate their eggs in the estuary and return to the sea to spawn. This movement occurs in the evenings so that hatching of the larval crabs occurs at dawn in the sea. The larvae develop to a certain extent in the sea before returning to the estuary and the richer feeding grounds. Thus, both juvenile and egg-bearing female crabs are present in the estuary during summer. The smaller greasyback or school prawn *(Metapeneas dalli)* utilises the estuary permanently and is heartily sought by amateur fishermen.

There are about eight species of small crustaceans: The shrimp *(Palaemonetes australis),* the crab *(Halicarcinus australis)* and a number of amphipods and isopods. *P. australis* is also common in fresh water, even though it lives successfully in water more saline than the sea. Mussel masses give shelter to the small estuarine crab *(H. australis)* and so it is common over much the same range as *X. securis.* Again, other species of *Halicarcinus* replace it toward the seaward end of the estuary even though the adults at least can live in sea water. Amphipods and barnacles also live in mussel masses. Barnacles are common on jetty piles, but they seldom grow large in the basin, because even though they are fast growers, the fresh water kills them.

Copepods are planktonic throughout life and are the most abundant crustaceans. Only four species are at all common in the estuary, even in summer when salinity is the same as in the sea where there are many more species. They feed mainly on single-celled algae and in their turn are an important food resource of small fish such as hardyheads and fish larvae. Two of the species are confined to estuarine and other brackish waters and manage to survive the strong river flow of a wet winter. One, *Gladioferens imparipes,* seeks the shelter afforded by seaweeds; while the other, *Sulcanus conflictus,* occurs in deeper water. The other two species, *Oithona nana* and *Acartia clausi,* also live in the sea and can recolonise the estuary from there. A detailed study of the distribution of some of the copepod crustaceans in the river may be found in Rippingale and Hodgkin (1974).

Polychaete Worms

What is true of molluscs is also true of some other elements of the fauna. Only six species of polychaete worms live permanently in the estuary.

Fishermen dig the large worm, *Marphysa sanguinea,* from the muddy banks of the river for bait. But the mud here or the sloppy mud of deep water and the shallows of the Canning is less productive than the sand flats. There are fewer species and they are less abundant as was shown in a recent quantitative survey by Wallace (1977) on part of the estuary. This is partly because of the almost total lack of oxygen in the sediment, but the fine slimy mud does not provide the same diversity and abundance of food as in the sand of the shallows. A sedentary worm, *Mercierella enigmatica,* secretes masses of calcareous tubes on rocks and timber at low water. Other species of polychaete worms have been described by Munro (1938), which are probably occasional invaders from the sea.

Foraminifera

Foraminifera constitute a group of skeleton-producing protozoans with a long geological history. The study of their distribution is important for oil exploration and recently they have been used to determine the effects of pollution and human use of rivers and estuaries.

Quilty (unpublished) has examined bottom sediments from 51 locations between the Narrows Bridge and Fremantle Harbour. Many trends have been noted and are summarised simply as follows:

Ammonia becarii (Linne) is a world-wide estuarine species and can tolerate great fluctuations of temperature and salinity. It makes up more than 50% of the fauna in the deeper areas at the Narrows and in Melville Water.

The group of foraminifera, the miliolids, are not tolerant of salinity fluctuation and are taken as indices of a marine environment. They are the majority of the fauna on the southern side of Blackwall Reach and extend just into Melville Water. The inverse relationship of *A. beccarii* and the miliolids is a marked feature of population distribution of this group in the river.

Foraminiferal number (number of specimens in 10 gram dry weight of sample) decreases markedly upstream, with a corresponding increased dominance upstream of a single species.

A narrow strip from the Narrows into Melville Water showed a higher count and a different faunal composition from surrounding areas. This may be accounted for by an influx of river-borne nutrients from upstream.

Some Other Invertebrate Groups of the Estuary

There are tiny planktonic creatures swimming in the water. Some of these are larvae of bottom-living animals and are only planktonic for a few days or weeks before they settle to the bottom. Starfishes, sea-urchins and many other marine animals form no part of the estuarine fauna, although some are occasionally found in the deep saline water of the lower estuary.

The starfish *(Anthemea australiae)* is reported as far as Peppermint Grove. The starfish *(Astropecten triseriatus)* and the small sea-urchin *(Temnopleuris michaelseni)* are distributed as far as Bicton (Marsh, pers. comm.).

The coelenterates are represented by 'jelly fish'. The clear *Aurelia aurita* and the brown *Phyllorhiza punctata* can be seen far up the estuary in summer. Occasionally the box jelly fish *(Carybdia rastoni)* is brought into the estuary by tidal movements and wind.

Two species of Bryozoa can be observed in the estuary. The marine *Membranipora sp.* encrust the edible mussel *Mytilus edulis* in the lower estuary. The more estuarine species *Conopeum sp.* encrusts on the smaller mussel *Xenostrobus securis* as far up as Guildford.

A detailed literature search of the fauna of the Swan-Canning Estuary has been completed by Hodgkin and Majer (1976) and provides additional references which may not have been presented here.

ALGAL POLLUTION

Ever since the establishment of the Swan River Colony there have been complaints of the so-called pollution of the estuary. A good deal of this criticism has been directed at the malodorous effects of the algae during summer when drift weed becomes stranded on the shores. The history of this criticism is well chronicled by the Swan River Reference Committee (1955).

No doubt the critics had cause for complaint when the estuary had extensive tidal flats bordering its course. Perhaps the disposal and treatment of sewage at Burswood Island between 1912 and 1936 added to the proliferation of the algae during the relatively stagnant summer phase of the estuary waters, although there is no conclusive evidence of this polluting effect.

It must be understood that many Australian river estuaries with extensive shallow tidal areas suffer seasonally from the rotting of stranded organic material on their shores. This is a natural phenomenon and is attributable to bacterial action and autodigestion of both plants and animal detritus.

Fortunately, the problem of excessive drift accumulation on shorelines and the odour of decomposition has almost disappeared from the Swan Estuary. The reclamation of the extensive tidal flats, the contouring of the shorelines and walling of many parts of the shoreline have prevented much of the drift material reaching the shore. (See Figure 27 for an aerial photograph of the Swan River Estuary in February 1978). Where beaches are preserved for swimming and recreation the drift detritus still comes ashore, but it is manually removed to prevent its accumulation to the point of being offensive.

It is most important that the public should understand that the algae of the estuary are an essential part of the ecosystem. They should not regard algae as pollutants as such, nor should they demand that algae be eradicated. What the public should realise is that the environmental factors which lead to eutrophication should be prevented or minimised by adequate management of the estuary and the sources of its waters from the hinterland and the sea. Algae is an important food resource for fish and wildlife.

THE AQUATIC FLORA OF THE ESTUARY

The aquatic flora of the estuary of the Swan River is derived from the marine flora of our coast by migration and survival of those species which have adapted to the considerable seasonal changes in salinity and other environmental factors of the estuarine situation.

This flora is an essential component of the complex food webs of the biota of the estuary. It is the primary producer of organic materials for the aquatic herbivorous fauna and it contributes to the oxygen and carbon dioxide balance of the biota. It also recycles part of the inorganic materials derived from degradation of organic detritus of the ecosystem, as well as utilising some of the nutrients from both the fresh waters entering the estuary and tidal water from the sea.

The aquatic flora comprises two major components — the phytoplankton (free-floating microscopic algae) and the benthic plant life (rockweeds or macro-algae, benthic micro-algae, and the sea-grasses).

Figure 27. Aerial photograph of the Swan River Estuary, 1978. *Courtesy — Lands and Surveys Department.*

The ecology of the phytoplankton has not yet been studied in any detail, but the benthic flora has been the subject of two studies: that of Royce (1955) and a recent detailed ecological survey by Allender (1970).

(1) Planktonic Flora

As already mentioned, the microscopic free-floating algae or phytoplankton of the estuary have not been the subject of any detailed ecological study to date. It is an important field of research awaiting investigation.

Seasonal water blooms or population explosions of one or other species of phytoplankton are a function of the coincidence of optimal environmental parameters for the growth and reproduction of a given species. A notable example of a water bloom in the estuary is that of the colonial diatom, *Melosira moniliformis,* which is abundant for long periods in summer, expecially in the shallow waters of the upper reaches of the estuary from Perth Water to Burswood Island.

Other recorded water blooms are those of the dinoflagellates, *Ceratium furca* and *Peridinium sp.*, in summer and autumn (Serventy, 1955).

The visual effects of these water blooms is a clouding of the water in shades of brown or grey, and it is not unreasonable for the public, seeing such blooms, to think them some manifestation of pollutants in the water. However, the phytoplanters are important food sources for the smaller herbivorous animals, especially as the metabolites of these algae are mainly energy-rich oils rather than the sugars or starches metabolised by most of the macroscopic algae.

(2) The Benthic Flora

The marine flora of our sea coast is rich in species of rockweeds or macro-algae, some 258 genera and 600 species having been recorded to date. In contrast to these statistics, Allender lists only 44 genera and 66 species in the Swan Estuary.

Another category of plants of the marine flora is the sea-grasses. These are marine flowering plants with prostrate creeping stems bearing erect leafy shoots and true roots at each node of the stem. They mostly inhabit sandy or muddy substrates which they stabilise by their grass-like habit of growth. Of the 8 genera and 11 species of sea-grasses of the south-west coast only two inhabit the Swan Estuary — *Halophila ovalis* and *Zostera mucronata.*

Other estuaries of the south-west such as Peel and Harvey have even fewer species of marine flora. Clearly few species of marine plants can adapt to the rigours of the estuarine situation. However, south-western estuaries do have extensive communities of aquatic flora, growing mostly on their sandy mud substrates.

Plant Communities of the Rocky Shore

The area of rocky shore in the Swan Estuary is not extensive. In the lower estuary from Fremantle to Preston Point limestone escarpments provide a substrate for the algae on much of both sides of the river and continue along the north bank to the north-west corner of Freshwater Bay. Further upstream there is little natural outcropping of limestone abutting on the water, since reclamation of the shallows of the river has reduced the abutment of natural rock in the littoral and sublittoral, but limestone retaining walls have provided a very limited area of rocky shore for algal colonisation.

The supralittoral of the rocky shore is desiccated in summer except for splash and spray created by the prevailing westerly winds. An encrusting belt of the blue-green alga *(Calothrix parietina)* prevails in this zone as far upstream as Perth Water. In winter this rocky littoral bears communities of *Enteromorpha spp., Ulvaria oxysperma* and *Bangia fuscopurpurea* in the supralittoral.

The littoral of this substrate is also vertically restrictive because of the narrow tidal amplitude. In the lower estuary *Enteromorpha spp.* predominate during the winter months. In Melville Water and Perth Water the green algae *Cladophora spp.* become co-dominant with the *Enteromorpha spp.*, forming a bright green band on the littoral of cliffs and stone embankments. At the lower limits of the littoral *Polysiphonia macrocarpa* replaces much of the green algae.

In the sublittoral of the rocky shore *Gracilaria verrucosa* is dominant throughout much of the estuary, and associated with it are numerous species of fine red algae. Downstream from Preston Point the *Gracilaria* community is replaced by an upper sublittoral community of *Ulva lactuca, Grateloupia filicina* and *Colpomenia peregrina.*

In mid-estuary in the vicinity of Freshwater Bay there is a community of the fucoid alga *Cystoseira trinodis* from a depth of 1-3½m, succeeding the *Gracilaria* community downshore. An understorey of *Gelidium pusillum* and *Cladophoropsis herpestica* encrusts the substratum, the whole community being heavily epiphytised by numerous species of small benthic algae.

Plant Communities of the Sandy Shore

The sand-mud bottom of the estuary supports extensive communities of sea-grasses and loose-lying algae with their epiphytic flora. From the mouth of the estuary up to Como the sea-grass *(Halophila ovalis)* is abundant. At Preston Point *Halophila* is co-dominant with the other sea-grass *(Zostera mucronata),* but elsewhere in the mid-estuary *Halophila* is associated with extensive stands of *Gracilaria verrucosa.* The *Gracilaria* is notable for its loose-lying habit in estuarine habitats. Here as in other estuaries the alga is loosely attached by entanglement in the sea-grasses or simply anchored in the mud to small solid objects to which its spores attach and germinate. Mature plants are commonly loose-lying on the bottom.

Gracilaria is also abundant in Matilda Bay and the estuarine reaches of the Canning River. The abundance of this alga accounts for its prevalence in drift on river beaches.

The brown alga *(Hormophysa triquetra)* is another benthic species which adopts a loose-lying form in estuarine habitats. Like the *Gracilaria* its sporelings develop on small solid objects in sand and mud, and the adult plants become entwined with other algae but are not attached by a holdfast to the substratum. Large communities of *Hormophysa* occur in Melville Water. From Perth Water upstream the sandy-mud bottom is practically devoid of macro-algae apart from small populations of *G. verrucosa* on mussel clumps, and on shells held firmly in the mud.

The inter-tidal region of the sandy shore lacks an algal community for want of stable substrates. The lower limit of the littoral on the sandy shore is readily observable by reference to the *Halophila* communities which occur downshore from the low water of spring tides.

The Epiphyte Flora

Of the 66 species of algae recorded from the estuary, many are small macro-algae which adhere abundantly to the larger aquatics and are consequently called epiphytes. Few of them are specific in their choice of living substrates; in fact most of them occur on a great number of different species of large algae as well as on non-living subtrates such as rock, wood and even synthetic materials like plastic and nylon detritus anchored in the mud.

The more common and abundant epiphytes of the estuary are *Ectocarpus siliculosus, Chaetomorpha aerea* and *C. linum, Giffordia intermedia, Dictyota dichotoma, Acrochaetium thuretii, Melobesia membranacea, Champia parvula, Corynospora australis, Ceramium spp.*, and *Polysiphonia macrocarpa.*

These and other epiphytes account for a considerable part of the estuarine flora and they have marked seasonality. It is notable that epiphytes proliferate to a far greater degree in calm waters of estuaries and oceanic embayments than in oceanic habitats. It is the abundance of epiphytes on estuarine algae and macro-algae that makes the latter look so unattractive compared with their marine counterparts, but it makes them microscopically interesting to the algologist as a source of many small epiphytes and micro-algae.

FLOWERING PLANTS OF THE ESTUARY

Charles Fraser, colonial botanist of New South Wales, gave glowing reports of the vegetation of the Swan River Estuary following his visit in 1827. Descriptions of the vegetation of the river margins and surrounding countryside were given for a number of localities including the present day Point Walter, Heirisson Island and East Perth (Hay, 1906).

A more or less complete zone of salt-tolerant vegetation such as samphire flats, reedswamps, fringing shrublands and forests once existed along the estuary. In general terms the vegetation of the limestone areas at the mouth of the estuary has been largely destroyed, though some remnants near Rocky Bay remain. Further upstream the vegetation of the areas surrounding the estuary varies according to the soil type. Where sufficient soil is developed over limestone, such as the Mosman Park, Dalkeith, Crawley and Mount Henry foreshores, there was once an extensive tall tuart forest. The foreshore areas of deep sands from Applecross to South Perth were once extensive jarrah-banksia woodland.

Development of roadways and recreation areas has destroyed or reduced much of this vegetation, though many areas remain relatively unaffected. It is still possible to gain some idea of the original vegetation from a study of these, as well as from observations of the Peel-Preston Lakelands and Leschenault Inlet further south.

The pattern of vegetation of the estuary is strongly influenced by its exposure, the slope of the river bank and the salinity of the water. The vegetation nearest the water's edge is rigidly controlled by the twice daily tidal movement. Above this zone the shore is only rarely inundated. Each of the plant species which grows on the estuary margin has an individual degree of tolerance to environmental factors such as submergence, salinity, exposure and soil type. It is usually possible to recognise distinct vegetation zonation involving over 30 species of native plants and some introduced ones which make up the local estuarine flora. This zonation of vegetation is obvious at any one point of the estuary where there is still some flora remaining. It is also apparent along the estuaries themselves from the more saline mouth of the Swan to the fresher upper Swan-Canning Estuary.

Steeply Sloping Shorelines

The marginal vegetation in the lower part of the Swan Estuary usually occupies a narrow zone especially where the river bank is steep. For example, along Blackwall Reach and near The Chine (Mosman Park) as well as the Dalkeith foreshore, the vegetation is only able to occupy a narrow band. In these situations the most common plant of the whole estuary is often the only one present. The reed, *Juncus kraussii,* previously known as *Juncus maritimus,* usually grows in large clumps or as an unbroken zone in these situations. Riverside trees frequently remain along these steeply sloping shores. The most common is the saltwater She-oak *Casuarina obesa.*

Most of the original vegetation which occupied steep shorelines has been drastically reduced or modified by development. The areas around Rocky Bay, Nedlands and the foreshore below Kings Park have been adversely affected by quarrying for limestone or landfill followed by construction of walls. Except in these latter areas, natural recolonisation has taken place in the same way as that which has occurred along the Kwinana Freeway, South Perth.

Saltmarshes

Extensive areas of salt-tolerant vegetation are developed on gently sloping estuarine shores. These are now rare in the lower Swan Estuary. The best remaining examples are south of Pelican Point and the Applecross-Attadale shorelines, especially at Alfred Cove. Originally, dense vegetation covered much of the section now alienated by the Kwinana Freeway, recreation areas east of Point Walter, the Nedlands foreshore, Heirisson Island and upstream from the Perth Causeway.

Fortunately there are still large tracts of saline wetlands in the upper parts of the Swan-Canning Estuary.

The remaining saltmarsh and associated wetland vegetation, such as the dense tree and shrub fringed low forests, are of vital biological importance to the whole estuary. The functional importance of such vegetation has only recently begun to be appreciated. The great biological diversity and richness of the wetland vegetation have far reaching implications, affecting the nutrient balance and hence the biological diversity of the rivers themselves.

Lower Swan Estuary

The two remaining extensive saltmarshes of the lower Swan River at Pelican Point and Alfred Cove are characterised by an outer zone of samphire which forms a low shrub community. Species such as *Salicornia blackiana* are very common in areas which are partly inundated even by normal tides. Other species of salt-tolerant flowering plants may occur in the lower tidal zone. These are the small sedge-like *Triglochin striata* and the succulent *Suaeda australis.*

The next recognisable zone is the upper tidal one which is irregularly flooded by higher tides. This is characterised by two species of samphire, *Arthrocnemum bidens* and *Arthrocnemum halocnemoides,* as well as *S. blackiana.*

Above the samphire flats occurs the common reed referred to earlier, *Juncus kraussii.* This can occur in dense stands which are almost pure or they can include smaller plants such as one of the samphires or the white-flowered *Samolus repens.* The familiar coastal sand-dune plant *Scirpus nodosus* frequently occurs with *J. kraussii,* though usually on more elevated ground on the shoreline. Inland from the dense reedswamps of *Juncus* and *Scirpus* at Pelican Point there occurs the saltwater paperbark *Melaleuca cuticularis,* and at Alfred Cove on one of the freshwater paperbarks *Melaleuca rhaphiophylla* as well as the rough-barked *Melaleuca hamulosa.*

Along less sheltered bays of the lower Swan and Canning Rivers the samphire zone may be completely absent or represented by only a few plants. In these situations, as with the steeply sloping shores described earlier, the dominant plant is the reed *J. kraussii.* Remnant isolated trees of *Casuarina obesa* and one or more of the three common paperbarks are almost always present. Examples of this vegetation type can still be seen along parts of the Applecross and Mt Pleasant foreshores. The new shoreline created by the Kwinana Freeway has been colonised largely by *J. kraussii* and introduced grasses such as the Giant Reed or so-called bamboo *Arundo donax*. So far, there has been little natural re-establishment of any trees, though this could be expected.

Middle Swan-Canning Estuary

The best preserved saltmarsh and associated vegetation is in the Canning River between the old Riverton Bridge and Kent Street Weir. This area is a virtual wilderness of marsh and *Casuarina* and *Melaleuca* thickets. *Juncus kraussii* forms enormous pure stands around some of the backwaters as well as forming the dominant vegetation along the banks of the stream channels.

Three species of paperbark commonly occur along the water's edge of the Canning River upstream from Canning Bridge. The saltwater paperbark *Melaleuca cuticularis*, mentioned previously, can easily be recognised by its gnarled appearance, white bark, grey leaf colour and star-shaped fruits. This species is more salt tolerant than the other paperbarks and frequently overhangs the river. *Melaleuca rhaphiophylla* and *Melaleuca preissiana*, the common freshwater paperbarks, have a creamy bark and rounded fruits. Both species normally have different habitat requirements. The former is more tolerant of longer inundation by fresh water and *M. preissiana* usually is a species of winter-wet depressions. Along the Canning River upstream from Canning Bridge both freshwater paperbarks occur in the super-tidal zone and are frequently mixed. There is some evidence that they may hybridise in at least one locality near Mt Henry.

The existence of seemingly freshwater-loving paperbarks along the Swan and Canning Rivers even as far downstream as Attadale and Dalkeith foreshores may be explained by postulating the presence of freshwater soil flushes. Such flushes may also explain the presence of mildly salt-tolerant plants such as the introduced bulrush *Typha orientalis*, the native bulrush *Typha domingensis* and the 'Flooded Gum' *Eucalyptus rudis* in estuarine vegetation as far downstream as the area east of Point Walter. These latter species are much more common in the upper reaches of the estuary.

In the middle reaches of the Canning, referred to earlier, extensive saltmarshes border the rush and tree-lined streams. These are dominated by the same species of samphire common downstream; but in addition there are areas of the sedge *Gahnia trifida* and tracts of *Leptocarpus* and other members of Restionaceae. The same vegetation types occur in the middle reaches of the Swan River near Maylands, though some areas have been filled.

Upper Swan-Canning Estuary

The vegetation of the upper estuary of the Swan and Canning Rivers is characterised by more freshwater-tolerant species.

Casuarina obesa, which has a wide range of salinity tolerance, is still common, but *Melaleuca rhaphiophylla* becomes dominant at the limits of the tide-affected waterways. The Kent Street Weir on the Canning River marks the boundary of salt and fresh waters. Upstream from the weir the vegetation has been undergoing change since its construction. *Melaleuca rhaphiophylla* and *Eucalyptus rudis* have endeavoured to replace *Melaleuca cuticularis* and to a lesser extent *C. obesa,* but the river bank has been adversely affected principally by clearing and grazing. Beyond Mason's Landing the streamside is dominated by *M. rhaphiophylla* and *E. rudis.* On the Swan River from Guildford upstream there are fine specimens of the 'Northern River Gum' *Eucalyptus camaldulensis;* these may be hybrids between planted specimens of that species and its close relative *E. rudis.*

Chapter Five

River Monitoring and Management

Since 1958 systematic sampling of the Swan and Canning Rivers has been carried out by the Public Health Department and the Government Chemical Laboratories for the Swan River Conservation Board, to assess chemical and bacterial levels and record information on the physical parameters of the estuary.

The sampling sites are shown in Figure 28 and their locations are given in Appendix A6. The sampling sites were selected as follows:

(1) For determining chemical and physical levels in areas of the river in close proximity to industrial waste, stormwater drains, sanitary landfill sites, septic tanks and popular swimming areas.

(2) For monitoring bacteriological levels in areas used for public swimming which could be subjected to contamination from septic tanks, industrial waste or animal faeces.

The results of the analysis from chemical and bacteriological sampling and a general summary of the effect these levels are having on the river are discussed in this chapter.

The management of the river by the Swan River Conservation Board was on a day-to-day basis and, by developing a system of regular field reports from inspectorial staff, the Chairman was continually briefed on current happenings within the river system. The monthly meetings of the Board were formal and a system was devised whereby written reports from the inspectorial staff and sub-committees were circulated prior to the meetings, allowing the Board of 19 to deal quickly and efficiently with a large agenda. In short, the Chairman was able to implement management proceedings instantly, often averting serious problems.

To explain the operations of the Board, examples of problems which each sub-committee had to deal with are given later in this chapter. The examples were selected as being typical problems and have not been singled out for any reason or prejudice by the Board. In many cases the information given to the Board was confidential, as waste disposal information could be used by competitors in detecting processes or manufacturing techniques adopted by a company and therefore have not been selected for discussion.

WATER SAMPLING

Chemical Data

The Government Chemical Laboratories have undertaken analysis for the

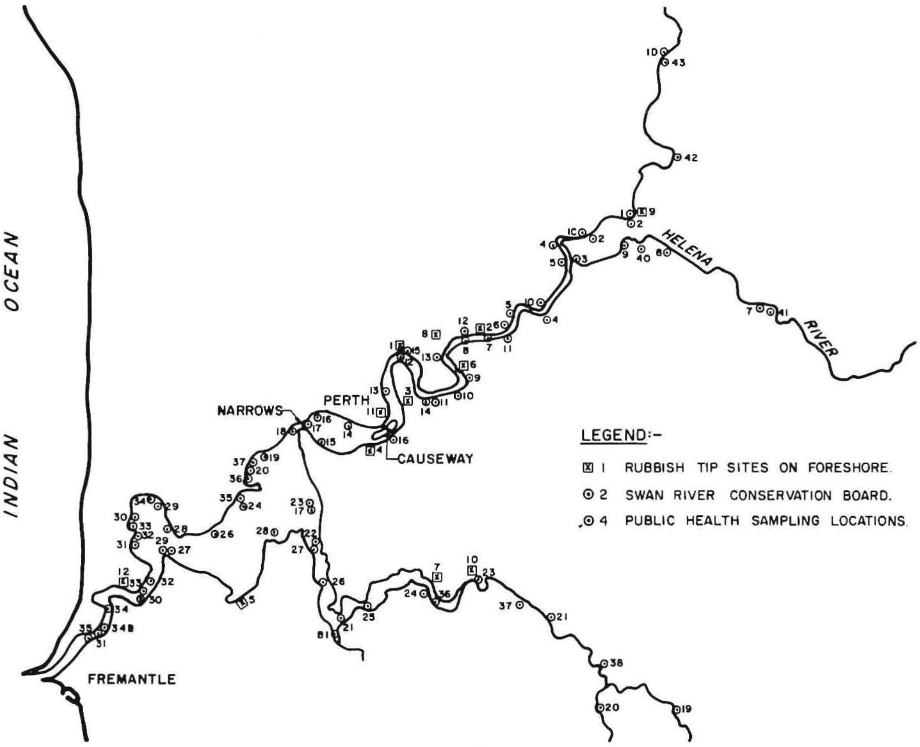


Figure 28. Map of sampling localities for the Swan River Conservation Board, Public Health Department, and location of sanitary landfill sites on river foreshores.

following chemical and physical parameters at 47 locations on the river:

Temperature
pH (acidity)
Chloride content
Oxygen absorbed from permanganate
Phosphorus
Ammonia
Biological Oxygen Demand (B.O.D.)
Dissolved Oxygen (D.O.)

To give an indication of the range of physical and chemical properties, two sites have been selected — Garratt Road Bridge (Sample Site 8) on the upper estuary and White Beach (Sample Site 28) on the middle estuary. The details of the physical and chemical analysis at these two sampling locations are given in Appendices A7 and A8 respectively. Both these areas would be representative of the average quality of the river, as the sample sites are not influenced by drains or industrial wastes, but are in locations where river water has had time to mix.

In assessing the cleanliness of the river and its suitability as a habitat for living organisms the results of sampling for B.O.D. and D.O. are most meaningful. The range of values for B.O.D. at Garratt Road Bridge was 0.7 to 16.0 with a mean of 2.8, and the range for D.O. was 8.1 to 12.8 with a mean of 7.2. The range of values at White Beach for B.O.D. was 0.1 to 4.8 with a mean of 2.3 and the D.O. was 6.6 to 11.9 with a mean of 7.9.

In comparing the mean of the samples taken at Garratt Road Bridge and White Beach with standards set by the United Kingdom Royal Commission River Classification, the 'observed condition of stream' for B.O.D. would fall between the categories of 'clean' to 'fairly clean', while the level of D.O. would fall between 'fairly clean' to 'doubtful'.

United Kingdom Royal Commission River Classification

Observed condition of stream	5-day B.O.D.	4 hours Oxygen absorbed by KMNO4	Ammoniacal N	Susp. Solids	Dissolved Oxygen (D.O.)
		— mg/l —			
Very clean	1	2.0	0.04	4	11.0
Clean	2	2.5	0.24	15	9.3
Fairly clean	3	3.0	0.67	15	8.6
Doubtful	5	5.0	2.50	21	6.6
Bad	10	7.0	6.70	35	low

The B.O.D. and D.O. levels of all sampling points on the Swan River Estuary are shown in Figures 29 and 30 respectively for the period of 1971-1975. The range of the means was 1.6 to 8.0 for B.O.D. and D.O. was 5.4 to 8.0. For ease of assessing the results of the samples for all sites on the river, a dotted line has been drawn on Figures 29 and 30 to separate the two categories of cleanliness. Both B.O.D. and D.O. from the majority of sample sites in the river are within the 'clean river' category (Figures 29-30).

Details of temperature, pH, chloride content, oxygen absorbed from permanganate, phosphorus and ammonia for all sampling points are in preparation by the Government Chemical Laboratories for publication early in 1978.

Bacteriological Data

The Public Health Department analysis of levels of bacteria present from each sample site is based on culture of three 10 ml samples, three 1 ml samples

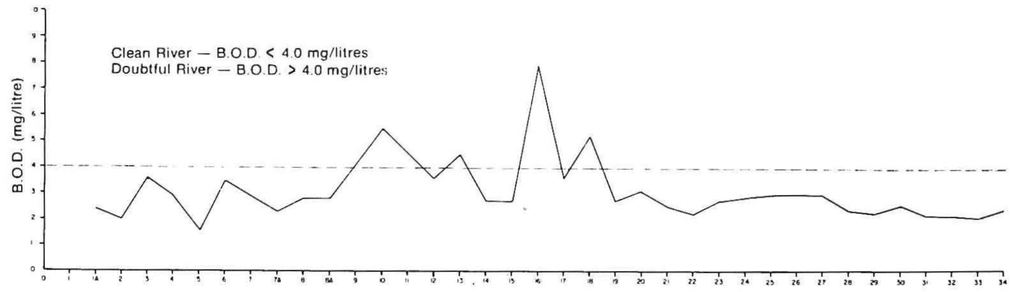


Figure 29. Biochemical Oxygen Demand (B.O.D.) along the Swan River, 1971-1975 (average values)

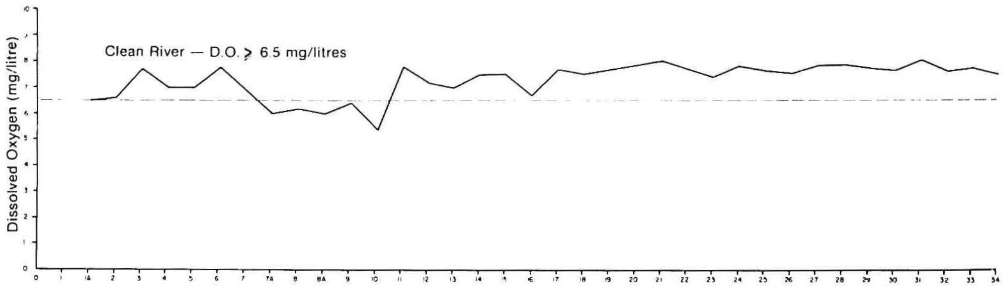


Figure 30. Dissolved Oxygen (D.O.) along the Swan River, 1971-1975 (average values)

and three 0.1 ml samples of the river water. The method of estimating the 'Most Probable Number' (M.P.N.) of bacteria present is fully described in *Standard Methods for the Examination of Water and Wastewater,* published by the American Health Association (1971).

The two types of bacteria tested are not harmful to man, but have been chosen by pathologists as indicators of pathogenic organisms such as *Salmonella* (including typhoid), *Shigella* and viral hepatitis. The bacteria monitored for routine purposes are:—

(1) Coliform bacteria which are widely distributed on decaying organic matter and are in the gut of many vertebrates; thus their presence shows general organic pollution.

(2) *Escherichia coli (E. coli),* a sub-group of the coliforms, found only in gut of warm-blooded animals. Most of these bacteria are not harmful to man but their presence is indicative of faecal pollution. Only inspection can determine whether the source of a high count is of human origin.

The presence of human sewage in recreational water poses a serious health hazard as the pathogenic organisms mentioned above are all acquired through the gastro-intestinal tract, the danger arising from their accidental ingestion. Faecal bacteria such as *Salmonella* may also infect animals such as shellfish, used by man for food. The following criteria for water quality in the river is used by the Public Health Department of Western Australia and is shown in Table 9.

TABLE 9. Criteria for water quality used by the Public Health Department of Western Australia.

*MPN of *E.coli*/100 ml	Classification
0 to 35	excellent
35 to 110	good
110 to 350	satisfactory
350 to 1100	requires investigation
1100+	unsatisfactory

*(Most probable number)

Results

The sampling results for the years 1972-1975 are given in Appendix A9. In general there are certain factors which influence the distribution of bacteria in the estuary.

(1) High bacterial readings tend to occur in rural areas upstream through drainage of surface water which concentrates the bacteria in the river.
(2) Dilution and bacteriocidal effects of salty water in the lower estuary are reflected by lower readings.
(3) High bacterial readings occur with runoff from winter rains.
(4) Dredging and desnagging operations tend to stir up the sediment resulting in high bacterial readings.

Review of the bacterial levels for the year 1976 in Table 10 shows the effects previously described. High *E. coli* readings in the Canning River in November 1976 were caused by runoff from unseasonal rain following two dry months. High readings in the Helena River are associated with manure from the holding paddocks at the abattoir. This section of the river is not a gazetted public swimming area and is usually dry by mid-summer. Occasional high readings in the lower estuary, e.g. November 1976 at Peppermint Grove, were associated with a leaking toilet on a boat.

It should be emphasised that the monthly sampling does not give a true indication of river quality, as water quality can change dramatically many times in a 30-day period, especially at areas which are consistently bad. One such area is the Canning River which can be seen in Appendix A9 to be consistently bad over a long period of time and requires detailed surveys to detect the source of pollution, so that corrective measures may be taken. The Public Health Department has not found it necessary to declare the river unsuitable for public swimming, except during the polio epidemic of 1948.

TABLE 10. Levels of coliform and *E.coli* bacteria at 37 locations on the Swan and Canning Rivers for 1976.

BACTERIA COLIFORM

1976	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1a Walyunga Short Pool	4	1	1	1	3	2	1	2	1	2	4	—
1b Walyunga Long Pool	1	1	4	1	5	2	2	3	2	2	3	—
1d Douglas Rd	1	1	2	2	4	3	3	2	1	2	5	—
2 Midland Pool	2	5	1	—	2	3	2	1	3	2	5	2
1c West Swan Bridge	2	1	2	4	1	3	2	1	4	1	3	1
4 Success Hill Reserve	2	2	1	2	4	1	2	3	2	4	4	1
5 Point Reserve	3	3	1	1	4	1	2	3	3	3	2	5
7 Scott St Bridge	1	—	—	4	2	2	2	4	1	4	5	3
8 Stock St Bridge	1	2	4	4	3	5	2	5	5	5	5	4
9 Swan St Bridge	2	1	5	3	1	4	3	5	4	4	3	1
10 Sandy Beach Reserve	1	2	1	3	2	1	1	5	3	2	2	5
11 Ascot Pool—East	1	3	1	1	1	1	1	4	3	2	1	1
12 Garratt Rd Pool	4	2	4	1	1	1	2	5	1	5	5	2
13 Bath St Pool	1	1	2	2	2	1	1	5	1	2	1	2
14 The Springs Pool	1	1	1	2	4	2	2	5	3	5	2	2
15 East St Jetty	5	1	4	3	2	1	1	5	1	5	3	2
16 Heirisson Island	1	1	1	—	1	1	1	5	4	1	2	2
17 Como Jetty	1	1	3	1	1	1	1	—	1	2	1	—
28 Applecross Jetty	3	3	1	4	1	1	1	4	1	2	1	1
29 Pt Walter Jetty	1	3	1	3	2	1	1	2	1	4	1	1
32 Mosman Park	1	2	1	2	1	2	1	1	2	1	2	1
33 Peppermint Grove	1	1	1	2	1	1	1	2	1	2	5	2
34 Claremont Baths	1	2	3	1	1	1	1	3	1	1	1	2
35 Nedlands Baths	1	2	1	3	1	1	1	1	1	1	1	1
36 Matilda Bay	1	2	1	5	1	1	1	4	1	2	3	1
37 Matilda Bay UBC	4	4	4	3	1	1	1	2	1	4	2	3
30 Bicton Pool	1	1	1	2	3	1	4	1	2	1	1	1
31 East Fremantle Pool	1	1	1	1	5	4	5	1	3	1	5	1
18 Kelmscott Pool	1	1	1	3	1	2	2	3	3	2	5	2
19 Station St, Gosnells	3	3	3	2	2	2	1	3	3	3	5	5
20 Southern River Bridge	4	4	2	5	4	4	2	2	2	4	4	2
21 Harris St Pool	4	4	1	5	5	5	1	2	5	3	2	2
23 Kent St Weir Salt	1	5	3	4	2	2	3	3	2	1	2	3
24 Riverton Bridge Pool	4	4	3	5	2	5	5	5	3	3	5	2
25 Fifth Ave, Riverton	1	3	1	2	2	4	2	4	2	5	2	2
26 Deep Water Point	2	4	2	5	2	1	1	3	2	3	3	1
27 Canning Bridge Nth	2	1	1	1	2	1	3	2	3	2	3	1

TABLE 10. Levels of coliform and *E.coli* bacteria at 37 locations on the Swan and Canning Rivers for 1976.

BACTERIA E. COLI

1976	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1a Walyunga Short Pool	4	2	3	4	3	3	4	4	3	4	5	—
1b Walyunga Long Pool	3	4	5	4	5	4	4	4	3	3	5	—
1d Douglas Rd	2	3	3	3	4	3	4	4	3	2	5	—
2 Midland Pool	4	5	3	—	3	4	3	3	4	3	5	2
1c West Swan Bridge	3	4	3	4	2	3	3	4	4	4	5	3
4 Success Hill Reserve	2	4	3	2	4	2	3	4	4	4	4	1
5 Point Reserve	3	5	1	2	4	5	4	4	4	3	5	5
7 Scott St Bridge	3	—	—	4	4	4	4	4	4	4	5	4
8 Stock St Bridge	4	4	4	5	4	5	4	5	5	5	5	5
9 Swan St Bridge	3	5	5	5	3	4	5	5	4	4	5	4
10 Sandy Beach Reserve	4	4	3	3	4	3	4	5	4	3	5	5
11 Ascot Pool-East	1	4	2	3	1	2	2	5	4	4	5	5
12 Garratt Rd Pool	4	4	4	1	5	3	3	5	4	5	5	4
13 Bath St Pool	1	4	2	3	4	3	3	5	3	4	5	4
14 The Springs Pool	1	2	1	4	5	2	3	5	4	5	5	2
15 East St Jetty	5	1	5	4	4	3	5	5	4	5	5	5
16 Heirisson Island	1	2	2	—	4	1	4	5	4	4	4	4
17 Como Jetty	1	1	4	1	1	1	1	—	2	4	2	—
28 Applecross Jetty	3	3	1	4	1	1	1	4	4	5	1	2
29 Pt Walter Jetty	1	4	1	3	2	1	1	3	2	4	1	2
32 Mosman Park	4	3	3	5	2	5	1	3	4	2	3	1
33 Peppermint Grove	1	1	1	4	2	3	2	2	4	3	5	2
34 Claremont Baths	1	5	3	3	1	1	1	4	3	1	2	3
35 Nedlands Baths	1	2	1	3	4	1	1	1	3	1	1	3
36 Matilda Bay	1	3	1	5	1	1	1	5	2	3	4	2
37 Matilda Bay UBC	4	4	4	3	1	1	3	3	3	4	2	4
30 Bicton Pool	1	2	2	3	4	1	4	1	2	1	1	2
31 East Fremantle Pool	2	3	1	2	5	4	5	1	4	1	5	2
18 Kelmscott Pool	4	3	4	5	4	4	3	3	4	4	5	4
19 Station St, Gosnells	4	3	4	4	4	4	5	5	4	5	5	5
20 Southern River Bridge	5	4	4	5	5	5	5	5	5	5	5	5
21 Harris St Pool	5	5	4	5	5	5	5	4	5	5	5	4
23 Kent St Weir Salt	4	5	5	4	5	4	5	5	5	4	4	5
24 Riverton Bridge Pool	5	5	4	5	2	5	5	5	4	4	5	5
25 Fifth Ave, Riverton	2	4	3	3	3	4	4	5	4	5	4	5
26 Deep Water Point	2	5	2	5	4	1	2	5	2	4	4	4
27 Canning Bridge Nth	2	3	3	2	3	1	4	4	3	2	5	2

MANAGEMENT

Works and Structures Committee

The following examples of works carried out on the river are of current interest:-

Dredging

There are problems of disposal of spoil dredged up during maintenance of navigation channels in Perth Water. Much of this area is barely covered at low tide and must be dredged to about 2 m to allow the ferries to operate.

Any major works of dredging in Perth Water will not be undertaken because the spoil cannot be dumped on the banks or used for horticultural purposes. It would be too expensive to truck it away by road.

Analysis of mud from Perth Water by the Government Chemical Laboratories shows that commercial utilisation of this material is difficult. The mud is rich in clay (kaolin) and calcite, with some quartz, feldspar, mica and pyrite. Salt content is also high. Blending with other material for cement manufacture or for road aggregate is possible, though expensive.

Foreshore Erosion

In the last six or seven years of the Board, residents on the foreshore lodged complaints concerning erosion of the banks caused by power boats. Investigations upstream from the Causeway have shown undercutting and erosion in areas where the bank is higher than 0.65 m above high water mark. It has become apparent that river traffic is only one cause of foreshore erosion, in that human activity such as worm digging, presence of a pathway or access to the river by livestock, all disturb the vegetation and start erosion.

Experiments have shown that, due to the great variety of hull design, reducing the speed limit of boats in the upper reaches from eight knots to four knots does not reduce the erosive power of the wash. Regeneration can only occur if access to the banks by people, livestock and boats is controlled.

The Board's policy was to use natural vegetation as a means of protecting river banks, since mechanical means such as gabions, sand bags and rubble look unsightly and can cause further problems of erosion by abrasion of the bank beneath. On the advice of the Department of Agriculture, rushes *Juncus kraussii* and salt-resistant couch grass *Paspalum disticum* have been used with success. Further assistance from the State Herbarium, along with effort and care for transplanted areas, may induce natural growth and restore former appearance.

Jetties and Structures

Inspectorial staff make an annual survey of all jetties and marinas on the Swan, Canning and Helena Rivers. Structures which become neglected can often cause erosion. Other factors such as safety and aesthetics are important considerations.

The jetties are grades A, B, C or D and must conform to a standard set by the Public Works Department. For example, a D grade jetty needs to be upgraded in 1 or 2 years, or be removed at the owner's expense. About 40 unregistered derelict jetties were removed by the Swan River Conservation Board in its last 3 years.

Industrial Committee
The Swan River Conservation Board issued 21 permits to discharge effluent to the river by 18 government or private industries. See Appendix A10 for a list of permit holders. The Industrial Committee was responsible for assessing the quality of the effluent, setting the conditions of the permit if the effluent was not acceptable, and ascertaining if the industry was conforming to the conditions set out in the permit. The following four subjects represent typical examples of companies which have discharged into the river.

The Brewery
The first brewery building on the foreshore at Crawley was established in 1837 (see Figure 31) of the early brewery on the old Mounts Bay Road. By 1926 there was still no sewage outlet available and the brewery had been discharging waste water into the river for many years. The industrial waste contained some diatomaceous earth from the filters and the solution from the bottle wash. The most important problem was that the large organic loading of the effluent was contributing to a high B.O.D. in the river adjacent to the

Figure 31. Mounts Bay Road 1889, showing the old brewery originally built as a flour mill. Travellers westward were invited to a free drink from the cask at the brewery's front door.
Courtesy — West Australian Newspapers Ltd.

brewery. Additionally, the presence of an antiquated septic system near the bank presented a potential threat of pathogens leaching into the river.

In 1960 the Board made the following recommendations to the company:

(1) To move the septic tanks away from the river.
(2) To chlorinate the washings.

In 1966 the company moved to more modern premises in Spring Street and later, due to the continuing problems of high B.O.D. of the effluent, and of odour in the area of the Spring Street drain, the brewery spent considerable sums of money to construct a pumping station and main drain to discharge waste into Perth main sewer.

The old brewery building at Crawley is still used for storage and fermenting cellars, but all waste is tankered away. The company was co-operative in upgrading its waste disposal methods to meet the Board's requirements.

The Zinc Plating Industry

In 1973 the Board issued a permit to a company to carry out zinc plating provided it used a cyanide-free process. The conditions were given:-

(1) Only zinc plating was to be carried out.
(2) 24 hours notice was to be given prior to discharge of effluent.
(3) pH was to be in the range of 7 to 8.2.
(4) Zinc concentration limit was 0.5 ppm.

In 1975, water sampling showed that cyanide was entering the drain and pH was outside the limit. It appeared that the original process was not working well and that the company had been using cyanide unbeknown to the Board since July 1974.

The Industrial Committee subsequently agreed that the cyanide was necessary to the industry and requested that the effluent be stored in large sealed tanks prior to being tankered away.

During the next few months, several serious overflows from the tanks occurred and cyanide was found in the drain, which was several kilometres from the river. The company installed a safety tank; however, the permit was deferred since it had become imperative that the process and effluent storage be made fail-safe.

In June 1976 the permit was renewed on the proviso that a bore be installed between the tanks and the drains so that inspection could detect a leak. In August 1976 a serious spillage occurred and the company agreed to certain other conditions to prevent a similar accident. It was emphasised by the Committee that only cooling water was to enter the drain leading to the river or the permit would not be renewed.

Cyanide levels in the bore were observed to fall, indicating that the cyanide present in the soil was breaking down, and that seepage was no longer occurring.

The Abattoir

There are two potential sources of pollution from the abattoir which operates near the Swan and Helena Rivers; these are as follows:-

(1) In the holding yards sheep have access to the river, where they cause bank erosion, pollute the water or sometimes die. Dust, dirt and manure, blow or are washed into the river and, in the summer when the river is not flowing, the pools become stagnant and anaerobic. Ideally there should be a fenced foreshore reserve which would exclude livestock from the immediate area of the river.

(2) Effluent from the processing plant such as washing water and other waste has been accidentally released into the Helena River in the past. The Board maintained regular inspection at the abattoir because of large liquid waste ponds near the river. A consultant engineer was employed by the abattoir to test the structural stability of the clay banks of the holding ponds. In the consultant's opinion these banks are stable and are unlikely to be affected by adverse conditions such as heavy rain. At present, because of the risk factor, the abattoir is inspected on a regular basis.

The Wool Scourers

In 1966 the Swan River Conservation Board was concerned by the problem of oil and grease released into the river in the North Fremantle area. The objectionable effluent was being washed upstream by the tide and covering beaches and boats. At the time the Industrial Committee recommended that the level of suspended solids in the effluent not exceed 1.5g/l (grams per litre). The amount of discharge was limited and time of discharge was to occur only on an outgoing tide.

In the following years there was a continuing problem. The company hired a consultant engineer, but acted only in part on the advice given, and so failed to achieve the desired results.

In 1974, acting on the advice of a technical sub-committee, the Board reviewed the standards set in 1966 for effluent discharged from the wool scourers. It was considered that the standard was in fact too difficult and too expensive to attain. At the same time the sub-committee also noted that the "extent and intensity of the (visual) pollution will impinge on public susceptibilities and cannot be ignored by the Board".

A recommended achievable level of 6g/l was proposed, which could be attained by the process of sedimentation and would minimise the visual pollution. Most importantly, the Board agreed to review a design by a consulting engineer to ensure satisfactory plant operations.

On reviewing the 1977/78 permit, the Swan River Conservation Board made the following conditions:-

(1) A retention period sufficient to achieve adequate sedimentation prior to discharge into the river was essential. As an interim guide suspended solids of 6g/l were considered as initially acceptable.

(2) The final holding tanks were to be desludged at a time to achieve optimum removal of solids prior to each discharge.
(3) The discharge should be controlled by an automatic tide switch so that discharge could be made only when there was an outgoing tide of 0.5 knots or greater.
(4) The rate of discharge for a maximum of 409 140 l per day, inclusive of wastes from the associated tannery, of the effluent should not be more than 2 410 l per minute and that the total time of discharge should not exceed 3-5 hours.
(5) No solid or semi-solid floating substances should be discharged.
(6) Discharge of effluent should be measured by means of a recording meter on the effluent discharge line and be recorded on a daily basis.
(7) Desludging operations should be monitored and records of daily quantities maintained.
(8) A log of operations should be kept in a form approved by the Board.
(9) All records relevant to these conditions should be open to inspection by the Board and copies supplied on request.
(10) Security had to be provided to prevent manual operation of discharge of the effluent without the prior approval of the Board.

Two consultants were hired, one to design suitable plant equipment and the other to set up an effective pipeline for the disposal of the effluent downstream from Fremantle Traffic Bridge. At the present time the company is complying with the conditions set out for the permit and is closely surveyed by the inspectorial staff.

Planning Committee

The decisions of this committee had wide implications, as any recreational facilities, foreshore structures or river works have a direct influence on the preservation and management of the river. The relationship of this committee with local and government authorities was of great importance.

Some examples of projects which have been of concern are as follows:-

Point Water Spit

In 1974 a proposal to dredge a channel through the sand spit was made. This proposed channel would have a bottom width of 50 m, a length of 350 m and a depth of 3.3 m, and would be situated 180-250 m from Point Walter navigational trig. The channel would reduce boat travel distance to Perth, relieve congestion near Karrakatta Bank, eliminate wash at Royal Freshwater Bay Yacht Club and lessen constriction of river flow.

Preliminary investigations made by Public Works Department showed that the channel would lessen the distance between Fremantle and Perth by 1.6 km. Previously, in 1844 a channel had been dug through the spit, which later silted up. See Figure 3 for the location of the old channel. There is a distinct possibility that siltation by river currents would once more fill up the proposed channel. The original estimate of cost of $180 000 could be well exceeded.

Further investigations are being undertaken before deciding whether the project is warranted. These investigations include drilling to determine cost, maintenance, effect on river currents and resultant effects on the feeding grounds of fish and crustacea. Most importantly, the Planning Committee needed an assessment of benefits gained by boat owners as against loss of passive recreational resources which provide enjoyment to hundreds of people who walk along Point Walter Spit.

Swan and Western Australian Rowing Clubs

These two rowing clubs were established in the 1880s and were occupying buildings on the river foreshore near the Barrack Street jetties. The buildings became derelict and have been demolished. At present an alternative site is being sought by the two rowing clubs for a joint club house.

The criteria borne in mind by the Planning Committee in selecting a suitable site included protection from prevailing winds, a stretch of sheltered water for training, adequate launching area, access, parking and ample space on shore for the entire building.

The Amateur Rowing Association of Western Australia specially requested that the Club's premises be kept on Perth Water.

Four sites were proposed for the buildings in the area of Perth Water, though Harbour and Lights Department considered only the Causeway site suitable, provided that regattas did not interfere with other river traffic. Subject to design of a recessed launching ramp, the Planning Committee supported selection of this area.

Point Roe

The Planning Committee endeavoured to establish a picnic area at Point Roe below the Colonial Sugar Refinery, this being done as the Swan River Conservation Board's contribution to the 150th Year Celebrations of Western Australia in 1979.

This area is Colonial Sugar Refinery's freehold land, so that the proposed picnic ground would interfere with the drawing and discharging of cooling water and would mean loss of non-conforming rights. The Planning Committee undertook negotiations with the Colonial Sugar Refinery to acquire the land. The foreshore of the area is still mostly in its natural state since it has been protected by the fence around the refinery. It is likely that the adjoining land may be proclaimed 'A' class reserve and that access to Point Roe may only be by boat.

Recreational Planning of the River

One of the most difficult tasks for the Planning Committee was to assess the present and future recreational facilities required on the foreshores of the river. Recent reports by Forbes and Fitzhardinge (1977) and the Community Recreation Council (1977) have shown an ever increasing number of people are using the river for passive or active recreational purposes. The objectives of the Planning Committee were to preserve the river in as near a natural state as possible and to allow amenities on the river to cater for all recreational needs.

Biological Committee

Problems such as weed growth, use of pesticides and fish deaths in the Swan River Estuary need specialised knowledge and management. One of the problems associated with this committee was the use of foreshore areas for sanitary landfill sites. The policy of the Biological Committee for waste disposal sites along river foreshores was to request an engineering plan to be included with each new proposal. This decision stemmed from the past experience of the Board and the Public Health Department with waste disposal sites on the foreshores and adjacent wetlands. The following history of river land being used for waste disposal is given to demonstrate the present concern regarding future use of river lands for this purpose.

Rubbish Disposal Sites on River Foreshores

During the 1960s local authorities were planning considerable emphasis on rehabilitation of previously unused land for recreational purposes. This often meant that disposal sites were situated on river foreshores, since there was a shortage of possible sites within the metropolitan boundaries and an important by-product of landfill is the elimination of mosquito breeding areas. This policy has resulted in the filling of about 250 ha of river foreshore and adjoining wetlands. These areas given in Table 11 were habitat and feeding grounds for waterfowl. The rubbish disposal sites are shown in Figure 28.

There is another serious problem associated with river foreshore disposal sites. This is leachate, which is formed when water percolates through a site, dissolving impurities from the waste material and building up poisonous concentrations in the soil underneath. The properties of leachate are as follows:-

pH	4-8
Hardness	400-500 mg/l
Chloride up to	2 000 mg/l
Sulphate	500 mg/l
Phosphate	100 mg/l
Organic nitrogen	up to 400 mg/l
Ammonia nitrogen	0-400 mg/l
B.O.D.	200-30 000 mg/l
Total dissolved Solids	5 000-10 000 mg/l

TABLE 11

RIVER FORESHORE & WETLANDS RECLAIMED BY LANDFILL

LOCAL AUTHORITY	LOCATION	COMMENCED	COMPLETED	AREA RE-CLAIMED HA	DEPTH	ESTI-MATED LIFE OCT.1973
City of Stirling	Deeley Street Maylands	Feb 1960	July 1960	1.2	0.9-1.8	Complete
Shire of Bayswater	Slade Street Bayswater	July 1960	Proceeding	18.2	1.5-2.4	28-32 ha
City of Perth	Rivervale	1950	1972	101.0	1.2-1.5	Complete
City of South Perth	Swanview Terrace South Perth	1959	1969	32.4	1.8-2.4	Complete
City of Melville	Canning Highway Attadale	August 1952	1970	60.7	1.4	Complete
Shire of Belmont	Stoneham Street Belmont	1952	Proceeding	8.0	3.4	36 ha
Town of Canning	Wendouree Road Wilson	January 1962	Proceeding	14.2	1.5	81-121 ha
City of Stirling	Queen Street Maylands	July 1961	1963	2.4	1.2	Complete
Shire of Swan Guildford	Third Avenue West Midland	June 1958	Proceeding	8.0	2.7-3.0	28 ha
Town of Canning	Kent Street Cannington	January 1956	December 1959	0.8	0.9-1.2	Complete
City of Perth	Trinity College East Perth	—	1972	1.5	1.5	Complete
Town of Mosman Park	Queen Street	1951	—	0.8	4.5	6 ha
			TOTAL	249.2		

Any disposal site located on a river could, depending on the hydrological conditions, discharge leachate through the soil and cause deterioration of the river water.

The Government Chemical Laboratories use the presence of ammonia as an indicator of leaching from tip sites on river foreshores. Sampling at Wilson, Midland and Bayswater sites all showed increased ammonia in the water adjacent to each, and although no algal growth was evident, the immediate vicinity would certainly be unsuitable for fish.

The Metropolitan Refuse Disposal Planning Committee (1974) proposed the use of 130 ha of foreshore and 170 ha of adjoining wetlands for future use as refuse sites, though traditional methods of sanitary landfill would not be recommended.

Techniques outlined by the World Health Organisation such as pulverising, shredding, compaction and baling are being used by local health authorities in other parts of the world, and these methods reduce the problem of leachate. The World Health Organisation (1971) also recommended that all sites for disposal of solid waste be subjected to a hydrogeological survey to ensure that groundwater and surface water will not form leachate. In view of the sandy nature of the local soils, the Biological Committee considered that any of these proposals must be accompanied by an engineering design which accounted for the problem of leachate. It is also necessary to consider that all manner of dangerous substances may be dumped by accident or ignorance and that rubbish remains an eyesore for many years. These sites are the natural habitat for wildlife and need preservation.

Aquatic Weed Infestation

The small floating plant *Salvinia molesta,* introduced as an aquarium plant, grows in such abundance in river systems as totally to block the flow and suffocate the existing plants and animals. The weed grows on the surface of fresh water, drops spore into the mud beneath where it germinates under the correct conditions of light and heat, and then floats to the surface. Under favourable conditions the species exhibits rapid vegetative growth. The plants do not tolerate salt water for long periods.

In the winter of 1972 *Salvinia* had reached troublesome proportions in the Canning River (see Figure 32). It was decided that the saline conditions of summer would kill it. Later that year winds and high tides floated the weed into fresh water above the Kent Street Weir and it was feared that the weed would eventually contaminate the waters of the Canning Dam. The Agricultural Protection Board instituted a fortnightly spraying programme using Diquat.

By 1976, the spraying had not been effective and the river was a solid mass of weeds. As *Salvinia* is not salt tolerant, it was decided to place a sand bund across the river upstream from Nicholson Road Bridge and remove the boards from Kent Street Weir to allow the distance between to become tidal.

Figure 32. *Salvinia molesta* on the Canning River at Castledare
Courtesy — Agriculture Protection Board of W.A.

Unfortunately, cyclonic conditions forced the weed upstream of the bund, creating an extra problem area.

The upstream area was 'raked' using a floating oil boom. Downstream from the bund, salt quickly killed the weed which was raked up. The adjoining swamp was pumped full of salt water, blocked and then drained. This was done several times so that the weed became stranded above the high water mark where it could be raked up and mechanically removed.

At present it is clear that chemical control is not successful. It appears that only continued work of raking and draining over a period of years will eradicate the problem.

Reserve at Alfred Cove

In 1970 recommendations were made by the Department of Fisheries and Wildlife for several reserves on the foreshores of the estuary. One of these, Alfred Cove, is a shallow backwater area bordered by samphire flats, the sand banks at Point Walter and a shoreline border of the reed *Scirpus sp.* The bottom is muddy and grown with sea-grass. The mud flats and reedbeds provide shelter and feeding grounds for wading birds, and in particular, the transequatorial migratory birds. The cove harbours a large population of fish which provides a food resource for the fish-eating birds.

The Metropolitan Region Planning Authority and the Swan River Conservation Board were proposing to develop the area for swimming and boating which necessitated the dredging of Alfred Cove and the sand bars at Point Waylen. This would have completely destroyed the feeding grounds of the birds and the depositing of spoil onto the foreshore would have covered the fossil shell deposits at Point Waylen. Dredging and reclamation in 1964 had already changed the marshy foreshore between Point Walter and Point Waylen.

In 1975 the City of Melville agreed to create a reserve along the foreshore of Alfred Cove and Lucky Bay. At present this area is in the process of being classified as a 'C' class reserve vested in the Western Australian Wildlife Authority. There are two other reserves which are important refuges for birds on the estuary. Reed Island is a 'C' class reserve from high water mark to 3 m from the fence along the Kwinana Freeway. Pelican Point is a recreation reserve vested in the National Parks Authority.

Special Projects

The Board as a whole has dealt with various problems which fall outside the concern of a specific committee, but are serious matters relating to public welfare. Some examples are given below:-

Mosquito Control

The large population of mosquitoes emanating from the area between Riverton Bridge and Nicholson Road on the Canning River was affecting residential and recreational use of adjacent land up to 5 km away. The problem was not confined to the Canning River, though other areas were less affected, due to reclamation and filling of mosquito breeding sites.

A survey was completed by the Public Health Department in 1963, which identified 9 species of mosquito and 63 actual and potential breeding sites on the Swan and Canning Rivers. It was considered that 950 ha of foreshore and adjacent wetland should be treated in the following ways:-

(1) by drainage
(2) introduction of the fish predator *Gambusia affinis,*
(3) the spreading of oil or malaroil on the water surface, or
(4) spraying with pyrethrins, D.D.T., Lindane, Dieldrin and Baytex. (Note: The above sprays are not currently being used by the Public Health Department for environmental reasons.)

The common mosquito *Culex fatigans* was partly controlled by covering the vents to septic tanks where they breed.

In 1974 and 1975, two separate environmental impact statements on mosquito control were commissioned by the Town of Canning. The following information was considered:-

(1) Three species of mosquito occur upstream from Kent Street Weir.
(2) Ten species of mosquito occur downstream in the tidal influence.
(3) Two species which are a nuisance to man are *Aedes vigilax* and *Aedes camptorhynchus.* The female *A. vigilax* lays eggs on the muddy tidal

flats; these hatch in vast numbers following flooding by summer tides, which leave warm saline pools standing for 3-4 days. *A. camptorhynchus* uses mud flats in brackish to fresh water following flooding.

(4) *A. vigilax* and *Culex annulirostris* are both known to be potential vectors of viruses. Ross River fever has been reported in Perth, but encephalitis is not believed to be a problem.

In 1976, a technical sub-committee was convened by the Town of Canning and, based on the recommendations of the consultant reports, it was decided to install a piped sand bund across the inlet on the eastern bank near Kent Street Weir. This pilot scheme is to investigate water levels and assess the depth in the breeding sites of mosquitoes. The bund was completed in February 1977, and this site has been monitored by the Town of Canning, the Public Health Department and the Board.

One must sympathise with mosquito pestered inhabitants of riverside areas; however, most control measures have had only short-term effects and long-term consequences. The filling of breeding sites is very expensive and narrows the river, causing erosion at flood time. Sanitary landfill cannot be considered because of the potentially toxic leachate. Spraying with Dibrom has an unfortunate blanket effect on all insect larvae which are the food source of fish and birds. Abate, an organo phosphate larvicide, is more specific, as it may be scattered on the mud flats to kill the newly emergent larvae as they hatch; however, using this type of larvicide requires caution and investigation before adopting it as a standard procedure for reducing mosquito populations.

Heavy Metals

Cadmium and mercury are both toxic elements which may enter aquatic food chains and become concentrated in some marine animals consumed by man. This problem of environmental poisoning is related to increased technological development throughout the world, and the Board took consideration of this fact.

The National Health and Medical Research Council of Australia has chosen a maximum permissible concentration of 0.5 ppm (parts per million) for mercury in seafood, while retaining 0.03 ppm for maximum level in other food (Hancock, Edmonds and Edinger, 1977). Blue manna crabs from the Swan River were examined by the Public Health Department and samples were within the range of 0.06 ppm and 0.17 ppm for mercury.

The World Health Organisation (1963) declared the maximum advisable concentration limit for cadmium to be 10 ppb (parts per billion) for drinking water. A study by Rosman and DeLaeter (1977) shows that cadmium content of the Swan River is 100 times lower than the W.H.O. limits.

Salmonella Studies

Salmonella are a group of enteropathogenic bacteria which are widely distributed in humans, domesticated animals, contaminated foodstuffs and the environment. *Salmonella* organisms from infected individuals or animals may contaminate the external environment, either directly when voided in faeces, or indirectly via contaminated sewage, effluents or other waste discharges.

Recent research into problems of Salmonellosis in humans, aquatic resources and wildlife, conducted by the State Health Laboratories and Public Health Department, has revealed that the Silver Gull *(Larus novaehollandiae)* may become infected with *Salmonella* serotypes which are commonly isolated from humans, foodstuffs and effluents in urban areas. These epidemiologically significant types, including the main human pathogen *S. typhimurium,* are also present in island breeding colonies and associated fauna located within the Perth metropolitan region, but are not present in marsupials, reptiles and birds inhabiting remote or less disturbed areas (Iveson, 1976 and 1977).

TABLE 12. Salmonella serotypes predominant in river wastes, seagull droppings, mussels and riverside waste disposal sites, Perth, W.A.

SEROTYPES	WATERS		SEAGULL DROPPINGS		MUSSELS	TOTALS
	River & Estuary	Tipsites	River & Estuary	Tipsites		
S. adelaide	1	1	4	9	0	15
S. anatum	2	1	1	10	0	14
S. bovis-morbificans	2	2	0	1	0	5
S. cambridge	0	0	0	0	7	7
S. chester	1	0	2	4	0	7
S. coleypark	0	0	1	6	1	8
S. derby	4	6	11	31	0	52
S. give	0	2	0	21	0	23
S. havana	3	8	1	9	0	21
S. livingstone	0	0	1	5	0	6
S. muenchen	2	0	3	7	1	13
S. newington	0	0	0	4	0	4
S. newport	0	0	0	11	0	11
S. oranienburg	1	1	1	9	1	13
S. orion	0	0	0	4	0	4
S. saint-paul	0	0	0	2	1	3
S. senftenberg	4	1	3	3	8	19
S. tennessee	0	0	0	5	0	5
S. typhimurium	2	7	1	24	3	37
TOTALS	22	29	29	165	22	267
Total (all sero-types)	23	37	32	178	28	298
Samples	172	23	423	351	118	1 087
Samples Positive	18	12	23	128	22	203
% Positive	(10.5%)	(52%)	(5%)	(37%)	(19%)	(18.7%)

Sanitary landfills located in river, wetland and coastal environs attract large numbers of seagulls, and at these forage sites the interaction of food wastes, bird droppings, contaminated soil and surface waters creates active foci of infection, with subsequent transmission of pathogens by bird vectors to adjacent areas.

The results of studies, summarised in Table 12 show the distribution patterns of commonly occurring *Salmonella* serotypes in river waters, seagull droppings and mussels. With the exception of only *S. cambridge* the serotypes listed have been isolated from humans, and are of major epidemiological significance in the metropolitan area. *S. derby, S. havana* and *S. typhimurium* were widely distributed in river waters, bird droppings and tipsites, whereas *S. cambridge, S. senftenberg* and *S. typhimurium* were predominant in mussels.

Over the years, no *Salmonella* infections have been traced to bathing, boating or skiing in river or estuarine waters; however, in 1967 two children contracted gastro-intestinal infections after eating lightly cooked mussels which they had collected at North Fremantle. *S. typhimurium* was isolated from the two children and also from mussels collected in the area.

Swans, water hens and wild duck frequenting river environments and nearby ponds and lakes have occasionally been found to harbour *Salmonella* (Iveson, pers. comm.). Infections have not been detected in pelicans, cormorants and a variety of transequatorial migrants including Red-necked Stints, Curlew Sandpipers, Knot, Great Knot and Grey Plovers.

The lower reaches and foreshores of the Swan and Canning Rivers are extensively used for public recreation, particularly during the summer months. It must be considered that unnatural foci of infection at riverside waste disposal sites, with subsequent dispersal of contaminated birds to recreational areas, maintains a circle of infection which results in wildlife and river environments becoming more directly involved in the epidemiology of human Salmonellosis.

The Port of Fremantle

The management of the river from the mouth to the upstream side of the Fremantle Traffic Bridge is under the jurisdiction of the Fremantle Port Authority (F.P.A.). The maintenance of a harbour of this size and importance is a difficult task and the F.P.A. has very clear and stringent regulations governing disposal of garbage and oily or chemical water from local or foreign ships.

It is a breach of the law to deposit waste material within the harbour or within three nautical miles from the coast. To encourage proper disposal the F.P.A. has installed an oil-fired incinerator on North Mole which complies with the requirements of the Commonwealth Department of Health. Should oil waste and water, sewage or chemical waste which may be injurious to marine or animal life or cause oxygen depletion of the river water, need to be disposed of, this can be tankered away from the wharf. The F.P.A. takes a very serious view of oil spillage. The Prevention of Pollution of Waters by Oil Act (1960) provides for a maximum penalty of $50 000 for each offence. To ensure that the river is not polluted by a spill, the F.P.A. has installed an air boom which can be activated in case of accident.

Drainage

The area known as the Perth metropolitan region has an extremely high ground water level. Originally the area which is now the city was swamp land with several lakes, and as a consequence there is a vast system of land drainage comprised of subsoil drains, open drains and pipe drains. These systems take water from surface runoff, roads, gutters, pavements, developed areas and land used for small agricultural pursuits such as chicken raising or stabling of horses, and discharge it into the river. Consequently water sampled at drains will have high bacteriological counts and biological oxygen demand, as rotting vegetation in recreational areas and on verges contributes a great deal of organic matter to the runoff.

Originally, all industries which grew up on the foreshores discharged directly by drains into the river, since only the metropolitan area and Fremantle were serviced by sewage treatment plants. The sewage plant at Claisebrook caused great problems with algae growth, and in 1936 the sewage from the Perth area was directed to the Subiaco Treatment Works

In the following years, the Trades Waste Inspectors, with the authority of the Metropolitan Water Supply, Sewerage and Drainage Act (1909), were instrumental in many industries going on sewerage. The Swan River Conservation Act (1958) later provided more specific control of industrial effluent and use of drains to the river.

Septic Tanks

It has been estimated by Sanders (1976) that 45% of the Perth region uses septic tanks. A standard domestic septic unit has a total capacity of 3 180 l. It is estimated that on the average each resident of Perth uses 135 l of domestic water each day, so that the average family will use the total capacity of the tank in less than 5 days. From the soakwell, the septic effluent flows through the ground to enter the water table. The Public Health Department has a requirement that septic tanks must be at least 30 m from any known water source.

The Mines Department Annual Report (Allen, 1975) estimates that 36.5 times 10^6 cubic metres per year of unconfined groundwater flows into the Swan River and Ellen Brook. Considering the widespread use of septic systems, the possibility of bacteria and enriching nutrients entering the river was of concern to the Board.

Research is being undertaken by several workers at the C.S.I.R.O. on the effects of leachate on groundwater and the flow of affected groundwater into streams. This information is important for the following reasons:

(1) It is necessary to understand the effects on groundwater of bacteria, nitrates and phosphates from septic tanks.
(2) Water resources in Western Australia are limited and the possibility of using aquifers for domestic water in the future is very real.

The investigators have already found some interesting facts. Septic systems located on the Swan Coastal Plain work very efficiently due to the sandy soil. The yellow sands of the plain are rich in iron and aluminium which tend to bond and hold the phosphate as the effluent filters through the soil. The presence of detergents makes the flow of groundwater easier and faster. It seems that the eventual build-up of chemicals, particularly nitrates, in the groundwater could eventually make the water unpotable; however, the purifying properties of the soils and the soil bacteria of this region are not yet fully understood. It is estimated that at present-day costs, the conversion of Perth to deep sewerage will cost 1 000 million dollars.

Chapter Six

The Waterways Commission

With the increasing usage of the Leschenault Inlet and Peel Inlet waterways some degree of control became necessary and in 1968 the Leschenault Inlet Advisory Committee was established, a similar organisation for the Peel Inlet being formed in 1971. While these two committees rendered excellent service they had no statutory powers and no funds with which to promote research and management programmes. Furthermore, while the Swan River Conservation Board was a statutory body, the 18 years of its operations revealed some inadequacies in its Act.

Firstly, the boundaries of the Board were restricted to high water mark with terminal boundaries at the Fremantle Traffic Bridge, the junction of the Swan River with the Gatta River, immediately upstream from Walyunga National Park, the lower diversion dam on the Helena River and the Brookton Road Bridge on the Canning River. Secondly, penalties for breaches of the Act were small and under present-day money values not an adequate deterrent; and finally, the Board was only empowered by the Act to expend moneys on administrative costs.

In view of the increasing importance of all three waterways to the community, their recreational value and the need to preserve and enhance the quality of the waters, the Government passed the Waterways Conservation Act in December 1976, and proclaimed it in July 1977. This Act provides for the setting up of a Waterways Commission and three Management Authorities under its jurisdiction, i.e. the Swan River, the Leschenault Inlet and Peel Inlet, and at the same time for the abolition of the Swan River Conservation Board. The Act also provides for the establishment of Management Authorities for other waterways within the State, if and when considered desirable.

The boundaries for these Authorities are not restricted to high water mark, but include all land areas that could be of interest to the Authorities in the performance of their functions of preventing pollution and the co-ordinating of recreational facilities. With respect to the latter, moneys may be appropriated from time to time to assist in the funding of such facilities.

Penalties for breaches of the Act have been substantially increased to realistic figures and provision has been made for the appointment of honorary wardens and increased powers for inspectors.

Summarising, the new Act has the following major differences as compared to the provisions of the old Swan River Conservation Board Act:-

(1) Boundaries have been expanded from high water mark to include land areas likely to be of interest.
(2) Penalties have been substantially increased.
(3) Powers of inspectors have been increased and honorary wardens may be appointed.
(4) Moneys may be expended on assisting the establishment of shore based recreational facilities.
(5) The operations of the Authority will be funded entirely from government sources whereas, previously, local government authorities provided one-third of the funds required.

With the experience gained by the old Board and the additional powers and moneys provided under the new Act, the Authority should now be in an excellent position to fulfil the intent of the Act, to maintain water purity concurrently with maximum recreational usage of the waters and adjoining public lands, and the preservation of flora and fauna.

Chapter Seven

Proposals for Future Research

The people of Western Australia are fortunate that no major industry has ever been allowed to develop on the foreshores of the estuary and its tributaries or in its catchment area. The geographical characteristics of the estuary with the flushing effect of marine tidal water and winter rains act to keep the river refreshed and living. Since settlement, the changes brought about by man's development have directly affected the biological character of the river. With few exceptions, all the species of flora and fauna originally sighted by the early settlers can be seen on the river today, though loss of habitat has meant that many species are less abundant.

During the course of this research it became evident that there is a lack of in-depth knowledge in many fields which are of importance to the future management of the fish and wildlife of the estuary. It is interesting that so many people who are very familiar with the estuary take for granted that the ecology is well known and understood; however, such is not the case. This study has found that there are large gaps in the knowledge of the river's ecology and its hydrodynamics.

The following proposals for future research on the Swan-Canning Estuary have been forthcoming from many workers who have contributed to this project. It is hoped that the State through its Waterways Commission will support and encourage these studies to be carried out by government instrumentalities, academic institutions or private individuals.

(1) The quality and quantity of the water which enters the estuary via its tributaries and groundwater have been greatly altered. Increased land-use around the catchment areas has affected surface runoff while septic tank effluent and leachate from waste disposal sites pose a threat to groundwater supplies. Works in the lower estuary have increased the tidal influence, while damming of the rivers has reduced the flow of fresh water into the estuary. Indications are that the estuary is remaining more saline for longer periods each year and has altered chemically over the years. There is need to assess the true nature of these changes along with evaluating the effect rainfall has on the system, total river discharge, and the scouring effect that winter rains have on the estuary. These studies should be established in such a manner that they may be conducted over a long period of time.

(2) There is little information available on the sediments of the estuary, or on the effect increased sedimentation from the river training

programme in the upper reaches is having on the life-cycle of bottom dwelling fauna or on fish breeding areas.

(3) The present system of water sampling was designed to monitor industrial effluent, drains or agricultural runoff. It is necessary to extend the sampling programme so as to gauge true water quality in areas of importance for fish and wildlife.

(4) Some information on leachate from rubbish disposal sites and from septic tanks has been acquired; however, the studies need to be conducted over a lengthy period in order to establish seasonal trends, the time that leachate will continue to be produced from tip sites, and the possible effects that leachate will have on the quality of river water and the flora and fauna that live in it.

(5) An urgent study is needed on foreshore rehabilitation and bank erosion in areas which are damaged by excessive use by people, boat wash or natural wave action. Much foreshore area is at present in a degraded state and overgrown with weeds. The problem can be aided by research into salt-tolerant species of plants which would restore stability of the banks and the use of native species which would re-establish the natural appearance of the foreshore.

(6) There have been few studies on the invertebrates of the estuary. Particularly lacking are investigations on the crustaceans and polychaetes which are an important food source for fish and birdlife. Studies need to be conducted to understand the ecological relationships between invertebrates, the sediments and the plants (including diatoms), and the feeding habits of the fauna that depend on them.

(7) Two important areas of interest are:-

(i) To obtain quantitative data on the seasonal and annual abundance of all fish and crustaceans of commercial or amateur importance in the Swan-Canning Estuary.

(ii) To study in detail the biology of selected fish and crustaceans, including all species which have commercial or sport fishery application, including investigational aspects of their natural history such as growth rates, breeding times and distribution. This information would be useful as a basis for formulation of appropriate management policies.

(8) Information is required on the effects of dredging, effluent discharge and the discharge of hot water in relationship to the distribution of fish and crustaceans and their food resources. It may be that such physical and chemical alterations or the existence of a thermal curtain, particularly in the narrow reaches of the estuary, are interfering with the normal seasonal migration of fish and crustaceans and rendering large areas of the estuary unsuitable as feeding or breeding grounds.

(9) Studies are required to determine the magnitude of the annual production of the commercial species of fish, crabs and prawns if

breeding stocks are to be maintained.

(10) Commercial production statistics of fish, crabs and prawns should be maintained and kept on an annual basis for the Swan-Canning Estuary.

(11) Investigations into the total biomass of phytoplankton and benthic flora need to be undertaken. It is thought that the growth of weed in the estuary is not solely determined by nutrient levels in the water. This problem may be better assessed by research into primary productivity of the individual species and the hydrological regime that each requires to live and reproduce.

(12) The estuary is particularly vulnerable to pollution in the summer when there is only tidal exchange to clean the water. It is important to examine the potential for it to become polluted during this time of the year, since recreational use of the estuary is becoming more intense, especially during the summer period.

(13) The soundings shown on all maps available date from the early 1900s. It is suggested that detailed soundings of the river be made at intervals of about 10 years. This would be valuable in showing the movement of sediments and the alterations to the bottom contour by dredging operations.

(14) Natural and man-made waves cause serious erosion of banks. It is suggested that waves be studied in relation to weather patterns, sea breeze, heavy winter blows and abnormal water levels. These studies would aid in the preparation of management plans for foreshore stabilisation to cope with natural man-made wave action.

It is clear from this study that sufficient information exists on the physical, chemical and biological aspects of the estuary and an attempt should be made to establish the basic relationships between the hydrodynamics of the estuary and the flora and fauna that inhabit it either on a permanent or a transitory basis.

In order to take into account the many interactions between the biological life and its changing habitat it would be necessary to assemble the data so that a mathematical model could be formed. This approach to the complex relationships that exist within a river or estuary system is well documented in Great Britain and North America. Similar models have been described by Williams and Hinwood (1976) for Australian waterways.

This type of approach is necessary when dealing with a complex biological system which lives in a habitat that is changing through tidal influence, fresh water or brackish tributaries in its upper reaches, the development projects of man and possibly also climatic changes. A challenge exists for a group of research workers to co-operate in the assembling of all data and to produce a mathematical model which will be of practical value for use in the future management programme of the Swan-Canning Estuary.

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APPENDIX A1

LOCATION OF DREDGING AND SPOIL FROM 1892-1976 CARRIED OUT BY PUBLIC WORKS DEPARTMENT

DATE	LOCATION OF DREDGING	REASON	AMOUNT cu. m.	LOCATION OF SPOIL
1892-1896	Fremantle Harbour and entrance	Navigation	1 414 008	Northern bank and Arthur Head
1895-1896	Claisebrook channel from Guildford	Navigation	5 293 071	Foreshore
1896-1897	Canning River to Kennedy's landing	Navigation	10 167	Foreshore
1897-1901	Barrack St. Jetty and Mends St. channel	Navigation	31 681	Deep water
1901-1905	Barrack St. Jetty and Mends St., Coode St. channel	Navigation	30 000	Barrack Square
1914-1922	Fremantle Harbour and entrance	Navigation	986 895	Ocean
1909-1910	Barrack St. to Narrows channel	Navigation	50 000	Mounts Bay reclamation
1909-1912	Lord St. to Causeway	Navigation	20 000	Riverside Drive and Mounts Bay Rd.
1920-1930	Fremantle Harbour	Navigation	602 421	Ocean
1922-1926	East Perth Power House	Construc.	29 705	Shell for roads
1922-1929	Channels in Perth Water	Construc.	103 260	Riverside Drive roads
1927-1928	East Perth-Langley Park	Mosquito control	132 345	Foreshore Langley Park
1927-1928	Causeway	Navigation	20 486	Heirisson Island
1929-1935	Barrack St. to Causeway and Heirisson Island	Navigation	787 299	Causeway and Heirisson Island
1935-1936	Melville	Mosquito control	136 170	Melville foreshore
1935-1939	South Perth from Mill Point	Mosquito control	163 842	Foreshore South Perth
1936	Pelican Point	Mosquito control	96 372	Royal Perth Yacht Club
1936	Armstrong Spit and Dalkeith	Mosquito control	342 743	Foreshore Dalkeith
1936-1939	Causeway to Manning Point	Navigation	400 129	Foreshore and Heirisson Island
1936-1938	Nedlands, Dalkeith, Subiaco scheme	Mosquito control	2 076 750	Nedlands foreshore
1937-1938	Causeway	Navigation	20 486	Heirisson Island
1939-1941	Mill Point Rd. to Coode St. and Millers Pool	Mosquito control	404 127	Foreshore South Perth
1936-1940	Fremantle Harbour	Navigation	264 600	Ocean
1946-1964	Causeway up to Bunbury Bridge	Flood control	1 060 935	Heirisson Island, Victoria Park
1946-1949	Inner harbour Fremantle	Navigation	10 058	Ocean
1947-1950	Fremantle Harbour entrance	Navigation	90 909	Ocean
1950	Garratt Rd. Bridge	Construc.	small	Shell for cement
1950	Maylands Swimming Club	Recreation	small	Maylands foreshore
1952-1954	Upstream and downstream from Causeway	Construc.	920 820	Heirisson Island Hay St. Bank

APPENDIX A1

LOCATION OF DREDGING AND SPOIL FROM 1892-1976 CARRIED OUT BY PUBLIC WORKS DEPARTMENT CONTINUED

DATE	LOCATION OF DREDGING	REASON	AMOUNT cu. m.	LOCATION OF SPOIL
1954	Pelican Point	Foreshore protection	small	Mounts Bay Sailing Club
1956-1962	East end Fremantle Harbour	Construc.	2 217 268	North Wharf, No.10
1956-1962	Fremantle channel and 'Knuckle'	Navigation	123 804	Reclamation North Wharf
1956-1962	Fremantle Harbour entrance	Navigation	181 570	Reclamation North Wharf
1956-1962	Fremantle Harbour	Navigation	675 319	Reclamation North Wharf
1956	Narrows to Barrack Street and Mill Point Spit	Navigation	425 172	Mounts Bay Rd. and Mill Point
1957-1960	Mill Point, Narrows, Barrack St., and Mends St. channel	Construc.	1 149 598	Mounts Bay reclamation
1957-1960	Barrack St. jetties	Construc.	10 863	Mounts Bay reclamation
1957-1960	Mill Point	Construc.	348 195	Shell for Mounts Bay Rd.
1957-1960	Mill Point — South	Construc.	1 325 427	Mounts Bay reclamation
1958-1960	Como to Canning Bridge	Construc.	637 690	Kwinana Freeway
1958-1960	Mill Point — Narrows mud waves	Construc.	1 511 636	Kwinana Freeway
1958-1960	South Perth Yacht Club	Recreation	577 580	Point Heathcote
1959	Downstream Canning Bridge	Foreshore protection	233 592	Canning Bridge embankment
1959	Nedlands Yacht Club	Recreation	9 211	Foreshore Nedlands
1960-1961	Perth Water at South Perth	Recreation	422 037	Sir James Mitchell Park
1960&1962	Waylen Bay	Recreation	100 000	Foreshore Applecross
1962	Barrack St. jetties	Navigation	small	Deep water
1962&1964	Nedlands and Pelican Point	Recreation	7 268	Perth Flying Squadron
1962-1963	Preston Point	Recreation	22 958	Preston Point foreshore
1962-1964	Point Walter	Recreation	20 943	Point Walter foreshore
1962	Empire Games Rowing Course	Recreation	30 600	Rowing Association Club House
1962	Fremantle	Recreation	29 660	Fremantle Rowing Club
1963	Upstream Fremantle Traffic Bridge	Foreshore protection	64 260	North Fremantle
1964-1965	Point Walter to Point Waylen	Recreation	263 160	Attadale foreshore
1960-1964	Canning River, Rivervale	Mosquito control	284 580	South-eastern bank
1964	Chidley Point	Recreation	small	Chidley Point foreshore
1965-1967	Upstream from Causeway	Flood control	735 473	Rivervale foreshore
1965-1966	Barrack St. jetties, drains and channels	Navigation	45 464	Deep water
1965	Narrows	Construc.	158 355	Mitchell Freeway
1965	Site of old North Fremantle Traffic Bridge	Navigation	2 502	Ocean
1965	North Fremantle	Construc.	75 520	North Fremantle

APPENDIX A1

LOCATION OF DREDGING AND SPOIL FROM 1892-1976 CARRIED OUT BY PUBLIC WORKS DEPARTMENT CONTINUED

DATE	LOCATION OF DREDGING	REASON	AMOUNT cu. m.	LOCATION OF SPOIL
1967	Mosman Bay	Beach	5 355	Mosman Bay beach
1968	Bunbury Bridge to East St., Maylands	Flood control	395 505	Burswood Island (Belmont)
1968	Upstream Garratt Rd. Bridge	Flood control	92 565	North bank, Bayswater
1968	Upstream Canning Bridge	Navigation	5 011	Foreshore
1969	Garvey Park	Flood control	227 205	Central Ave., Redcliffe
1969	Point Heathcote	Foreshore protection	16 402	Como Sea Scouts and deep water
1969	Garratt Rd. Bridge	Foreshore protection	10 178	Garratt Rd. Bridge and deep water
1969	Point Walter and Armstrong Spit	Recreation	69 893	Perth Flying Squadron and deep water
1969	South Perth-Melville Water	Foreshore protection	18 781	Kwinana Freeway foreshore
1969	Maylands	Flood control	14 114	Beach
1969	East St., Perth	Navigation	49 779	Burswood Island
1970	South Guildford	Flood control	42 190	Guildford Primary School fields
1967-71	Upstream from Causeway	Flood control	575 460	Maylands Peninsula Stage I
1973-74	Upstream from Causeway	Flood control	900 000	Maylands Peninsula Stage II
1972-73	Upstream from Causeway	Flood control	42 685	Garvey Park
1972	W.A.I.T. Rowing Club — Canning River	Recreation	15 094	Beach
1971	Barrack St. and Spring St. drain	Navigation	42 809	Deep water
1971	North Fremantle	Recreation	61 437	Preston Point foreshore
1971	Swan River Yacht Club and Leeuwin Jetty	Navigation	7 604	Deep water
1971	Point Walter and navigation channel Attadale	Navigation	38 020	Deep water
1972	Como	Foreshore protection	800 000	Como foreshore
1972	Point Walter ramp	Recreation	790 000	Beach
1976	New Mends St. Jetty and channel	Navigation	15 743	Deep water
1976	Maylands Swimming Pool	Recreation	4 700	Beach
1976	Barrack St. Jetty	Navigation	2 243	Deep water
1976	Applecross	Recreation	4 333	Deep water
1976	Canning River Rowing Course	Recreation	small	Foreshore
up to 1952				
1973-76	Upstream and downstream from Causeway	Cement	1 530 000	Shell for Swan Portland Cement
	Upstream and downstream from Causeway	Pipes	8 844	Blizzard Sand Company

APPENDIX A2

HISTORICAL REFERENCES TO WILDLIFE

DATE	REPORTER	LOCATION	TYPE	SPECIES	NOTES
1696	Willem de Vlamingh	Cottesloe	Birds	Wild parrots, parakeets Black swans, cormorants	Plenty Many
		Swan River	Fish Birds	Not stated "Nightingale", pelicans, geese, cockatoos	A quantity
			Insects	Flies	Terribly tormenting
June 1801	Fréycinet of 'Naturaliste'	Swan River	Birds	Pelicans	Prodigious multitude at entrance
			Birds Mollusca	Land birds and elegant parrots Transparent molluscs	Great flocks
		Perth Water		More pelicans	
		Heirisson Island		Black swans, dugong	Frightened the party
June 20 1801	Stanislas Levillain of the 'Naturaliste' — died 6 months later of dysentery	Swan River	Mammals Birds Birds	Kangaroos Red-bellied green parrots Large vulture like bird of prey, probably *Uroaetus audax*	Several Large numbers One
			Birds	Large nest in a fig tree probably — White-breasted Sea-Eagle *(Haliacetus leucogaster)*	One
			Plants	Macro-zamia Reidlei	Company became very ill after eating its fruit
1827	Charles Fraser	Swan River	Birds Reptiles Birds	Corellas Land tortoises Black swans, pelicans, ducks and other aquatic birds, emu	Large flocks Plentiful 500 swans were shot and eaten with relish
			Mammals Fish	Kangaroo, native dog	Abundant
1827	Capt. Stirling	Swan River	Mammals	Kangaroo possum, native dog	Heard at night
			Reptiles	Tortoise, lizards, goannas and and one snake seen	
			Birds	Emu, abundance of swans, several varieties of duck, parakeets, cockatoos, white and black pigeons, quail	

APPENDIX A2

HISTORICAL REFERENCES TO WILDLIFE CONTINUED

DATE	REPORTER	LOCATION	TYPE	SPECIES	NOTES
May 1829	Capt. C.H. Fremantle	Swan River	Birds	Cormorants	Many
1829	Lieut. Preston	Canning River	Birds	Emu, swan, cockatoos, parakeets	
			Mammals	Dingo,kangaroo and kangaroo rats	
Nov. 1829	Lieut. Breton	Swan and Canning Rivers	Birds	Black swan, ducks, teal, widgeon and other birds, cockatoos, white and black, common crow	Numbers of all rapidly decreasing due to hunting
			Arachnid	Scorpions	Three
			Insects	Winged ants	Incredible number
			Mammals	Native dog or wolf	
			Insects	Blowflies	Swarming
Nov. 1829	Rev. J.G. Powell	Swan River	Mammals	Kangaroo, kangaroo rats, possums	
			Birds	Emus, quails, pigeons, black swans, wild ducks, widgeons, pelicans, cockatoos, parrots, parakeets, crows, jays and flycatchers	
			Reptiles	Lizards and venomous snakes	Mentioned
			Fish		Plentiful
			Insects	Mosquitoes	Very annoying at night
1829	Spencer Trimmer	'Lagoons'		Large animal like the hippopotamus, (dugong?)	Reports only
Oct. 1829	Dr. Wilson	Darling Range	Birds	Black cockatoo (red)	Feathers on aboriginal hair ornament
			Insects	Grubs from a grasstree	Loathsome looking
Jan. 1830	Mrs. Jane Roberts	Fremantle	Birds	Black swans	Thousands and tens of thousands rose and darkened the air
			Insects	Mosquitoes	Buzz and sting at night
			Reptiles	Lizard	Feeding on the above
Jan. or Feb 1830		Swan River & Tributaries	Birds	Wild duck, teal, widgeon, black swans and pelicans	Black swan much persecuted All large flocks
			Fish	Several kinds	Swarms — excellent eating and easily caught

APPENDIX A2

HISTORICAL REFERENCES TO WILDLIFE CONTINUED

DATE	REPORTER	LOCATION	TYPE	SPECIES	NOTES
			Reptiles	Turtle — *Chelodina oblonga*	Makes very excellent soup
			Birds	White and black cockatoo, quails, 2, 3 varieties of pigeons, crows, magpies, eagles, hawks, owls; several kinds of gull, sandpipers, other sea birds, parakeets	Great numbers, all very good eating
			Reptiles	Number of species — diamond snake	Exceeding 9ft. quite harmless
			Insects	White ants	Often in large timber
Aug. 1830	Ensign Dale	Darling Range	Mammals	Native dogs	1 litter
			Birds	Emus	Tracks only
Sept. 1830	Lieut. Erskine	Avon River	Mammals	Kangaroos	Numerous
			Birds	Emu tracks and black swans	
Oct. 1830	Mr. Harvey	Mt. Elizabeth	Reptiles	Lizards	Astonishing number
			Birds	Fairy Martin	Several nests — judged to be swallows.
				Ducks, musk ducks and small fish	pools of fresh water
Jan. 1830	Mrs. Mary-Anne Friend		Insects	Flies and fleas	Were beyond description — annoying.
March 1831	G.F. Moore	Guildford	Mammals	Kangaroo	Hunted with dogs
				Possum, kangaroo rat, rats and mice	Abundant — mischievous
			Birds	Wild turkeys, cockatoos, (white, black grey and black, with red tail)	
				Parrots, pigeons, quails, magpies, jays, hawks, black swan, pelican, scarlet breasted robin, buff-bellied shrike-thrush, banded blue wren	Description of 28s, pigeons, bronze coloured wing.
			Fish	Perch	Abound, caught with a trammel net
			Reptiles	Turtle	
				Snakes	Do not seem to be at all dreaded
			Insects	Lion ant, small brown ants, white ants	Wonderfully numerous, trees swarm inside and out
			Mollusca	Clams	

APPENDIX A2

HISTORICAL REFERENCES TO WILDLIFE CONTINUED

DATE	REPORTER	LOCATION	TYPE	SPECIES	NOTES
June 1831	G.F. Moore	Guildford	Reptiles	Snake 18" long, black headed, yellow body	One — put him in a bottle of rum
			Arthropoda	Centipede	4" long
			Birds	Leaden crow-shrike (squeaker)	Shot
				Crows	Destructive
				Emu	Shot
				Like thrushes	Beautiful
			Amphibians	Frogs	Mottled with bright green
			Reptile	Turtle — *Chelodina oblonga*	Two, plus eggs weighing 4lb each
			Birds	Rail — Handsomely freckled	
				Wagtail or black and white fantail	Associating with farm animals
Sept. 1831	Ensign Dale	Avon River	Mammals	Numbat	We also saw a small and beautiful animal, which appears not to have been before discovered . . . the size of a squirrel . . .
Aug. 1832	G.F. Moore	Guildford	Mammals	Wild cattle	36 head
			Fish	Herrings (or trumpeters), kingfish (rack), snapper, bream, mullet, perch, guard fish, cobbler	10 000 one draught of the seine
			Reptiles	Snake-necked turtle	Steal your bait
			Crustacea	Crayfish	2-6 inches long
				Crabs	In the salt water
			Mollusca	Clams	In abundance
Nov. 1832	G.F. Moore	Guildford	Birds	Duck	10 eggs. Shot it
			Reptiles	Long tailed yellow spotted iguana	
				Black iguana	Dogs killed them
June 1833			Insects	White ants	
			Arthropoda	Centipedes	In white ant mound
Dec. 1833	Rev. F.W. Hope	Swan River	Insects	6 new species of beetle	Entomological Society of London
1833	Capt. Stokes	Guildford	Birds	Black tailed native hen	Innumerable host, when the corn was green

APENDIX A2

HISTORICAL REFERENCES TO WILDLIFE CONTINUED

DATE	REPORTER	LOCATION	TYPE	SPECIES	NOTES
Feb. 1834	G.R. Gray	Swan River	Insects	Stick insect (phasmid)	Entomological Society of London
May 1834	Rev F.W. Hope			Weevil (curculeonid)	
	G.F. Moore	Guildford	Insects	White worm or maggot	Numbers under red gum bark, natives have been feasting
			Amphibians	Frogs	
			Birds	White cockatoos — long billed	Very troublesome upon the wheat
Nov. 1835	G.R. Water-house	Swan River	Insects	2 species of Coleoptera	Entomological Society of London
Dec. 1835	G.F. Moore	Guildford	Insects	Bees	Great numbers on the lucerne
June 1840	Rev. F.W. Hope	Swan River	Insects	Stenochoridae	8 new species
Aug. 1840	Gould	Swan River	Reptile	Spiny lizard	Zoological Society
Oct. 1840	Gould	Near Swan River	Birds	Brush turkey	Zoological Society
		Swan River	Mammals	Kangaroos	Zoological Society
Nov. 1840	Gould	Swan River	Birds	*Podargus strigoides* *Colluricincla rufiventris* *Acanthiza inornata* *Microeca fascinans*	Zoological Society
Dec. 1840	Edward Newman		Birds	*Bettongia lesueuri grayi*	Zoological Society
			Insects	Longicorn	New species
1840 (summer)	Clauncey	Swan River	Fish	Large snapper 10-15 lb each	Shoal — driven into shallows by aborigines
		Lakes and swamps		Tortoises, waterfowl, frogs, prawns and crayfish	
1860	Thomas Briggs (1917)	Fremantle	Mammals	Kangaroo	Teeming with game
			Birds	Wild turkey, large bronze-wing pigeons, blue pigeons, wild duck, parrot and magpie	Birds were caged and sold to captains in Fremantle

APPENDIX A2

HISTORICAL REFERENCES TO WILDLIFE CONTINUED

DATE	REPORTER	LOCATION	TYPE	SPECIES	NOTES
			Fish	Flounder, flathead, snapper, skipjack mullet, tailor and others	River was 'alive' snapper 20 pounders
			Crustacea	Crabs, prawns	

Compiled from: Alexander (1914) (1917)
Whittell (1947)
Hallam (1975)
Serventy and Whittell (1977)

APPENDIX A3

PRELIMINARY CHECK LIST OF FISHES AND CRUSTACEANS IN THE SWAN-CANNING ESTUARY*

Family/Scientific Name	Common Name	Preferred Habitat				Social Behaviour		Human Exploitation		
		Pelagic	Demersal	Under 2 m	Over 2 m	Solitary	Schooling	Professional Fishing	Angling	Nil
TELEOSTS										
Mugilidae										
Aldrichetta forsteri	Yelloweye mullet		*	*			*	*	*	
Mugil cephalus	Sea mullet		*	*			*	*		
Sillaginidae										
Sillago punctata	King George whiting		*	*	*		*	*	*	
Sillago schomburgkii	Western sand whiting		*	*			*	*	*	
Sillago bassensis	School whiting		*	*	*		*	*	*	
Sillago maculata	Trumpeter whiting		*	*	*		*	*	*	
Plotosidae										
Cnidoglanis macrocephalus	Cobbler		*	*	*	*		*	*	
Arripidae										
Arripis georgianus	Australian herring	*		*	*		*	*	*	
Arripis trutta esper	Australian salmon	*			*		*	*	*	
Exocoetidae										
Hyporamphus melanochir	Dusky sea garfish	*		*	*		*	*	*	
Hemiramphus regularis	Western river garfish	*		*	*		*		*	
Sparidae										
Mylio butcheri	Black bream		*	*	*	*		*	*	
Rhabdosargus sarba	Tarwhine (silver bream)		*	*	*	*		*	*	
Platycephalidae										
Platycephalus fuscus	Dusky flathead		*	*	*	*		*	*	
Platycephalus bassensis westralie	Sand flathead		*	*	*	*			*	
Carangidae										
Caranx georgianus	Trevally		*		*		*	*	*	
Trachurus mccullochi	Yellowtail		*		*		*		*	

APPENDIX A3

PRELIMINARY CHECK LIST OF FISHES AND CRUSTACEANS IN THE SWAN-CANNING ESTUARY* CONTINUED

Family/Scientific Name	Common Name	Preferred Habitat				Social Behaviour		Human Exploitation		
		Pelagic	Demersal	Under 2 m	Over 2 m	Solitary	Schooling	Professional Fishing	Angling	Nil
Bothidae										
Pseudorhombus jenynsii	Small toothed flounder		*	*	*	*		*	*	
Pomatomidae										
Pomatomus saltator	Tailor	*		*	*		*	*	*	
Engraulidae										
Engraulis australis faseri	Southern anchovy	*		*	*		*	*		
Clupeidae										
Amblygaster postera	Scaly mackerel	*			*		*	*		
Sardinops neopilchardus	Pilchard (mulie)	*			*		*	*		
Hyperlophus vittatus	Sandy sprat (whitebait)	*		*	*		*	*		
Spratelloides robustus	Blue sprat (blue sardine)	*		*	*		*	*		
Fluvialosa vlaminghi	Perth herring		*	*			*	*		
Scombridae										
Scomber australasicus	Common or slimy mackerel	*			*	*			*	
Tetraodontidae										
Torquigener pleurogramma	Banded toadfish (blowfish)		*	*	*		*		*	
Gobiidae										
Arenigobius bifrenatus	Brindled goby		*	*		*				*
Favonigobius tamarenis	South-west goby		*	*		*				*
Favonigobius lateralis	Long finned goby		*	*		*				*
Lizagobius olorum	Blue spot goby		*	*		*				*
Gerridae										
Gerres australis	Roach		*	*	*	*		*		
Apogonidae										
Gronovichthys ruppelli	Gobbleguts		*	*	*	*				*

APPENDIX A3

PRELIMINARY CHECK LIST OF THE FISHES AND CRUSTACEANS IN THE SWAN-CANNING ESTUARY* CONTINUED

Family/Scientific Name	Common Name	Preferred Habitat				Social Behaviour		Human Exploitation		
		Pelagic	Demersal	Under 2 m	Over 2 m	Solitary	Schooling	Professional Fishing	Angling	Nil
Atherindae										
Atherinisoma sp.	Hardy head	*		*			*			*
Theraponidae										
Helotes sexlineatus	Striped perch		*	*	*		*		*	
Amphitherapon caudavittatus	Yellowtail grunter		*	*	*		*	*	*	
Sciaenidae										
Sciaena antarctica	Mulloway		*	*	*	*	*	*	*	
CRUSTACEA										
Portunidae										
Portunus pelagicus	Blue manna crab		*	*	*	*		*	*	
Penaeidae										
Penaeus latisulcatus	King prawn		*	*	*	*				
Metapeneas dalli	School prawn		*	*	*	*		*	*	

Fishes of the following families are probably less commonly found in this estuarine system:

Balistidate (leatherjackets)
Labridae (parrot fishes)
Kyphosidae (drummers)
Mullidae (goat fishes)
Ostraciontidae (boxfishes)
Cynolossidae, Soleidae, Pleuronectidae (soles)
Clinidae (weed fishes)
Odacidae (weedy whitings)

Enoplosidae (old wives)
Diodontidae (porcupine fishes)
Syngnathidae (sea horses)
Scorpaenidae (scorpion fishes)
Elopidae (giant herrings)
Pempheridae (pemferets)
Echelidae, Ophlichthidae (eels)

Sharks and rays likely to be caught include members of the families:

Carcharhinidae (whaler sharks)
Rhinobatidae (shovelnose rays)
Dasyatidae (stingrays)

* This list was prepared for the Forbes and Fitzhardinge Report to the Department of Conservation and Environment "Activity Study of the Swan River".

APPENDIX A4

ALPHABETICAL LIST OF BIRDS SEEN ON THE SWAN RIVER ESTUARY

Anas castanea — Chestnut Teal
Anas gibberifrons — Grey Teal
Anas rhynchotis — Blue-winged shoveler
Anas superciliosa — Black Duck
Anhinga rufa — Australian Darter
Ardea novaehollandiae — White-faced Heron
Ardea pacifica — White-necked Heron (Pacific Heron)
Athus novaeseelandiae — Australian Pipit
Aythya australis — White-eyed Duck
Biziura lobata — Musk Duck
Calidris acuminata — Sharp-tailed Sandpiper
Calidris alba — Sanderling
Calidris canutus — The Knot
Calidris ferruginea — Curlew Sandpiper
Calidris ruficollis — Little Stint
Calidris tenuirostris — Great Knot
Charadrius cucullatus — Hooded Dotterel
Charadrius leschenaultii — Large Sand-Dotterel
Charadrius melanops — Black-fronted Dotterel
Charadrius mongolus — Mongolian Dotterel
Charadrius ruficapillus — Red-capped Dotterel
Chlidonias leucoptera — White-winged Black Tern
Chlidonias hybrida — Marsh Tern
Cinclorhamphus cruralis — Brown Songlark
Circus approximans — Swamp Harrier
Cladorhynchus leucocephalus — Banded Stilt
Cygnus atratus — Black Swan
Dupetor flavicollis — Black Bittern
Egretta alba — White Egret
Egretta sacra — Reef Heron
Elanus notatus — Black-shouldered Kite
Eudyptula minor — Little Penguin
Falco berigora — Brown Hawk
Falco cenchroides — Nankeen Kestrel
Falco longipennis — Little Falcon
Fregata minor — Greater Frigate-bird
Fulica atra — Coot
Gallinula tenebrosa — Dusky Moorhen
Gelochelidon nilotica — Gull-billed Tern
Glareola maldivarum — Oriental Pratincole
Haliaeetus leucogaster — White-breasted Sea-Eagle
Haliastur sphenurus — Whistling Eagle
Himantopus himantopus — White-headed Stilt
Hirundo neoxena — Welcome Swallow
Hydroprogne caspia — Caspian Tern
Larus novaehollandiae — Silver Gull
Larus pacificus — Pacific Gull
Limosa lapponica — Bar-tailed Godwit
Limosa limosa — Black-tailed Godwit
Macronectes giganteus — Southern Giant Petrel
Malurus leuconotus — Blue-and-White Wren
Megalurus gramineus — Little Grass-bird
Numenius madagascariensis — Eastern Curlew
Numenius phaeopus — Whimbrel
Pachyptila vittata — Broad-billed Prion
Pandion haliaetus — Osprey
Pelecanus conspicillatus — Australian Pelican
Petrochelidon nigricans — Tree-Martin

APPENDIX A4

ALPHABETICAL LIST OF BIRDS SEEN ON THE SWAN RIVER ESTUARY CONTINUED

Phalacrocorax carbo — Black Cormorant
Phalacrocorax sulcirostris — Little Black Cormorant
Phalacrocorax varius — Pied Cormorant
Podiceps poliocephalus — Hoary-headed Grebe
Porphyrio porphyrio — Swamphen
Porzana tabuensis — Spotless Crake
Pluvialis dominica — Eastern Golden Plover
Pluvialis squatarola — Grey Plover
Rallus philippensis — Banded Landrail
Recurvirostra novaehollandiae — Red-necked Avocet
Sterna bergii — Crested Tern
Sterna fuscata — Sooty Tern
Sterna nereis — Fairy Tern
Tadorna tadornoides — Mountain Duck
Threskiornis spinicollis — Straw-necked Ibis
Tringa brevipes — Grey-tailed Tattler
Tringa hypoleucos — Common Sandpiper
Tringa nebularia — Greenshank
Vanellus tricolor — Banded Plover
Xenus cinereus — Terek Sandpiper

From: Serventy (1938)
Tarburton (1974)
Serventy and Whittell (1976)
Lane (unpublished)
Riggert (unpublished)
Storr (pers. comm.)

APPENDIX A5

MOLLUSCA OF THE SWAN RIVER ESTUARY

Species living continuously upstream from Blackwall Reach.

Family	Species	Group
BIVALVIA		
Mytilidae	*Xenostrobus securis*	3
Erycinidae	*Arthritica semen*	3
Cardiidae	*Spisula trigonella*	2
Tellinidae	*Tellina deltoidalis*	2
Psamobiidae	*Theora lubrica*	2
Lyonsiidae	*Anticorbula amara*	3
GASTROPODA		
Hydrobiidae	*Potamophyrgus sp.*	3
	Tatea preissi	3
Asimineidae	*Asiminea sp.*	3
Thiaridae	*Plotropsis australis*	4
Potamididae	*Batillaria australis*	2
Nassariidae	*Nassarius burchardi*	2
	Nassarius pauperatus	2

APPENDIX A6

SAMPLING LOCATIONS USED BY THE SWAN RIVER CONSERVATION BOARD AND PUBLIC HEALTH DEPARTMENT.

S.R.C.B. SAMPLING LOCATIONS

1a. Midland Swimming Pool
2. Meadow St. Bridge
3. Helena River
4. Aerodrome Drain
5. Cumming-Smith Drain
6. Forbes Street
7a. King William Street
8. Garratt Road Bridge
8a. Maylands Swimming Pool
9. Belmont Creek
10. Hardy Park
11. The Springs
12. Maylands
13. Gasworks
14. Hill Street
15. Mends Street
16. Spring Street
17. The Narrows
18. Swan Brewery
19. Crawley Baths
20. Matilda Bay
21. Mount Henry
22. Coffee Point
23. Como
24. Nedlands
26. Armstrong Spit
27. Point Walter
28. White Beach
29. Claremont Baths
30. Peppermint Grove
31. Mosman Bay
32. Blackwall Reach
33. Bicton
34. Rocky Bay
34b. Crabbs Jetty
35. Fremantle Traffic Bridge
36. Riverton Bridge
37. Nicholson Road Bridge
38. Herbert Street
39. Brookton Road Bridge
40. Chatham Street Bridge } Helena
41. Scott Street Bridge } River
42. Middle Swan Bridge
43a. Barrett Street
44. Walyunga Pool
45. Long Pool (Avon River)
46. Wooroloo Brook
47. Ellen Brook Road Bridge
B1. Bull Creek

PUBLIC HEALTH SAMPLING LOCATIONS

1a. Walyunga Short Pool
1b. Walyunga Long Pool
1c. Upper Swan Bridge
1d. Park Street, Herne Hill
2. West Midland Swimming Reserve
4. Success Hill Reserve
5. Point Reserve
7. Scott Street Bridge
8. Stock Street Bridge
9. Swan Street Bridge
10. Sandy Beach Reserve
11. Ford Street
12. Garratt Road
13. Bath Street
14. Spring Street Pool
15. East Street Jetty
16. Heirisson Island
17. Como Jetty
18. Kelmscott Pool
19. Station St., Gosnells
20. Southern River Bridge
21. Harris Street Pool
23. Kent St. Weir
24. Riverton Bridge
25. Fifth Avenue
26. Deep Water Point
27. Canning Bridge
28. Applecross Jetty
29. Point Walter Jetty
30. Bicton Pool
31. East Fremantle Swimming Reserve
32. Johnson St., Mosman Park
33. Keane St., Peppermint Grove
34. Jetty Road
35. Nedlands Baths
36. Hackett Drive Jetty
37. Hackett Drive (U.B.C.)

APPENDIX A7

CHEMICAL AND PHYSICAL PARAMETERS AT GARRATT ROAD BRIDGE

GARRATT ROAD BRIDGE (SAMPLE SITE 8)

Year	48-50	51-55	56-60	61-65	66-70	71-75	48-75
Temperature °C							
max	28.3	27.2	27.2	26.7	27.8	26.7	28.3
min	14.4	12.2	12.2	10.6	12.2	13.3	10.6
mean	21.1	20.6	20.0	19.4	20.6	19.8	20.2
pH							
max	—	—	8.2	7.8	8.1	8.3	8.3
min	—	—	7.3	7.0	7.0	7.1	7.0
mean	—	—	7.6	7.5	7.4	7.4	7.5
			--------------------	mg/l	--------------------		
Chloride							
max	16 000	13 760	13 370	14 590	11 800	14 500	16 000
min	1 050	1 120	1 110	1 070	920	1 120	920
mean	7 770	4 720	5 700	6 120	4 920	5 550	5 797
Dissolved oxygen							
max	14.7	9.1	9.3	12.5	10.9	12.8	14.8
min	6.6	4.8	5.4	6.7	6.0	5.1	4.8
mean	9.2	7.8	7.7	8.0	7.8	7.2	7.9
B.O.D.							
max	7.8	3.1	5.6	15.6	9.4	16.0	16.0
min	0.1	0.2	0.4	0.5	0.5	0.7	0.1
mean	2.7	1.5	1.6	2.4	2.9	2.8	2.3

APPENDIX A7

CHEMICAL AND PHYSICAL PARAMETERS AT GARRATT ROAD BRIDGE CONTINUED

Oxygen absorbed from $KMnO_4$							
max	4.8	7.4	6.5	5.5	6.1	8.8	8.8
min	2.7	2.4	2.0	2.6	2.0	2.4	2.0
mean	3.8	4.7	3.8	3.9	3.6	5.0	4.1
Ammonia							
max	0.6	0.9	0.6	1.4	2.0	2.8	2.8
min	0.1	0.3	0.2	0.2	0.2	0.2	0.1
mean	0.3	0.5	0.4	0.6	0.6	0.6	0.5
Phosphorus							
max	0.08	0.14	0.26	0.20	0.16	0.48	0.48
min	0.01	0.02	0.02	0.03	0.03	0.06	0.01
mean	0.05	0.06	0.05	0.06	0.09	0.17	0.08
			-------------------MPN/100 ml --------------------				
Total coliform							
max				1 100+	1 100+	1 100+	1 100+
min				15	21	43	—
median				460	460	600	—
Faecal E. coli							
max				1 100+	1 100+	1 100+	1 100+
min				0	0	0	0
median				93	75	75	—

APPENDIX A8

CHEMICAL AND PHYSICAL PARAMETERS AT WHITE BEACH

WHITE BEACH (SAMPLE SITE 28)

Year	48-50	51-55	56-60	61-65	66-70	71-75	48-75
Temperature °C							
max	25.6	27.8	26.1	25.0	24.4	25.6	27.8
min	14.4	12.8	12.8	15.0	13.3	14.8	12.8
mean	20.0	18.9	19.4	18.9	20.0	19.1	19.4
pH							
max	—	—	8.5	8.3	8.3	8.7	8.7
min	—	—	7.6	7.5	7.7	7.8	7.5
mean	—	—	8.0	8.0	8.0	8.2	8.0
			--------------------	mg/l	--------------------		
Chloride							
max	20 860	20 800	20 300	20 760	20 100	20 400	20 860
min	3 710	520	1 120	1 200	990	2 730	520
mean	16 340	14 260	13 810	14 180	13 600	14 910	14 517
Dissolved oxygen							
max	11.0	13.3	12.0	10.1	10.3	11.9	13.3
min	6.9	6.0	6.7	6.9	6.7	6.6	6.0
mean	8.7	8.0	8.4	8.0	8.2	7.9	8.2
B.O.D.							
max	4.4	3.8	3.0	5.2	4.7	4.8	5.2
min	0.8	0.2	0.7	0.6	0.1	0.1	0.1
mean	2.0	1.6	1.7	1.6	2.2	2.3	1.9

APPENDIX A8

CHEMICAL AND PHYSICAL PARAMETERS AT WHITE BEACH CONTINUED

Oxygen absorbed from $KMnO_4$							
max	4.0	10.0	7.2	4.5	3.8	5.7	10.0
min	0.7	1.2	0.6	0.6	0.6	0.3	0.3
mean	1.6	2.7	2.2	1.7	1.7	1.9	2.0
Ammonia							
max	0.4	0.7	0.8	0.5	0.7	0.7	0.8
min	0.1	0.1	0.1	0.1	0.1	0.1	0.1
mean	0.2	0.3	0.3	0.3	0.4	0.3	0.3
Phosphorus							
max	0.06	0.10	0.12	0.07	0.08	0.06	0.12
min	0.01	0.01	0.01	0.01	0.01	0.02	0.01
mean	0.02	0.05	0.03	0.03	0.03	0.04	0.03
			-------------------- MPN/100 ml --------------------				
Total coliform							
max				240	240	460	—
min				0	0	0	0
median				15	23	4	—
Faecal E. coli							
max				9	43	23	—
min				0	0	0	0
median				0	4	4	—

APPENDIX A9

TABLES SHOWING M.P.N. OF COLIFORM AND *E.COLI* BASED ON SAMPLING DONE BY PUBLIC HEALTH DEPARTMENT 1972-1975.

BACTERIA E. COLI

	1972	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UPPER ESTUARY	1a Walyunga Short Pool	1	1	1	2	1	1	4	2	3	4	1	1
	1b Walyunga Long Pool	1	1	1	1	1	2	5	4	4	4	1	1
	1d Douglas Rd	—	—	—	—	—	—	—	—	—	—	—	—
	2 Midland Pool	1	2	2	2	2	1	3	5	4	2	1	4
	1c West Swan Bridge	1	3	4	3	3	3	5	4	4	1	4	5
	4 Success Hill Reserve	2	2	1	2	2	1	3	5	2	3	2	3
	5 Point Reserve	1	2	2	2	2	3	5	3	4	4	2	2
HELENA RIVER	7 Scott St Bridge	3	5	3	1	5	3	3	2	4	5	4	1
	8 Stock St Bridge	5	4	3	5	5	4	4	4	5	5	5	4
	9 Swan St Bridge	4	2	1	2	2	3	4	4	4	3	3	3
	10 Sandy Beach Reserve	2	2	3	2	1	2	4	3	2	4	1	4
	11 Ascot Pool — East	1	2	1	1	1	1	4	4	2	4	1	2
	12 Garratt Rd Pool	1	2	2	1	1	1	3	4	4	4	2	2
	13 Bath St Pool	1	2	1	1	1	2	1	5	3	4	2	2
	14 The Springs Pool	1	1	1	1	4	—	1	3	4	2	2	3
	15 East St Jetty	1	4	3	1	1	4	3	3	2	2	1	1
	16 Heirisson Island	1	5	2	1	1	1	1	3	2	2	1	1
MIDDLE ESTUARY	17 Como Jetty	1	2	1	2	2	2	1	1	1	1	1	1
	28 Applecross Jetty	3	4	2	1	1	5	1	2	3	4	2	1
	29 Pt Walter Jetty	2	3	1	1	1	1	1	2	1	1	1	2
	32 Mosman Park	1	1	1	1	1	1	1	1	1	1	1	1
	33 Peppermint Grove	1	1	1	1	1	1	1	1	2	2	1	1
	34 Claremont Baths	1	1	2	1	1	1	1	1	1	1	1	1
	35 Nedlands Baths	1	1	1	1	1	1	1	1	5	1	1	1
	36 Matilda Bay	1	1	1	2	1	1	1	2	3	1	1	3
	37 Matilda Bay UBC	3	1	1	1	1	1	1	1	4	1	1	2
LOWER ESTUARY	30 Bicton Pool	1	1	1	1	1	1	1	1	1	1	1	1
	31 East Fremantle Pool	2	1	1	1	1	1	3	2	1	1	1	1
CANNING RIVER	18 Kelmscott Pool	2	2	3	3	2	2	1	1	3	4	3	3
	19 Station St, Gosnells	1	1	4	4	4	3	2	3	3	4	2	4
	20 Southern River Bridge	4	3	3	3	1	2	4	2	4	3	1	5
	21 Harris St Pool	1	3	2	1	1	2	4	3	4	4	4	2
	23 Kent St Weir Salt	1	2	2	3	4	5	3	5	4	4	2	2
	24 Riverton Bridge Pool	1	1	1	2	1	3	4	5	4	5	2	1
	25 Fifth Ave, Riverton	1	2	1	1	1	3	3	4	4	2	1	2
	26 Deep Water Point	1	1	1	1	1	1	1	2	3	1	1	1
	27 Canning Bridge Nth	1	1	1	3	1	1	3	1	2	1	1	1

1 — M.P.N. 0 — 35
2 35 — 110
3 110 — 350
4 350 —1 100
5 1 100+

APPENDIX A9

TABLES SHOWING M.P.N. OF COLIFORM AND *E.COLI* BASED ON SAMPLING DONE BY PUBLIC HEALTH DEPARTMENT 1972-1975.

BACTERIA E. COLI

	1972	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UPPER ESTUARY	1a Walyunga Short Pool	4	2	1	2	2	3	4	3	4	5	4	4
	1b Walyunga Long Pool	3	2	1	1	1	3	5	4	4	4	1	2
	1d Douglas Rd	—	—	—	—	3	3	5	4	4	5	1	4
	2 Midland Pool	3	2	2	2	2	2	4	5	4	2	1	4
	1c West Swan Bridge	—	—	—	—	4	3	5	4	4	3	4	5
	4 Success Hill Reserve	3	4	2	3	4	2	5	5	3	4	4	4
	5 Point Reserve	4	2	4	3	3	4	5	5	4	4	4	4
HELENA RIVER	7 Scott St Bridge	4	5	3	1	5	3	3	4	4	5	4	1
	8 Stock St Bridge	5	5	3	5	5	5	4	4	4	5	5	4
	9 Swan St Bridge	4	4	1	2	4	5	5	5	4	4	3	3
	10 Sandy Beach Reserve	2	4	3	2	1	3	4	4	3	4	4	5
	11 Ascot Pool — East	2	4	3	4	1	1	4	4	4	5	4	3
	12 Garratt Rd Pool	3	3	2	1	1	2	5	5	4	5	4	3
	13 Bath St Pool	4	2	2	1	1	4	5	5	4	4	3	4
	14 The Springs Pool	2	2	1	1	5	—	4	5	5	5	3	3
	15 East St Jetty	5	4	5	2	1	4	3	5	3	3	3	3
	16 Heirisson Island	5	5	3	1	1	1	3	3	4	3	2	1
MIDDLE ESTUARY	17 Como Jetty	2	2	1	3	2	3	1	3	5	1	1	1
	28 Applecross Jetty	4	4	2	1	1	5	1	3	5	4	2	1
	29 Pt Walter Jetty	3	4	1	1	1	1	1	2	3	1	1	2
	32 Mosman Park	1	1	1	1	1	1	1	2	4	1	1	1
	33 Peppermint Grove	1	1	1	1	1	2	1	1	3	2	1	1
	34 Claremont Baths	2	1	4	1	1	1	2	1	3	3	1	1
	35 Nedlands Baths	1	1	1	1	1	1	1	1	5	2	1	1
	36 Matilda Bay	3	4	1	2	1	2	1	2	5	1	3	3
	37 Matilda Bay UBC	4	2	2	1	1	1	1	1	4	3	2	2
LOWER ESTUARY	30 Bicton Pool	2	1	2	1	1	1	1	1	3	1	2	1
	31 East Fremantle Pool	2	2	1	1	1	1	3	2	3	2	1	1
CANNING RIVER	18 Kelmscott Pool	5	5	5	4	3	2	1	3	4	4	4	5
	19 Station St, Gosnells	4	4	4	4	4	4	4	5	4	4	2	4
	20 Southern River Bridge	4	5	4	3	3	4	4	3	4	4	4	5
	21 Harris St Pool	5	5	2	2	2	2	4	4	4	5	4	4
	23 Kent St Weir Salt	4	2	2	4	4	5	5	5	4	5	3	4
	24 Riverton Bridge Pool	1	3	1	4	1	5	5	5	5	5	2	1
	25 Fifth Ave, Riverton	2	3	1	1	1	4	5	4	5	3	2	2
	26 Deep Water Point	1	1	1	1	1	1	4	2	4	1	1	1
	27 Canning Bridge Nth	1	1	1	4	1	2	3	1	5	1	1	1

1 — M.P.N. 0 — 35
2 35 — 110
3 110 — 350
4 350 — 1 100
5 1 100+

APPENDIX A9

TABLES SHOWING M.P.N. OF COLIFORM AND E.COLI BASED ON SAMPLING DONE BY PUBLIC HEALTH DEPARTMENT 1972-1975.

BACTERIA E. COLI

	1973	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UPPER ESTUARY	1a Walyunga Short Pool	—	—	—	1	3	5	4	4	—	1	1	2
UPPER ESTUARY	1b Walyunga Long Pool	1	2	2	1	5	5	3	2	5	2	1	3
UPPER ESTUARY	1d Douglas Road	2	2	4	4	4	5	4	—	—	2	2	4
UPPER ESTUARY	2 Midland Pool	2	1	1	2	2	4	4	4	4	2	3	2
UPPER ESTUARY	1c West Swan Bridge	4	4	4	4	3	5	4	2	5	2	2	4
UPPER ESTUARY	4 Success Hill Reserve	3	1	1	2	2	3	4	3	5	3	4	4
UPPER ESTUARY	5 Point Reserve	3	1	1	1	1	5	4	4	5	2	2	2
UPPER ESTUARY — HELENA RIVER	7 Scott St Bridge	4	—	—	—	—	5	3	1	5	2	3	3
UPPER ESTUARY — HELENA RIVER	8 Stock St Bridge	5	5	5	5	1	5	5	3	5	3	4	3
UPPER ESTUARY — HELENA RIVER	9 Swan St Bridge	3	4	3	1	1	5	4	4	5	2	2	3
UPPER ESTUARY	10 Sandy Beach Reserve	2	1	1	1	2	4	—	3	—	3	1	2
UPPER ESTUARY	11 Ascot Pool — East	1	1	1	1	4	5	4	3	5	2	3	3
UPPER ESTUARY	12 Garratt Rd Pool	1	1	1	1	3	5	5	3	5	4	3	4
UPPER ESTUARY	13 Bath St Pool	1	1	1	1	2	4	5	4	4	2	2	3
UPPER ESTUARY	14 The Springs Pool	4	2	1	1	1	4	5	4	5	2	2	2
UPPER ESTUARY	15 East St Jetty	1	1	1	1	2	3	5	3	5	2	2	4
UPPER ESTUARY	16 Heirisson Island	1	1	1	1	3	1	5	3	5	2	3	1
MIDDLE ESTUARY	17 Como Jetty	1	1	1	1	2	2	2	2	4	1	1	2
MIDDLE ESTUARY	28 Applecross Jetty	1	1	1	2	4	1	3	2	1	1	1	1
MIDDLE ESTUARY	29 Pt Walter Jetty	1	2	1	1	4	2	1	1	2	1	2	2
MIDDLE ESTUARY	32 Mosman Park	2	1	1	1	4	1	1	1	3	1	1	1
MIDDLE ESTUARY	33 Peppermint Grove	2	1	5	1	1	3	1	1	2	1	1	1
MIDDLE ESTUARY	34 Claremont Baths	1	1	1	2	4	2	1	1	1	1	2	1
MIDDLE ESTUARY	35 Nedlands Baths	1	1	1	1	1	2	1	1	1	1	2	5
MIDDLE ESTUARY	36 Matilda Bay	2	1	1	1	1	1	3	2	3	1	3	1
MIDDLE ESTUARY	37 Matilda Bay UBC	2	1	3	1	2	1	5	3	4	1	3	4
LOWER ESTUARY	30 Bicton Pool	1	2	1	1	3	1	1	3	2	1	1	1
LOWER ESTUARY	31 East Fremantle Pool	3	2	5	1	4	4	3	5	3	2	1	1
CANNING RIVER	18 Kelmscott Pool	3	3	2	3	2	3	5	2	1	1	3	5
CANNING RIVER	19 Station St, Gosnells	5	2	3	2	4	4	5	2	2	2	2	5
CANNING RIVER	20 Southern River Bridge	5	2	2	3	2	5	5	2	1	2	3	2
CANNING RIVER	21 Harris St Pool	2	3	4	2	2	5	5	3	1	2	3	2
CANNING RIVER	23 Kent St Weir Salt	2	1	2	2	2	5	5	2	4	2	2	1
CANNING RIVER	24 Riverton Bridge Pool	4	1	3	1	3	4	5	4	5	2	3	4
CANNING RIVER	25 Fifth Ave, Riverton	1	2	4	1	2	4	4	3	1	3	3	4
CANNING RIVER	26 Deep Water Point	3	1	1	1	1	4	2	2	1	1	1	1
CANNING RIVER	27 Canning Bridge Nth	1	1	1	1	1	2	2	3	1	1	1	1

1	— M.P.N.	0 — 35
2		35 — 110
3		110 — 350
4		350 — 1 100
5		1 100+

APPENDIX A9

TABLES SHOWING M.P.N. OF COLIFORM AND *E.COLI* BASED ON SAMPLING DONE BY PUBLIC HEALTH DEPARTMENT 1972-1975.

BACTERIA E.COLI

	1973	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UPPER ESTUARY	1a Walyunga Short Pool	—	—	—	3	5	5	4	4	—	2	3	3
UPPER ESTUARY	1b Walyunga Long Pool	5	3	2	1	5	5	3	3	5	3	4	3
UPPER ESTUARY	1d Douglas Rd	3	3	4	4	4	5	4	—	—	2	4	4
UPPER ESTUARY	2 Midland Pool	4	4	4	2	4	5	4	4	4	3	3	2
UPPER ESTUARY	1c West Swan Bridge	5	4	5	4	5	5	4	4	5	3	2	4
UPPER ESTUARY	4 Success Hill Reserve	4	3	3	4	4	3	4	4	5	3	4	4
UPPER ESTUARY	5 Point Reserve	4	2	3	4	4	5	5	4	5	2	2	3
UPPER ESTUARY – HELENA RIVER	7 Scott St Bridge	5	—	—	—	—	5	3	4	5	3	4	4
UPPER ESTUARY – HELENA RIVER	8 Stock St Bridge	5	5	5	5	5	5	5	4	5	4	5	3
UPPER ESTUARY – HELENA RIVER	9 Swan St Bridge	4	4	4	4	4	5	4	4	5	3	4	5
UPPER ESTUARY	10 Sandy Beach Reserve	2	2	1	4	3	4	—	3	—	4	2	2
UPPER ESTUARY	11 Ascot Pool — East	2	2	2	3	4	5	4	4	5	4	4	4
UPPER ESTUARY	12 Garratt Rd Pool	2	2	1	2	4	5	5	4	5	4	4	4
UPPER ESTUARY	13 Bath St Pool	2	1	1	2	3	4	5	5	5	3	3	4
UPPER ESTUARY	14 The Springs Pool	4	3	2	3	5	4	5	4	5	4	4	2
UPPER ESTUARY	15 East St Jetty	1	1	1	3	3	4	5	4	5	2	3	4
UPPER ESTUARY	16 Heirisson Island	1	1	1	2	4	5	5	5	5	3	5	3
MIDDLE ESTUARY	17 Como Jetty	1	1	1	1	3	4	4	3	4	3	2	2
MIDDLE ESTUARY	28 Applecross Jetty	1	1	1	2	4	2	3	3	2	2	1	1
MIDDLE ESTUARY	29 Pt Walter Jetty	1	3	1	1	4	2	1	2	3	2	2	2
MIDDLE ESTUARY	32 Mosman Park	2	1	1	1	4	2	1	1	3	2	4	1
MIDDLE ESTUARY	33 Peppermint Grove	2	1	5	4	2	3	4	3	2	1	1	1
MIDDLE ESTUARY	34 Claremont Baths	1	1	1	3	4	4	1	2	2	1	4	3
MIDDLE ESTUARY	35 Nedlands Baths	1	1	1	1	1	3	1	5	4	4	4	5
MIDDLE ESTUARY	36 Matilda Bay	2	1	1	1	1	3	4	4	4	3	3	3
MIDDLE ESTUARY	37 Matilda Bay UBC	4	1	4	2	3	2	5	4	4	4	4	4
LOWER ESTUARY	30 Bicton Pool	1	2	3	1	3	2	1	3	3	2	1	1
LOWER ESTUARY	31 East Fremantle Pool	3	4	5	2	5	4	3	5	4	2	2	1
CANNING RIVER	18 Kelmscott Pool	5	5	4	3	3	5	5	4	4	3	4	5
CANNING RIVER	19 Station St, Gosnells	5	4	4	3	4	4	5	4	3	4	4	5
CANNING RIVER	20 Southern River Bridge	5	4	3	4	4	5	5	3	4	4	3	5
CANNING RIVER	21 Harris St Pool	3	4	4	2	3	5	5	4	4	4	3	3
CANNING RIVER	23 Kent St Weir Salt	2	2	2	2	3	5	5	4	5	4	2	3
CANNING RIVER	24 Riverton Bridge Pool	5	2	3	1	4	5	5	5	5	4	4	5
CANNING RIVER	25 Fifth Ave, Riverton	2	2	4	3	2	5	4	4	5	4	4	4
CANNING RIVER	26 Deep Water Point	3	1	1	2	2	4	4	4	5	2	2	2
CANNING RIVER	27 Canning Bridge Nth	3	1	1	1	1	2	2	3	4	3	1	1

1 — M.P.N.	0 —	35
2	35 —	110
3	110 —	350
4	350 —	1 100
5	1 100+	

APPENDIX A9

TABLES SHOWING M.P.N. OF COLIFORM AND *E.COLI* BASED ON SAMPLING DONE BY PUBLIC HEALTH DEPARTMENT 1972-1975.

BACTERIA E. COLI

Region	1974	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UPPER ESTUARY	1a Walyunga Short Pool	1	1	1	2	1	2	3	4	2	1	1	1
UPPER ESTUARY	1b Walyunga Long Pool	1	3	1	1	1	2	4	3	2	1	2	2
UPPER ESTUARY	1d Douglas Rd	4	3	1	2	—	—	—	—	2	—	4	—
UPPER ESTUARY	2 Midland Pool	2	2	2	2	2	2	3	4	2	1	—	4
UPPER ESTUARY	1c West Swan Bridge	2	4	4	2	1	2	3	2	4	1	3	3
UPPER ESTUARY	4 Success Hill Reserve	3	2	1	3	3	2	4	4	3	1	1	1
UPPER ESTUARY	5 Point Reserve	3	1	1	4	1	1	3	1	2	3	2	4
UPPER ESTUARY / HELENA RIVER	7 Scott St Bridge	—	—	—	3	3	2	3	1	4	2	2	3
UPPER ESTUARY / HELENA RIVER	8 Stock St Bridge	5	4	5	4	4	3	5	4	5	4	4	3
UPPER ESTUARY / HELENA RIVER	9 Swan St Bridge	2	2	2	4	1	2	5	5	—	1	2	4
UPPER ESTUARY	10 Sandy Beach Reserve	—	1	3	3	1	1	3	4	2	1	2	2
UPPER ESTUARY	11 Ascot Pool — East	2	1	1	4	1	1	3	4	2	—	1	2
UPPER ESTUARY	12 Garratt Rd Pool	2	3	1	4	1	1	2	3	2	5	1	1
UPPER ESTUARY	13 Bath St Pool	3	1	1	5	2	2	—	4	1	3	1	1
UPPER ESTUARY	14 The Springs Pool	2	1	1	4	3	—	1	4	—	2	—	3
UPPER ESTUARY	15 East St Jetty	3	1	1	3	1	2	2	2	5	2	1	4
UPPER ESTUARY	16 Heirisson Island	1	1	1	2	1	1	1	3	1	4	1	2
MIDDLE ESTUARY	17 Como Jetty	—	1	1	2	—	—	2	3	3	—	3	2
MIDDLE ESTUARY	28 Applecross Jetty	1	1	1	2	2	1	1	1	1	1	2	1
MIDDLE ESTUARY	29 Pt Walter Jetty	1	1	3	1	1	1	1	2	3	1	1	1
MIDDLE ESTUARY	32 Mosman Park	2	1	1	1	1	3	1	1	2	1	1	1
MIDDLE ESTUARY	33 Peppermint Grove	1	1	2	1	1	3	1	1	4	3	2	1
MIDDLE ESTUARY	34 Claremont Baths	3	1	1	2	2	1	1	2	3	1	2	2
MIDDLE ESTUARY	35 Nedlands Baths	5	1	1	1	2	1	3	1	3	1	2	2
MIDDLE ESTUARY	36 Matilda Bay	2	1	1	3	2	2	2	1	2	1	1	2
MIDDLE ESTUARY	37 Matilda Bay UBC	1	1	2	2	2	1	2	1	2	1	1	1
LOWER ESTUARY	30 Bicton Pool	1	1	1	1	1	1	2	2	—	1	1	1
LOWER ESTUARY	31 East Fremantle Pool	1	1	3	2	1	1	4	4	4	1	1	4
CANNING RIVER	18 Kelmscott Pool	4	1	1	2	1	1	4	2	4	1	5	3
CANNING RIVER	19 Station St, Gosnells	3	2	3	3	1	5	4	5	4	4	4	3
CANNING RIVER	20 Southern River Bridge	4	3	2	4	1	2	4	3	—	5	—	2
CANNING RIVER	21 Harris St Pool	3	2	2	2	1	5	4	3	3	4	3	2
CANNING RIVER	23 Kent St Weir Salt	1	2	3	4	2	2	3	4	4	4	2	2
CANNING RIVER	24 Riverton Bridge Pool	2	1	2	2	5	3	2	4	—	3	1	1
CANNING RIVER	25 Fifth Ave, Riverton	1	1	1	1	1	1	3	3	1	2	1	4
CANNING RIVER	26 Deep Water Point	3	1	1	1	3	1	3	3	2	1	4	1
CANNING RIVER	27 Canning Bridge Nth	1	1	1	1	4	1	3	3	3	1	3	1

1 — M.P.N. 0 — 35
2 35 — 110
3 110 — 350
4 350 — 1 100
5 1 100+

APPENDIX A9

TABLES SHOWING M.P.N. OF COLIFORM AND *E.COLI* BASED ON SAMPLING DONE BY PUBLIC HEALTH DEPARTMENT 1972-1975.

BACTERIA E.COLI

	1974	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UPPER ESTUARY	1a Walyunga Short Pool	1	2	2	2	3	2	3	5	4	2	4	5
UPPER ESTUARY	1b Walyunga Long Pool	1	3	1	2	3	4	5	3	4	1	3	5
UPPER ESTUARY	1d Douglas Rd	4	4	2	3	—	—	—	—	3	—	5	—
UPPER ESTUARY	2 Midland Pool	2	4	2	4	2	3	5	5	5	3	—	5
UPPER ESTUARY	1c West Swan Bridge	5	4	4	3	4	3	5	3	5	1	4	3
UPPER ESTUARY	4 Success Hill Reserve	4	2	3	4	4	3	4	4	5	3	2	3
UPPER ESTUARY	5 Point Reserve	4	2	2	5	3	3	4	5	5	3	4	4
UPPER ESTUARY – HELENA RIVER	7 Scott St Bridge	—	—	—	5	3	4	4	3	5	2	4	5
UPPER ESTUARY – HELENA RIVER	8 Stock St Bridge	5	5	5	5	4	4	5	4	5	4	5	3
UPPER ESTUARY – HELENA RIVER	9 Swan St Bridge	3	4	3	4	3	2	5	5	—	2	4	4
UPPER ESTUARY	10 Sandy Beach Reserve	—	1	4	4	2	3	5	4	4	4	2	4
UPPER ESTUARY	11 Ascot Pool — East	3	2	1	4	3	2	4	5	4	—	2	3
UPPER ESTUARY	12 Garratt Rd Pool	5	4	1	4	2	5	3	3	5	5	2	3
UPPER ESTUARY	13 Bath St Pool	3	1	1	5	4	3	—	5	4	4	2	4
UPPER ESTUARY	14 The Springs Pool	2	4	1	5	4	—	4	4	—	2	—	5
UPPER ESTUARY	15 East St Jetty	3	3	2	5	3	4	4	4	5	4	4	5
UPPER ESTUARY	16 Heirisson Island	1	3	1	4	4	2	4	4	3	4	4	2
MIDDLE ESTUARY	17 Como Jetty	—	1	1	4	—	—	3	4	5	—	3	4
MIDDLE ESTUARY	28 Applecross Jetty	1	1	1	2	2	2	1	4	2	3	2	3
MIDDLE ESTUARY	29 Pt Walter Jetty	1	2	3	1	1	2	1	4	5	1	1	2
MIDDLE ESTUARY	32 Mosman Park	2	2	1	1	3	3	2	2	4	1	2	2
MIDDLE ESTUARY	33 Peppermint Grove	1	1	5	1	3	3	1	2	4	3	2	1
MIDDLE ESTUARY	34 Claremont Baths	3	1	1	5	3	2	2	4	4	1	4	2
MIDDLE ESTUARY	35 Nedlands Baths	5	1	1	1	5	2	4	3	4	2	3	2
MIDDLE ESTUARY	36 Matilda Bay	2	1	1	4	4	3	3	3	5	1	3	2
MIDDLE ESTUARY	37 Matilda Bay UBC	2	1	4	2	4	2	3	3	3	1	3	1
LOWER ESTUARY	30 Bicton Pool	1	1	1	1	2	2	2	4	—	1	1	1
LOWER ESTUARY	31 East Fremantle Pool	1	2	4	3	1	2	4	4	4	1	1	4
CANNING RIVER	18 Kelmscott Pool	5	4	4	3	4	4	5	4	5	4	5	4
CANNING RIVER	19 Station St, Gosnells	3	3	3	5	3	5	5	5	5	5	4	5
CANNING RIVER	20 Southern River Bridge	4	4	4	5	4	4	5	5	—	5	—	4
CANNING RIVER	21 Harris St Pool	4	3	3	3	4	5	5	5	5	4	4	4
CANNING RIVER	23 Kent St Weir Salt	5	3	3	4	5	4	5	5	5	5	3	4
CANNING RIVER	24 Riverton Bridge Pool	3	2	2	4	5	4	4	5	—	5	3	2
CANNING RIVER	25 Fifth Ave, Riverton	1	4	1	4	3	1	5	4	4	3	2	5
CANNING RIVER	26 Deep Water Point	3	1	1	1	3	2	5	4	2	1	4	2
CANNING RIVER	27 Canning Bridge Nth	1	1	1	1	4	2	3	4	4	2	5	2

1 — M.P.N.	0 —	35
2	35 —	110
3	110 —	350
4	350 —	1 100
5	1 100+	

APPENDIX A9

TABLES SHOWING M.P.N. OF COLIFORM AND *E.COLI* BASED ON SAMPLING DONE BY PUBLIC HEALTH DEPARTMENT 1972-1975.

BACTERIA E.COLI

	1975	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UPPER ESTUARY	1a Walyunga Short Pool	5	2	1	4	—	—	—	4	4	3	—	4
	1b Walyunga Long Pool	2	3	2	3	—	—	—	3	5	3	—	4
	1d Douglas Rd	4	4	3	4	—	—	—	4	5	4	—	4
	2 Midland Pool	4	4	3	4	—	—	—	5	4	4	—	4
	1c West Swan Bridge	5	4	2	3	—	—	—	5	4	4	—	3
	4 Success Hill Reserve	3	3	2	3	—	—	—	5	4	4	—	3
	5 Point Reserve	5	5	4	3	—	—	—	3	5	4	—	5
HELENA RIVER	7 Scott St Bridge	4	5	4	4	—	—	—	4	3	4	—	4
	8 Stock St Bridge	5	5	4	4	—	—	—	5	3	5	—	4
	9 Swan St Bridge	2	4	—	4	—	—	—	5	4	4	—	4
	10 Sandy Beach Reserve	2	2	2	1	—	—	—	3	4	4	4	3
	11 Ascot Pool - East	2	1	3	1	—	—	—	4	4	4	4	2
	12 Garratt Rd Pool	4	4	4	1	—	—	—	3	5	5	5	5
	13 Bath St Pool	4	3	1	2	—	—	—	4	3	4	4	4
	14 The Springs Pool	2	4	1	1	—	—	—	3	5	3	—	3
	15 East St Jetty	3	5	5	1	—	—	—	4	3	5	4	3
	16 Heirisson Island	1	4	3	1	—	—	—	2	5	4	2	4
MIDDLE ESTUARY	17 Como Jetty	2	2	1	1	—	—	—	2	2	1	1	2
	28 Applecross Jetty	1	4	2	1	—	—	—	3	3	2	1	1
	29 Pt Walter Jetty	1	3	1	2	—	—	—	2	3	1	1	2
	32 Mosman Park	1	1	2	2	—	—	—	4	3	1	2	1
	33 Peppermint Grove	1	4	1	2	—	—	—	5	5	4	2	2
	34 Claremont Baths	1	5	2	1	—	—	—	4	3	1	2	2
	35 Nedlands Baths	1	4	1	1	—	—	—	5	3	3	1	1
	36 Matilda Bay	1	2	1	1	—	—	—	5	5	1	2	1
	37 Matilda Bay UBC	2	2	5	4	—	—	—	5	4	3	1	3
LOWER ESTUARY	30 Bicton Pool	1	1	2	4	—	—	—	2	2	1	1	1
	31 East Fremantle Pool	1	4	4	5	—	—	—	4	1	2	1	1
CANNING RIVER	18 Kelmscott Pool	5	5	5	4	—	—	—	4	4	4	2	5
	19 Station St, Gosnells	3	4	4	4	—	—	—	5	5	4	4	5
	20 Southern River Bridge	4	—	5	5	—	—	—	5	5	4	5	5
	21 Harris St Pool	4	5	3	5	—	—	—	3	4	5	3	4
	23 Kent St Weir Salt	3	5	3	4	—	—	—	5	5	5	5	4
	24 Riverton Bridge Pool	1	4	2	1	—	—	—	4	4	5	4	5
	25 Fifth Ave, Riverton	2	2	2	1	—	—	—	5	5	3	3	5
	26 Deep Water Point	2	1	1	1	—	—	—	5	4	2	4	1
	27 Canning Bridge Nth	1	2	1	4	—	—	—	2	4	3	1	1

1 — M.P.N. 0 — 35
2 35 — 110
3 110 — 350
4 350 — 1 100
5 1 100+

APPENDIX A9

TABLES SHOWING M.P.N. OF COLIFORM AND *E.COLI* BASED ON SAMPLING DONE BY PUBLIC HEALTH DEPARTMENT 1972-1975.

BACTERIA E.COLI

	1975	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UPPER ESTUARY	1a Walyunga Short Pool	2	1	1	1	—	—	—	3	1	2	—	4
UPPER ESTUARY	1b Walyunga Long Pool	1	1	1	1	—	—	—	2	1	2	—	2
UPPER ESTUARY	1d Douglas Rd	1	2	2	2	—	—	—	3	3	2	—	1
UPPER ESTUARY	2 Midland Pool	1	3	1	1	—	—	—	3	4	2	—	1
UPPER ESTUARY	1c West Swan Bridge	4	4	1	2	—	—	—	2	2	2	—	1
UPPER ESTUARY	4 Success Hill Reserve	1	2	1	2	—	—	—	3	4	2	—	1
UPPER ESTUARY	5 Point Reserve	4	3	3	1	—	—	—	3	2	4	—	4
UPPER ESTUARY — HELENA RIVER	7 Scott St Bridge	2	1	2	2	—	—	—	3	2	4	—	4
UPPER ESTUARY — HELENA RIVER	8 Stock St Bridge	2	5	3	4	—	—	—	4	2	4	—	4
UPPER ESTUARY — HELENA RIVER	9 Swan St Bridge	1	1	—	2	—	—	—	4	2	4	—	3
UPPER ESTUARY	10 Sandy Beach Reserve	1	1	1	1	—	—	—	2	3	3	2	2
UPPER ESTUARY	11 Ascot Pool-East	1	1	1	1	—	—	—	2	3	3	1	1
UPPER ESTUARY	12 Garratt Rd Pool	3	4	2	1	—	—	—	2	5	4	4	3
UPPER ESTUARY	13 Bath St Pool	4	1	1	1	—	—	—	2	1	2	2	4
UPPER ESTUARY	14 The Springs Pool	1	1	1	1	—	—	—	1	4	3	—	1
UPPER ESTUARY	15 East St Jetty	1	4	4	1	—	—	—	1	1	3	2	1
UPPER ESTUARY	16 Heirisson Island	1	2	1	1	—	—	—	2	5	3	1	2
MIDDLE ESTUARY	17 Como Jetty	1	1	1	1	—	—	—	1	1	1	1	1
MIDDLE ESTUARY	28 Applecross Jetty	1	4	2	1	—	—	—	1	1	1	1	1
MIDDLE ESTUARY	29 Pt Walter Jetty	1	3	1	2	—	—	—	1	2	1	1	1
MIDDLE ESTUARY	32 Mosman Park	1	1	2	1	—	—	—	1	1	1	2	1
MIDDLE ESTUARY	33 Peppermint Grove	1	4	1	2	—	—	—	3	2	1	2	2
MIDDLE ESTUARY	34 Claremont Baths	1	4	1	1	—	—	—	1	2	1	1	1
MIDDLE ESTUARY	35 Nedlands Baths	1	3	1	1	—	—	—	1	1	2	1	1
MIDDLE ESTUARY	36 Matilda Bay	1	1	1	1	—	—	—	1	4	1	2	1
MIDDLE ESTUARY	37 Matilda Bay UBC	1	1	4	1	—	—	—	2	2	1	1	1
LOWER ESTUARY	30 Bicton Pool	1	1	1	2	—	—	—	1	2	1	1	1
LOWER ESTUARY	31 East Fremantle Pool	1	2	3	4	—	—	—	2	1	1	1	1
CANNING RIVER	18 Kelmscott Pool	1	4	2	4	—	—	—	3	3	2	2	2
CANNING RIVER	19 Station St, Gosnells	2	4	3	2	—	—	—	2	3	2	4	4
CANNING RIVER	20 Southern River Bridge	1	—	4	4	—	—	—	3	4	4	4	4
CANNING RIVER	21 Harris St Pool	2	3	3	4	—	—	—	3	4	4	3	4
CANNING RIVER	23 Kent St Weir Salt	1	3	2	3	—	—	—	3	4	3	2	2
CANNING RIVER	24 Riverton Bridge Pool	1	4	1	1	—	—	—	3	2	5	1	5
CANNING RIVER	25 Fifth Ave, Riverton	2	1	1	1	—	—	—	3	2	3	2	5
CANNING RIVER	26 Deep Water Point	1	1	1	1	—	—	—	2	3	1	3	1
CANNING RIVER	27 Canning Bridge Nth	1	2	1	2	—	—	—	1	2	2	1	1

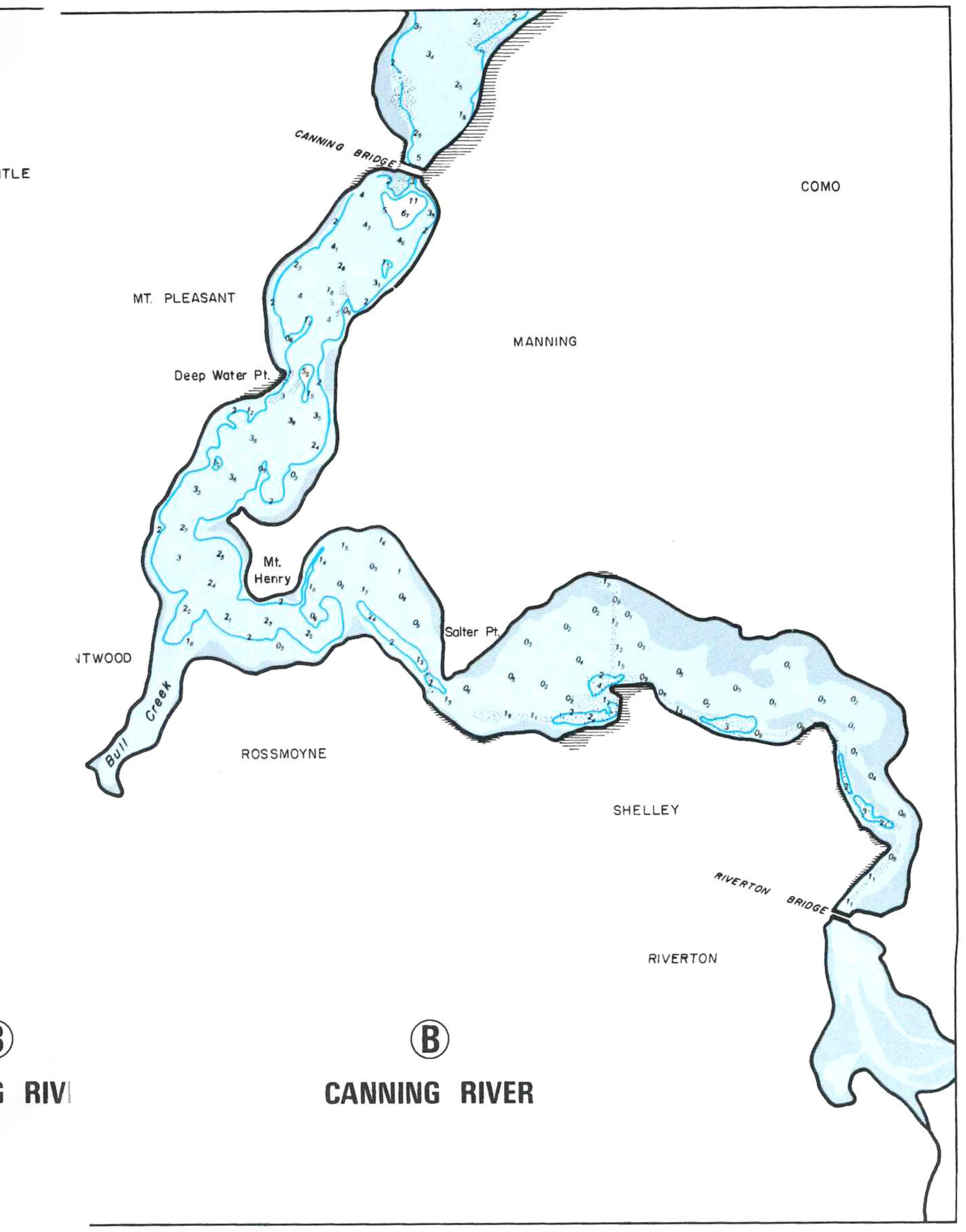
1 — M.P.N.	0 —	35
2	35 —	110
3	110 —	350
4	350 —	1 100
5	1 100+	

APPENDIX A10

COMPANIES HOLDING AN INDUSTRIAL PERMIT FROM THE SWAN RIVER CONSERVATION BOARD

ALCOA
BOTTLE RECYCLING
BRADY H.B. & CO.
CADBURY SCHWEPPES
COCA COLA BOTTLERS
COLONIAL SUGAR REFINERY
C.S.B.P. & FARMERS, CRESCO FERTILISERS
FREMANTLE STEAM LAUNDRY
GOLDEN MILE
JAMES HARDIE
KEWDALE PLATERS
McGILVRAY PTY. LTD.
S.E.C. GASWORKS
S.E.C. POWERHOUSE
SWAN BREWERY CO. LTD.
SWAN PORTLAND CEMENT
SWAN WOOL SCOURING (W.A.)
WALES MASONRY
WESTRAIL — EAST PERTH
WESTRAIL — FORRESTFIELD
WESTRAIL — KEWDALE

Figure 16.
Maps of:
A. Upper Estuary
B. Middle and Lower Estuary
C. Canning River
showing dredging, reclamation and foreshore treatment.



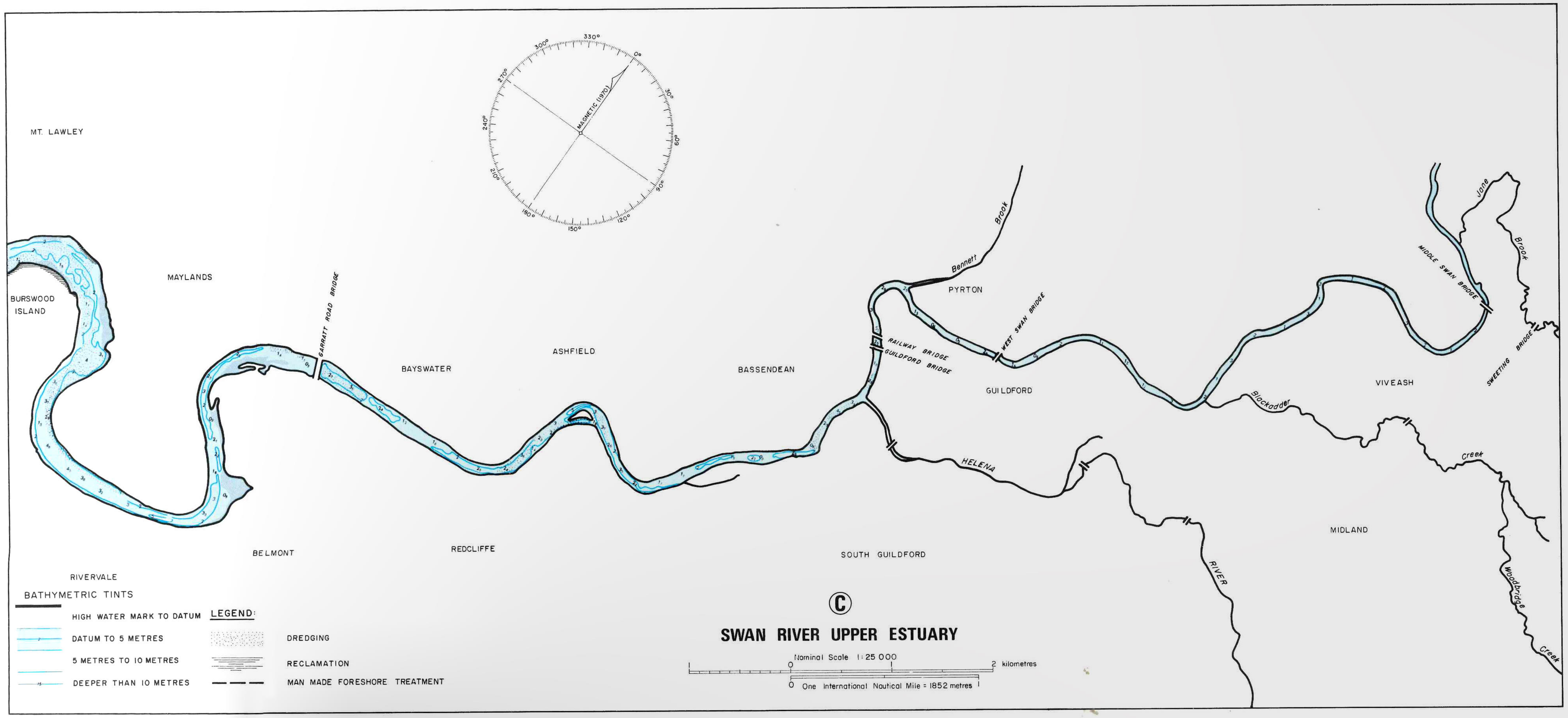


Figure 3. Admiralty Chart 1896. "Swan River, North Fremantle to Perth". Courtesy – P.W.D.